

Asthma in Urban Children: Epidemiology, Environmental Risk Factors, and the Public Health Domain

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Abstract Asthma is the most commonly reported chronic condition of childhood in developed countries, with 6.5 million children affected in the USA. A disparate burden of childhood asthma is seen among socioeconomically disadvantaged youth, often concentrated in urban areas with high poverty rates. Host factors that predispose a child to asthma include atopy, male gender, parental history of asthma, and also race, ethnicity, and genetic and epigenetic susceptibilities. Environmental factors, such as improved hygiene, ambient air pollution, and early life exposures to microbes and aeroallergens, also influence the development of asthma. With greater than 90 % of time spent indoors, home exposures (such as cockroach, rodent, and indoor air pollution) are highly relevant for urban asthma. Morbidity reduction may require focused public health initiatives for environmental intervention in high priority risk groups and the addition of immune modulatory agents in children with poorly controlled disease.

Keywords Asthma · Asthma and urban children · Asthma in inner-city · Asthma and poverty · Asthma and environment

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Introduction

Our understanding of asthma and its management has advanced, yet the burden of asthma in urban children remains high [1]. Asthma prevalence in the USA overall has increased, affecting 25 million people, including 6 million or more children [2]. The urban neighborhoods with high asthma prevalence also have a high density of minority and poor residents [3], and asthma prevalence varies significantly according to race and ethnicity [4]. Puerto Rican and black/African American children have the highest asthma prevalence, approximately 2.4-fold and 1.6-fold greater than white children, respectively [3]. Increased morbidity also follows increased prevalence in these same groups. Compared with white children, Hispanic children are twofold more likely to seek emergency asthma care. Black children have 2.6-fold more asthma-related emergency room visits and threefold more hospitalizations [5]. Risk for asthma-related mortality is highest among black children [5]. In this review, we first examine the epidemiology of urban asthma, then host and environmental factors that may influence asthma prevalence and morbidity, and in conclusion, we discuss strategies for management in urban children that incorporate both population health as well as immune modulatory treatments.

Epidemiology of Urban Asthma

The terms “urban” and “inner-city” as they relate to asthma convey a combination of urban residence, poverty, and, indirectly, black race/Hispanic ethnicity. Examination of the independent effects of these risk factors on asthma prevalence and morbidity has been challenging and has generated mixed findings [6•, 7]. A study of 1988 National Health Interview Study

(NHIS) data reported that urban residence, rather than race or poverty, was the primary predictor of asthma prevalence among black children in a nationwide sampling of 17,110 US children [7]. However, other studies have suggested poverty is a significant risk factor for asthma prevalence. Children of families living below the federal poverty level are at increased risk of asthma, with 13 % reporting asthma versus 8 % of children living above the poverty level [8]. In a low-income urban birth cohort, the Urban Environment and Childhood Asthma (URECA) birth cohort, poverty (annual family income < \$15,000/year) was also a risk factor for recurrent wheezing [9•]. Overall, there is good evidence that both race/ethnicity and poverty are important risk factors for prevalent asthma, but the effect of urban residence on prevalent asthma is less clear.

A recent study has challenged the notion that “urban” or “inner-city” areas have the highest prevalence of childhood asthma. Keet et al. analyzed 2009–2011 NHIS data sampling 23,065 children in the USA [6•]. Black race and Puerto Rican ethnicity were the leading risk factors for prevalent asthma. After taking race/ethnicity into account, poverty was found to be an independent predictor of prevalent asthma, but urban residence was not. In fact, equal or higher asthma prevalence was seen in poor children living in non-urban areas compared to urban areas. This study suggests the concept of an “inner-city” asthma epidemic, with respect to asthma prevalence, may need to be reconsidered. However, whether urban residence and/or poverty are risk factors for asthma morbidity among children with asthma was not addressed by the study and remains unclear. Understanding exactly how poverty, race/ethnicity, and geography exert their effects on asthma pathogenesis and asthma severity will be critical for informing primary prevention and treatment strategies for asthma.

Host Risk Factors for Urban Childhood Asthma

Knowledge about host determinants of asthma has grown with the study of urban birth cohorts and advancing genetic technology. The disparate asthma burden among urban minority children may be related in part to host factors.

As mentioned earlier, race and ethnicity confer risk for developing asthma. African ancestry was associated with asthma risk, but not frequency of exacerbations, in a large case–control sampling of self-reported blacks living in New York City, Baltimore, and Chicago [10]. Ethnically, Puerto Rican children had a high prevalence of lifetime asthma in a regression analysis of 46,511 children sampled from 1997 to 2001 NHIS data [11]. In the Keet et al. study discussed above, black race and Puerto Rican ethnicity were the strongest risk factors for prevalent asthma, independent of poverty and urban residence [6•].

Preterm birth (<37 weeks gestation) has been proposed as an independent risk factor for asthma [12]. Extreme prematurity (23–27 weeks gestational age) presented the highest risk for developing asthma [13]. Prematurity rates are increased in poor urban minority populations among whom asthma prevalence is high [12]. Preterm birth rates for black infants were approximately 60 % higher than that for white or Asian/Pacific Islander infants [14].

To date, no single gene has been shown to predict asthma. However, growing evidence from genetic linkage and association studies have highlighted a number of polymorphisms related to epithelial barrier function (such as filaggrin and ORMDL3), response to air pollution (involving pathways of oxidative stress and inflammation), and epigenetic interactions [15, 16•]. The most studied polymorphisms demonstrating gene by environment interactions involve the oxidative stress genes GSTM1, GSTP1, and NQO1 and their interaction in the response to air pollution. GSTM1 and GSTP1 occur as relatively high frequency polymorphisms. A common limitation of prior studies is they were under-powered to detect significant effects. Though epidemiology has clearly shown that air pollution influences asthma, the molecular mechanisms remain to be discovered [17].

Epigenetic effects are inheritable phenotypic traits that alter gene expression via DNA methylation, histone modification, or microRNA expression. Epigenetic regulators in asthma are thought to promote and sustain Th2 differentiation. Environmental factors that may trigger epigenetic changes in favor of asthma include tobacco smoke, air pollution, oxidants (such as ozone), and numerous other airborne particles (such as microbes and indoor allergens), each of which may play a role in urban childhood asthma [16•].

Environmental Risk Factors for Urban Childhood Asthma

Conditions in poor urban neighborhoods abound with potentially modifiable environmental exposures that can influence asthma, both in terms of prevalence and morbidity. Other exposures may also play a role, including obesity, diet, and psychosocial factors, such as stress, though detailed discussion of these factors is beyond the scope of this review. We will instead focus on exposures to microbes, indoor allergens, and pollutants (Table 1).

Early Microbe Exposure

The window of time in a child’s life when microbes and sensitizing allergens are encountered may affect a child’s propensity for developing asthma, and the first year of life appears most influential. The “hygiene hypothesis” proposes that reduced early exposure to microbes and their products (such as

Table 1 Environmental risk factors for urban childhood asthma and proposed interventions

Environmental factor	Intervention
Early microbial exposures	Data is insufficient to guide recommendations for intervention at this time
Indoor allergen: Mouse-sensitized urban children are at increased risk for asthma prevalence and morbidity Cockroach-sensitized urban children are at increased risk for asthma prevalence and morbidity Indoor allergen: Dust mite Cat/dog Mold	Multifaceted approach focusing on adult caregiver education and house cleaning practices with addition of allergen specific measures as appropriate Cockroach and mouse ^a : block entry points (repair holes and cracks in the walls and windows), remove open food and water sources (leaky faucets), and consider professional exterminator services Dust mite ^a : reduce indoor humidity <50 %; launder bedding weekly; encase bedding in impermeable covers; and remove carpeting. Additional strategies include limiting upholstery and stuffed animals in child's bedroom Cat/dog ^a : strategies are poorly effective, with exception of removing the pet from the home. If avoidance is not possible, restrict pet access to the child's bedroom, and remove carpeting Mold ^a : reduce indoor humidity; repair and seal water leaks; ventilate and clean basements, bathrooms, and kitchens; avoid using carpeting on concrete or damp floors; insufficient evidence for professional mold remediation
Tobacco smoke: Tobacco smoke exposures in utero and in childhood in urban children increase the risk for asthma prevalence and morbidity Traffic-related air pollutants	Avoidance of tobacco smoke exposure If avoidance is not possible, practical strategies may include frequent house cleaning and/or use of HEPA filter though evidence is not robust for either Data is insufficient to guide recommendations for intervention at this time

^a Indoor allergens [93]

endotoxin from gram-negative bacteria, other bacteria and their products, viruses, and parasites) as a result of our modernized lifestyle has imbalanced the Th1, Th2, and regulatory T cell dynamics in favor of atopy. Many ecologic studies point to associations between industrialization and higher asthma prevalence [18–20], and evidence also links specific microbial exposures to reduced risk of asthma. In the URECA birth cohort, for example, infants with less bacterial richness in their home's dust in the first year of life were more likely to develop allergic sensitization and wheezing [9••]. Additionally, early childhood exposures to farm animals, day care, and older siblings have been shown to protect children from developing asthma [21].

Microbe exposure may act jointly with allergen exposure to influence the risk of allergic asthma. In the URECA birth cohort, cumulative allergen exposure over the first 3 years to cockroach, mouse, and dust mite was associated with sensitization to those allergens at age 3 years. However, exposure to these allergens in the first year of life was negatively associated with recurrent wheeze at age 3. Furthermore, the combination of bacterial exposures in dust (Firmicutes and Bacteroidetes) and higher allergen levels in the first year was the most protective against later wheeze [9••].

Endotoxin

Endotoxin is perhaps the best-studied microbial factor in the context of asthma and allergic disease. Endotoxin is ubiquitous and thought to modulate the Th2 pathway through its stimulation of toll like receptor (TLR 4), within the innate arm of the immune system, and has been shown to have pro-inflammatory effects in occupational settings, for example in laboratory and agricultural animal facilities [22, 23].

Population studies indicate that endotoxin exposure may be a risk factor for wheeze in early childhood, but in some settings, it may protect against morbidity among those with established asthma [24–28]. It is unclear, however, whether early life endotoxin exposure is a risk factor for persistent wheeze into the school-aged years.

In US urban populations, several studies have linked endotoxin exposure to increased risk of wheeze in early childhood [25–27]. In two urban cohort studies, endotoxin was positively associated with wheeze, but protective of eczema, suggesting that it may have pro-pulmonary inflammatory effects but anti-atopy effects. Whether early life endotoxin exposure is a risk factor for persistent wheeze or asthma among urban populations remains unclear. In contrast, a European study of

house dust endotoxin from rural farming and non-farming households found that higher endotoxin levels appeared to protect children from developing atopic asthma [24]. This may be explained by the magnitude of the endotoxin exposure in European farm homes, which is significantly greater than endotoxin loads in US urban homes [25].

Endotoxin's effects also appear to vary depending on genetic background and co-exposures [28, 29]. For example, endotoxin's pro-wheezing and anti-atopy effects have been demonstrated among those children with CD14 polymorphisms [29]. In a study of urban children with asthma, endotoxin's effects on measures of asthma morbidity depended on the levels of other pollutants in the home, namely airborne nicotine and nitrogen dioxide (NO₂) [28]. When air nicotine was present in the home, endotoxin tended to be associated with asthma morbidity, whereas when high levels of NO₂ were present, endotoxin tended to be inversely associated with asthma morbidity [28].

Although the relationships between endotoxin exposure and asthma in urban populations are complex, so that it is not clear that modulating endotoxin exposure in early life would reduce the risk of asthma, what we are learning about endotoxin provides a context and framework for studying the effects of other microbial substances on asthma risk and the developing immune system.

Other Microbial Exposures

Since house dust contains many immunologically active substances in addition to endotoxin, the bioactivity of house dust rather than measured endotoxin level may track more closely with allergy, asthma, and related outcomes. In a study of urban Cincinnati children with aeroallergen sensitization by age 3 years, it was found that children from homes with highly bioactive extracts had smaller aeroallergen skin test responses. House dust bioactivity was not significantly related with the presence of house dust endotoxin, indicating that it captures a measure of immunologic activity that is distinct from endotoxin [30]. Although endotoxin appears to play a role in development of wheeze in urban settings, there are likely other biologically active substances in the home environment that also shape the risk of asthma-related outcomes.

Not surprisingly, additional TLR ligands have been examined for effects on allergic disease. Flagellin (TLR5 ligand) has shown potential in murine studies as a therapeutic adjuvant for allergic asthma [31]. In contrast, Wilson et al. proposed that flagellin in fact promotes asthma by priming TLR5-dependent allergic responses to indoor allergens [32]. Another TLR ligand, CpG (TLR9), has shown promise for ragweed-induced allergic rhinitis when conjugated to Amb a 1 in a pilot 6-week duration immunotherapy trial [33]. TLR-based therapies remain under investigation for potential clinical applications. Whether these microbial compounds are

present in different quantities in urban homes or act differently in urban populations, however, remains unclear.

Conflicting data exist as to whether early childhood viral respiratory infections are a cause of asthma. Nearly all children are infected with respiratory syncytial virus (RSV) by age 2 years. RSV encountered early in life has been shown to increase risk of asthma up to age 13 years [34]. In contrast, a study of 8280 pairs of twins found RSV infection in childhood did not predict later asthma development [35]. Although rhinovirus is a frequent cause of asthma exacerbation, rhinovirus infection in infancy was not associated with developing childhood wheezing [36].

Indoor Allergen Exposure

Urban children are often exposed and sensitized to multiple indoor allergens, including rodents, cockroach, cat, dog, dust mite, and mold [37, 38, 39, 40]. A study of 478 children hospitalized for asthma from the Cincinnati area found more than half of the children were sensitized by serum IgE testing to each of *Alternaria*, *Aspergillus*, dust mites, cat dander, and dog dander. Almost 30 % were sensitized to cockroach and 18 % to mouse. Nearly 70 % of children in this study had three or more sensitizations [37]. House dust mite is a geographically important inner-city allergen, prevalent in the southern and northwestern states [41]. In an inner-city asthma study, a home intervention was effective in reducing dust mite exposure and asthma symptoms, and the degree of dust mite reduction correlated with the degree of symptom improvement [38, 42].

Among these aeroallergens, mouse and cockroach are the most abundant in urban homes and both are recognized as risk factors for asthma prevalence and morbidity. More than 50 % of urban children with asthma are sensitized to either mouse or cockroach [43, 44]. Co-exposure is common, as the presence of mouse allergen in the home is often associated with cockroach infestation [45]. Poorly maintained multi-family urban dwellings frequently allow pests and rodents to circulate, making eradication difficult.

Mouse allergen is more common in the Northeastern and Midwestern USA and was detected in most, but not all, of the inner-city homes sampled in New York City, Boston, and Chicago as part of an inner-city asthma study [46]. Mouse allergen has also been noted to have neighborhood-specific distributions in New York City [47]. Mouse allergen is prevalent as well not only in homes but in urban schools in some areas of the USA [39].

Several studies have linked mouse allergy to prevalent asthma in urban children. For example, two inner-city birth cohort studies found significantly increased risk of wheeze in mouse-exposed children with evidence of allergic sensitization by age 2–3 years [35, 38]. Furthermore, exposure and sensitization to mouse were associated with worsened asthma

morbidity in urban children in several cities. As an example, exposure to mouse was independently associated with asthma morbidity in mouse-sensitized Baltimore preschool children, as measured by symptom days, short-acting beta-agonist (SABA) use, and asthma-related emergency or inpatient services [48]. Of note, the relationship appeared dose-dependent, and progressively higher bedroom dust levels of *Mus m 1* were associated with poorer disease control and increased use of medical care for asthma [49]. Therefore, a large body of evidence supports that mouse allergen exposure and sensitization are common among urban children and are independent predictors of asthma prevalence and morbidity.

Cockroach exposure has similarly been linked to risk of wheeze and asthma in urban children in various cities. For example, longitudinal studies from Boston have shown that cockroach exposure increased the risk of wheeze in children of atopic parents [50]. Cockroach exposure was also a predictor of physician-diagnosed asthma in a Boston birth cohort of children predisposed to asthma, and the exposure relationship was dose-dependent [51]. Additionally, cockroach exposure and sensitization are associated with asthma morbidity. The National Cooperative Inner-City Asthma Study (NCICAS), conducted in several inner-city locations, found that cockroach exposure in the home combined with skin test reactivity to cockroach was associated with the highest levels of asthma morbidity in this study population [44]. Furthermore, cockroach-sensitized children with asthma had greater than sevenfold risk for high SABA use (defined as ≥ 4 SABA fills in 12 months) in a group of 100 children living in Baltimore [52]. Taken together, there is evidence that cockroach exposure and sensitization also are linked to asthma prevalence and morbidity in urban children.

Pollutants

Air pollution adversely affects urban children with asthma. Important exposures include indoor tobacco smoke (the primary source of indoor particulate matter (PM)) and gas stove emissions (a primary indoor source of NO₂) and outdoor traffic-related gases (CO) and atmospheric particles generated from traffic emissions (NO₂, ozone). Other modifiable sources of indoor PM, generated by cooking and sweeping, contribute to overall indoor PM levels, and a rise in indoor PM has been associated with increased asthma symptoms in urban children [53].

Beginning with indoor pollutants, tobacco exposure is common in urban settings and both in utero and childhood exposures have been linked to risk of wheeze/asthma and asthma morbidity. The highest tobacco smoking rates are seen in the poor. Tobacco use was found in parents and caregivers of more than 50 % of urban children and 70–98 % of urban children hospitalized for asthma. More than 10 % of pregnant mothers use tobacco within the third trimester [54–57].

Several studies have demonstrated that in utero tobacco exposure is associated with subsequent wheezing and asthma in children [58–60]. Tobacco exposure in childhood has consistently been associated with altered lung development, reduced lung function, abnormal response to viral respiratory pathogens, and increased prevalence of wheeze [59–64]. Secondhand smoke exposure in urban children has also been linked to increased nighttime asthma and impaired response to inhaled corticosteroids [65, 66]. A public smoking ban in Scotland, as an example of a population-based initiative, significantly reduced childhood asthma hospitalizations [67]. Therefore, the evidence for tobacco smoke's adverse impact on urban childhood asthma is very strong.

Indoor NO₂ is another highly relevant source of urban indoor pollution which adversely affects childhood asthma. The primary source in cities is gas stoves. The NCICAS found nearly 90 % of homes in eight urban cities had gas stoves [68]. The National Institute for Occupational Safety and Health cautions that NO₂ exposure above 20 ppb represents the Immediately Dangerous to Life or Health Concentration [92]. Studies focusing on inner-city populations have found levels of exposure consistently higher than this [68–70]. NO₂ exposure has been shown to be associated with asthma morbidity in urban children. For example, Baltimore preschool children with asthma experienced increasing respiratory symptoms, such as cough and nocturnal symptoms, with increasing concentrations of NO₂ [69]. An Australian school study of NO₂ described positive outcomes after indoor NO₂ reduction. When unflued gas heaters were replaced with either electric or flued gas heaters, respiratory symptoms in children with asthma decreased along with indoor NO₂ concentrations [71]. The health burdens of NO₂ in urban childhood asthma are not as well established as for tobacco, though efforts aimed at reduced exposure as noted by limited studies have met with benefits in respiratory health.

Outdoor air pollutants can induce inflammation, airway hyper-responsiveness, and oxidative stress in the airways and long-term air pollution exposure impairs normal lung development and has been associated with increased asthma risk in children [72•, 73, 74, 75•, 76]. Fossil fuel combustion generates the majority of culprit pollutants impacting asthma in cities. Studies have shown that children who live near busy highways and bus routes experience difficulty with asthma control [77, 78]. The mixture of air pollutants most likely synergistically acts on the airways, though several individual molecules have been studied more closely.

Carbon monoxide and NO₂ are responsible for the largest adverse effects on asthma [79]. Short-term exposures were associated with increased asthma symptoms and use of rescue medications in the Childhood Asthma Management Program (CAMP) study population [79, 80]. Over the long term, exposures to ozone, carbon monoxide, and NO₂ were all associated with impaired lung function in the CAMP study population

[79]. Motor vehicle emissions are the primary source of carbon monoxide. Sources for NO₂ include traffic emissions and atmospheric reactions. Ozone is formed when sunlight reacts with NO₂ or hydrocarbons. Ozone exposure has been associated with incident allergic sensitization, a diagnosis of wheeze in children, and asthma exacerbation [81, 82].

Air pollution reduction strategies in California represent a successful population-based initiative with benefits to asthma. As air pollution levels have decreased in southern California, lung function growth among the region's children has increased [75•]. Improved lung function in all children, regardless of asthma, was most closely associated with lower levels of PM and NO₂ [75•].

Undeniably, urban children have substantial exposure to air pollution and evidence for a direct relationship between air pollution and asthma morbidity is well established. Research gaps currently exist in understanding air pollution effects on asthma onset, with efforts directed toward studying gene-environment interactions and co-exposure influences (allergens or microbes).

Interventions for Urban Childhood Asthma

The modifiable risk factors discussed above afford opportunities for intervention. Interventions may be at the individual patient care level (such as guidelines-based care) or at the population level (such as a policy change or public health program targeting a population). Interventions may be aimed at modifying the exposures (pollution, tobacco exposure, allergens, or microbes) or at modifying the host response to the exposures (immune modulatory agents). We will now highlight recent examples in the literature that describe interventions and their associated outcomes in urban children, starting with care of the individual.

Perhaps first and foremost, implementing guidelines-based asthma care is a fundamental and highly efficacious approach to asthma management for urban children with asthma. One study in particular highlights the impact of successfully implementing guidelines-based care in an urban population [83••]. In the Asthma Control Evaluation study, adolescents with persistent asthma and a recent exacerbation were randomized to receive guidelines-based medication titration or guidelines-based medication titration that incorporated exhaled nitric oxide levels into the decision making for controller medication therapy [83••]. Both groups had follow-up every 2 months in which symptom, exacerbation, adherence and medication, and lung function data were collected. The group whose treatment step was informed by FENO in addition to these other clinical parameters did no better than the control group that received guidelines-based care that did not incorporate FENO into the treatment decision. Both groups, however, had a marked reduction in exacerbations and

improvement in lung function. A key component of management of asthma among urban populations, who often come from low-income families, is the development of systems that will effectively implement guidelines-based care.

Home-based interventions targeting multiple indoor allergen exposures, including mouse and cockroach, have reported mixed results [38•, 84–86]. The NCICAS conducted in several urban cities found cockroach burden remained elevated despite professional home exterminations [84]. Other studies reported reductions in detectable airborne allergen with modest improvements in asthma morbidity [38•, 85, 86]. The Inner-City Asthma Study (ICAS) saw the most dramatic improvement with sustained reduction of cockroach allergen in bedroom dust and improved asthma control reported 1 year after the study intervention (cost of intervention was approximately \$1500/year) [38•]. Morgan et al. proposed the success of the intervention relied on behavioral change. The study staff modeled target behavior and verified the parent/caregiver's mastery of the assigned tasks. Through applied social cognitive theory, the study staff also reinforced expectations of success in the parents/caregivers [38•]. Guided environmental interventions that partnered families with asthma-trained social workers, as well as school-based asthma interventions, were also more likely to be successful. Perhaps complementary mechanisms, such as increased adherence to therapy and doctor's appointments, explain this benefit, rather than being attributable solely to the magnitude of environmental change [4]. Therefore, it appears that extermination alone may have minimal impact on mouse or cockroach allergen levels and asthma morbidity in urban children. However, those interventions that target behavior changes in caregivers as it relates to allergen control (and other behaviors such as adherence) have the greatest potential for improving indoor allergen levels and morbidity.

Immune modulatory therapies represent another intervention focused at the individual patient level, but they target not the exposure but the host response to exposure. Immune modulators are an appropriate consideration for urban children receiving guidelines-based care, who remain uncontrolled. Currently available immune modulatory agents include allergen immunotherapy and the monoclonal anti-IgE antibody, omalizumab. The Inner-City Anti-IgE Therapy for Asthma (ICATA) trial showed that omalizumab therapy reduced asthma morbidity in urban children ages 6–20 years old. The majority (73 %) of these children had moderate or severe asthma [87•]. Recently, researchers reported that omalizumab therapy was effective in preventing seasonal exacerbations in the fall and winter months in urban children when added prophylactically to existing therapy. Omalizumab was added 4–6 weeks prior the first day of school and then continued for 4 months [88]. The omalizumab treatment group had about half the number of exacerbations compared with the placebo group, 11.3 to 21 % [88]. A seasonal “September epidemic” in

asthma exacerbations has been identified by patterns of medical care and pharmacy utilization [89, 90]. Underserved communities had increased rescue and controller medication fills from September through December, with a relative lull over the summer months [89]. Respiratory viruses, perhaps coupled with allergen exposures, may be important triggers of this seasonal increase in asthma morbidity. As shown by the seasonal omalizumab example, perhaps initiating step-up therapy in high-risk groups prior to the anticipated seasonal peak may ameliorate asthma severity in the fall and winter months through modification of the host response to viruses and allergens.

Policy-level interventions have a potential to bring benefit more swiftly and impact the health of many urban children at once. Examples of environmental initiatives at a population level that were beneficial in urban children with asthma include the previously mentioned public smoking bans, regulation of vehicle emissions, and replacement of indoor gas heaters in schools with alternative heating sources. Indoor allergen and PM exposure may be of high interest in this regard, especially with the widespread rodent and cockroach presence in urban homes, frequency of indoor gas stoves producing NO₂ in excess of NIOSH recommended exposures, and prevalent tobacco use and exposure. Restructuring of public housing in order to improve overall living conditions and ventilation, and to provide sustainable eradication of pests, is not presently a feasible solution due to resource intensity. Quantifying the benefits of environmental control by equating an intervention with a pharmacologic dose equivalent may help communicate the value of important environmental modifications to legislators and health insurers. Studies examining environmental avoidance as it translates to medication equivalence are currently underway in Baltimore and New York City (the Environmental Control as Add-on Therapy in Childhood Asthma study in Baltimore (NCT02251379) and the Comparative Effectiveness of Environmental Intervention and Standard Care in Ability to Reduce Pharmacologic Therapy for Asthma in New York City (NCT01593111)).

Although organizational bodies (such as the American Heart Association) commonly recommend avoidance of air pollution for people with asthma (and other cardiopulmonary conditions) on days when air quality is poor, there is not evidence for efficacy of short-term pollution avoidance in reducing asthma exacerbations [72•, 91]. Furthermore, on days when air pollution concentration is high, controller medication use is not sufficient in mitigating asthma symptoms [79]. Since individual-level interventions (avoidance of air pollution or increased controller use) are likely to be ineffective, efforts targeting the population level are needed and warrant additional study, such as expanding reportable air quality surveillance to more cities and endorsing stringent pollution control.

Conclusion

Epidemiologic studies point toward increased asthma prevalence and morbidity among urban children, and further studies will help to elucidate the independent contributions of race/ethnicity, poverty, and geography to these disparities. Several environmental risk factors for asthma risk and morbidity among urban children have been identified, including microbial exposures, allergen exposure and sensitization, and air pollutants. Successful environmental and treatment-based interventions exist for urban children with asthma, yet widespread implementation remains a challenge. Pioneering molecular technologies continue to generate further insight into asthma pathogenesis in urban children. Efforts to improve air quality by reducing aeroallergen and/or air pollutant burden should address the individual as well as the greater urban community. One way to do so is by increasing legislative activity at the public health policy level. A collective effort will be required to extinguish the disparities of prevalence and morbidity currently experienced by urban children with asthma.

Compliance with Ethical Standards

Conflict of Interest Drs. Milligan and Sharma declare no conflicts of interest. Dr. Matsui reports personal fees from Environmental Defense Fund, from Church and Dwight; grants from Inspirotec LLC and from ThermoFisher, LLC; and non-financial support from Rabbit Air and from CleanBrands, LLC.

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- Of major importance

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