

Inner-City Asthma in Childhood



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KEYWORDS

• Inner-city • Asthma • Disparities • Children

KEY POINTS

- Inner cities include high-risk vulnerable populations of children with asthma.
- Multiple risk factors contribute to morbidity and mortality in inner-city pediatric asthma.
- Environmental and medical interventions that target risk factors have been successful in improving outcomes.

INTRODUCTION

Merriam-Webster defines an inner city as “the usually older, poorer, and more densely populated central section of a city.”¹ Historically, the inner cities of major metropolitan areas within the United States have been populated by minority residents,² many of whom live in poverty. Asthma is the most common chronic disease of childhood in general; however, asthma also exerts a particularly heavy burden on children living in inner cities.^{3,4} In this review, we discuss the epidemiology of asthma in the inner city. We examine both intrinsic and extrinsic contributing factors, including race and ethnicity, prematurity, obesity, specific aeroallergens, pollutants, socioeconomic status, poverty, and psychosocial factors. Finally, we review environmental and medical interventions specific to the management of asthma in the inner city.

EPIDEMIOLOGY

The prevalence of asthma in inner-city populations remains disproportionately high compared with non-urban areas. Typical rates of asthma prevalence among US

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children are estimated to be approximately 8% with rates in the inner city up to 28%.^{5,6} Overall childhood asthma prevalence seems to have plateaued this decade; however, there remains an increasing prevalence among poor children.⁵ Keet and colleagues⁷ demonstrated that the high prevalence of asthma in inner cities is not necessarily due to specifically living in an urban neighborhood, but instead may be related to demographic factors such as race, ethnicity, and lower household income. Likewise, a more recent study showed that after controlling for demographic factors, inner-city residence was not associated with an increased asthma prevalence. It was associated with significantly more asthma morbidity, including increased asthma-related emergency department visits and hospitalizations.⁸ Multiple studies have similarly shown increased asthma morbidity among inner-city children.^{8,9}

INTRINSIC RISK FACTORS

Race and Ethnicity

Evidence has shown that race and ethnicity are contributing factors to asthma disparities. A nationwide health survey linked to census information identified black children and Puerto Ricans of Hispanic ethnicity as independently at higher risk for current asthma among children.⁷ In the recent literature, the prevalence of current asthma in black children is twice the prevalence in white children.¹⁰ It is often hypothesized that asthma may be underdiagnosed in certain inner-city minority populations owing to a variety of factors, including concerns of access to care; however, there is evidence to the contrary. Akinbami and colleagues¹¹ demonstrated that, among symptomatic children, minority children were as or more likely to be diagnosed with asthma than non-Hispanic white children, even after adjusting for the increased severity of wheezing in the minority children. Among Hispanic children, there are varying rates of asthma prevalence with children of Puerto Rican ethnicity having the highest rates that are 2.4 times increased compared with matched white children.^{12,13} Interestingly, disparities in asthma morbidity are even seen within children of a similar heritage. One study in children of Caribbean descent living in the inner city found that Puerto Rican children had significantly greater asthma morbidity in the previous year when compared with Afro-Caribbean children; however, there were no differences in spirometry between the 2 groups.¹⁴ In general, emergency department use in Hispanic children with asthma is twice as frequent as in white children with asthma.¹⁰ Additional trends in asthma morbidity are also associated with race. Akinbami and colleagues¹⁵ found that race was an inherent risk factor for worse pediatric asthma outcomes with black children being 7 times more likely to die from asthma, 3 times more likely to be hospitalized for asthma, and more than 2 times more likely to require a visit to the emergency department for asthma when compared with white children.

Prematurity

Premature birth is a recognized risk factor for asthma development in young children and rates of prematurity are increased among inner-city, low-income, and minority neighborhoods.¹⁶ Extreme preterm birth at 23 to 27 weeks of gestation is associated with an even greater increased risk for developing asthma.¹⁷ Non-Hispanic black mothers have disproportionately higher rates of premature deliveries and low birth-weight infants.^{18,19} Martin and Osterman²⁰ reported a 60% higher rate of premature birth in black infants compared with children of white or Asian/Pacific Islander descent. Additional studies in low-income populations support prematurity as a risk factor for the development of asthma later in childhood and also identify low birth weight as an associated risk factor for asthma in this population.²¹

Obesity

Childhood obesity is more common in inner-city populations. Previous studies have shown 24% to 29% childhood obesity prevalence in inner-city children compared with 17% nationally.^{22,23} This may be related to obesity being more prevalent in certain races and ethnicities. A study by Vo and colleagues²⁴ examined the relationship among weight, ethnicity, and spirometric values in children with asthma living in the inner-city Bronx, New York. Investigators found that black and Hispanic children were more likely to be overweight or obese than white children. The forced expiratory volume in 1 second (FEV₁)/forced vital capacity ratio was lower in overweight and obese black and Hispanic children. A lower FEV₁/forced vital capacity ratio was associated only with obesity, not being overweight, in white children with asthma. Jensen and colleagues²⁵ reported that diet-induced weight loss in obese children with asthma resulted in improved lung function and asthma control.

EXTRINSIC RISK FACTORS

Aeroallergens

Pests (cockroaches and mice)

For decades, cockroach and mouse allergens have been well-documented to be implicated in the inner-city asthma problem. Older homes in multiunit buildings with poor upkeep provide the ideal breeding ground for cockroaches and mice. Cockroach allergen is commonly found in inner-city homes and up to 80% of inner-city children have cockroach sensitization.²⁶ The combination of sensitization and exposure to cockroach has been associated with an increased asthma morbidity in these children.²⁷ Similarly, mouse allergen exposure is a frequent problem in the inner city and up to one-half of children living in urban neighborhoods are sensitized to mouse allergen.^{28–32} Exposure to mouse allergen is a significant source of higher risk of asthma morbidity in children known to have sensitization.^{29,30} In fact, Ahluwalia and colleagues²⁹ have demonstrated that, in urban areas with high levels of both mouse and cockroach allergens, mouse allergen was more strongly and consistently associated with asthma morbidity when compared with cockroach allergen. Outside of the home, cockroach and mouse allergens have also been problematic in urban school settings with classroom-specific mouse allergen exposure in inner-city schools associated with increased asthma symptoms and decreased spirometry in asthmatic students.^{33,34}

Molds

Poor conditions in urban homes can lead to a wall cracks, water leaks, indoor dampness, and fungal spores. O'Connor and colleagues³⁵ discovered that mold-sensitized children with asthma living in inner-city environments were exposed to airborne fungi in both indoor and outdoor air. It was then demonstrated that urban children with asthma exposed to higher levels of indoor fungi had significant increases in unscheduled visits for asthma, even after controlling for outdoor fungal levels.³⁶

Pollens

Factors in urban areas may facilitate susceptibility to increased pollen production. For example, Ziska and colleagues³⁷ noted that, when compared with rural environments, urban environments in the United States had higher temperatures and carbon dioxide production that was associated with ragweed plants growing faster, flowering earlier, and producing more pollen. This is supported by European data demonstrating an increasing trend in yearly amount of airborne pollen that was more pronounced in urban areas.³⁸

Pollutants

Indoor pollutants

Two of the most significant indoor pollutants include environmental tobacco smoke and indoor nitrogen dioxide. Indoor nitrogen dioxide is most commonly emitted from gas stoves. In a multicenter inner-city asthma study, investigators found that almost 90% of urban homes had gas stoves and those homes had high levels of nitrogen dioxide with a median nitrogen dioxide level of 29.8 ppb and 24% of homes with extremely high exposures (>40 ppb).³⁹ Increased nitrogen dioxide exposure in these inner-city homes was associated with an increased risk for asthma symptoms in non-atopic children.³⁹ Similarly, Hansel and colleagues⁴⁰ evaluated the home environments of preschool children with asthma living in inner-city Baltimore and found a mean concentration of nitrogen dioxide in this population to be 30 ppb with increased indoor nitrogen dioxide levels associated with increased asthma symptoms.

Environmental tobacco exposure

Environmental tobacco exposure is a well-known risk factor for increased asthma that has been well-studied in inner-city children. A recent publication from the Urban Environment and Childhood Asthma (URECA) cohort demonstrated that prenatal exposure to tobacco smoke is associated with increased risk for asthma development.⁴¹ Investigators in the Inner-City Asthma Consortium (ICAC) study developed a conceptual model to explain how 8 risk-factor domains are linked to asthma severity. Results of the study revealed that the environmental tobacco smoke exposure pathway, which linked environmental tobacco smoke exposure and pulmonary physiology with asthma severity, resulted in significant effects on asthma severity.⁴²

Outdoor pollutants

Outdoor air pollutants such as outdoor traffic-related emissions like carbon monoxide, nitrogen dioxide, ozone, and particulate matter are associated with increased asthma risk in children.^{43–45} Children living in inner city environments have more exposure to outdoor air pollutants owing to living closer to major highways and bus routes.^{19,46,47} Investigators in the Childhood Asthma Management Program (CAMP) found that short and long-term exposures to outdoor air pollutants such as carbon monoxide, ozone, nitrogen dioxide, and sulfur dioxide were associated with impaired lung function in children with asthma.⁴⁸

Socioeconomic Status and Poverty

Poverty is both common in inner cities and a known risk factor for increased asthma prevalence. A 2012 National Health Interview Survey reported a 13% asthma prevalence rate in children living below the federal poverty level compared with an 8% asthma prevalence rate in children living above the federal poverty level.^{43,49} This finding may be related to race and ethnicity also being a risk factor as described elsewhere in this article. For example, in 2013, it was noted that 36.9% of African American children and 30.4% of Hispanic children were living in poverty, compared with only 10.7% of non-Hispanic White children.⁵⁰ Investigators in the inner-city URECA birth cohort identified poverty as a risk factor for recurrent wheeze.^{43,51} In a national epidemiologic study of more than 23,000 children, Keet and colleagues⁷ reported that poverty was an independent risk factor when controlling for asthma, race, ethnicity, and urban residence.

Psychosocial Factors

Psychosocial factors and social determinants of health have been shown to influence asthma morbidity in inner-city children. A study of caregiver's perception of

neighborhood safety found that children living in the inner city had increased asthma morbidity when their caregivers felt that the neighborhood was unsafe.⁵² Shams and colleagues⁵³ demonstrated that in inner-city black adolescents with persistent asthma, anxiety was associated with poor asthma control, impaired quality of life, insomnia, and increased emergency department visits for asthma. Even maternal stress and depression have been associated with recurrent wheezing at 3 years of age in inner-city populations.⁵⁴ Additionally, higher daily stress is associated with increased childhood asthma-related emergency service use.⁵⁵

INTERVENTIONS AND MANAGEMENT

In 2012, the President's Task Force on Environmental Health Risks and Safety Risks to Children published the Coordinated Federal Action Plan to Reduce Racial and Ethnic Asthma Disparities.⁵⁶ This action plan combines the collaboration of a broad spectrum of federal agencies that constitute the Asthma Disparities Working Group. The action plan has identified 4 strategies to address the preventable factors leading to asthma disparities. These 4 strategies include:

1. Reducing barriers to the implementation of guidelines-based asthma management;
2. Enhancing the capacity to deliver integrated, comprehensive asthma care to children in communities with racial and ethnic asthma disparities;
3. Improving the capacity to identify the children most impacted by asthma disparities; and
4. Accelerating efforts to identify and test interventions that may prevent the onset of asthma among ethnic and racial minority children.

The report identifies the need for integrated, multimodal approaches to addressing racial and ethnic disparities in asthma and provides a framework for intervention strategies. Several of the action plan's strategies specifically address priority actions that are risk factors for inner-city asthma, including reducing environmental exposures in homes and schools, protecting children from health risks associated with exposure to air pollutants, and decreasing exposure to environmental tobacco smoke.⁵⁶

Additional studies assessing home management of asthma in the inner city from the perspective of minority children have identified education and self-management support, environmental control measures, housing resources, access to smoking cessation interventions, and psychosocial support as a suggested multipronged approach to management.⁵⁷

Environmental Interventions

Several studies have targeted environmental interventions to reduce indoor allergen exposure as a treatment regimen. Depending on the specific population and location, children are more likely to be exposed to particular allergens. Interventions targeting these allergens have been studied with various approaches.²⁸

In a seminal study, Morgan and colleagues⁵⁸ demonstrated that an individualized, home-based, comprehensive environmental intervention decreased childhood exposures to cockroach and dust mites allergens resulting in reduced asthma morbidity in inner-city children with atopic asthma. In a more recent study, Rabito and colleagues⁵⁹ used a simpler approach of targeted cockroach bait insecticides, which resulted in sustained cockroach elimination and was associated with improved asthma outcomes. For areas of high cockroach infestation, this single allergen intervention may be an alternative to multifaceted interventions.

In addition to cockroach elimination strategies, interventions to reduce mouse allergen exposure have been investigated in the inner city. Mouse allergen reduction efforts typically rely on integrated pest management, which consists of a multifaceted approach that includes vigorous cleaning, sealing of holes and cracks, disposal or putting away of food, mouse traps, and application of rodenticide.⁶⁰ Integrated pest management is usually done by professional pest control services, but includes education for residents to maintain a beneficial environment long after the intervention. Pongracic and colleagues⁶¹ demonstrated that rodent-specific environmental interventions were able to reduce home mouse allergen levels and improve clinical outcomes in inner-city children with asthma.⁶² Alternatively, DiMango and colleagues⁶³ implemented an individualized allergen intervention that was able to decrease allergen levels, but did not result in a decrease in asthma medication use between intervention and control groups. More recently, the Mouse Allergen and Asthma Intervention Trial (MAAIT) compared professional integrated pest management with education to education alone in inner-city children with documented mouse exposure and mouse sensitization.⁶² The MAAIT trial did not find a significant difference in asthma symptoms days between the 2 treatment groups because many participants in both arms experienced a significant reduction in mouse allergen exposure and symptomatology.⁶² This finding indicates the success of education alone in this particular trial. However, across both groups, there was a dose-response relationship between mouse allergen reduction and improvements in asthma.⁶² These studies indicate that successful allergen reductions in the inner city can lead to improved asthma outcomes. Future studies may focus on the most efficient and effective ways to achieve these positive outcomes in the inner city.

Medical Management

In 2007, the National Heart, Lung and Blood Institute of the National Institutes of Health published the Expert Panel Report-3, which provides evidence-based guidelines for the diagnosis of and management of asthma. For more than 10 years, the Expert Panel Report-3 has been an effective tool for clinicians treating asthma.⁶⁴ The Asthma Control Evaluation (ACE) trial was developed by the ICAC and implemented from 2002 to 2008. This study showed that guidelines-based management for asthma in an inner-city population of adolescents and young adults was adequate for asthma control. Investigators also discovered that the addition of measuring fraction of exhaled nitric oxide to modify treatment did not result in better clinical control of asthma.⁶⁵ During the ACE trial, 71% to 78% of both control and intervention group participants maintained asthma control. This level of adherence to guidelines-based care can be more challenging to achieve outside the clinical trial setting.⁶⁵

Additional approaches, such as immunomodulatory therapies, have become an important tool for asthma management in recent years. Within ICAC, Busse and colleagues⁶⁶ showed that adding omalizumab (anti-IgE) to guidelines-based therapy in inner-city children resulted in a decrease in asthma symptom days, a decrease in seasonal peaks in exacerbations, and a decreased need for other controller medications. Based on these results, a second study by the same ICAC group evaluated targeted short-term omalizumab therapy beginning just before the start of the school year and continuing for only 4 months. The researchers found this temporary omalizumab treatment approach for inner-city children was able to significantly decrease autumnal exacerbation rates, particularly among those children with a recent exacerbation.⁶⁷

More recent studies of another immunomodulatory agent, dupilumab (anti-IL4 receptor alpha), has shown its effectiveness in decreasing oral steroid use, the frequency of severe exacerbations, and increasing FEV₁ in steroid-dependent severe

asthma.⁶⁸ Dupilumab has also been shown to significantly lower the frequency of asthma exacerbations and improve lung function and asthma control in individuals with uncontrolled moderate to severe asthma.⁶⁹ Additional studies of dupilumab in the inner-city pediatric population are warranted. Although immunomodulatory therapies such as omalizumab and dupilumab have proven to be effective interventions in asthma management, it is important to remain aware of barriers such as access to care, ability to obtain medications, and adherence to treatment regimens that may make achieving asthma control more difficult in this population.

In the Asthma Phenotypes in Inner-City (APIC) study, researchers uncovered certain factors associated with difficult-to-control pediatric asthma including elevations of circulating blood eosinophils, neutrophils, and certain cytokines (CXCL-1, IL-5, IL-8, IL-17A).⁷⁰ Investigators from the study initially showed that FEV₁ bronchodilator responsiveness was the most important distinguishing characteristic between difficult-to-control and easy-to-control asthma in children living in the inner city. Rhinitis severity and atopy were other distinguishing characteristics. Over time, difficult-to-control asthma in this population was associated with increased morbidity.⁷¹ Knowledge of these factors contributing to increased disease severity in inner city children with asthma may guide management and future research directions.

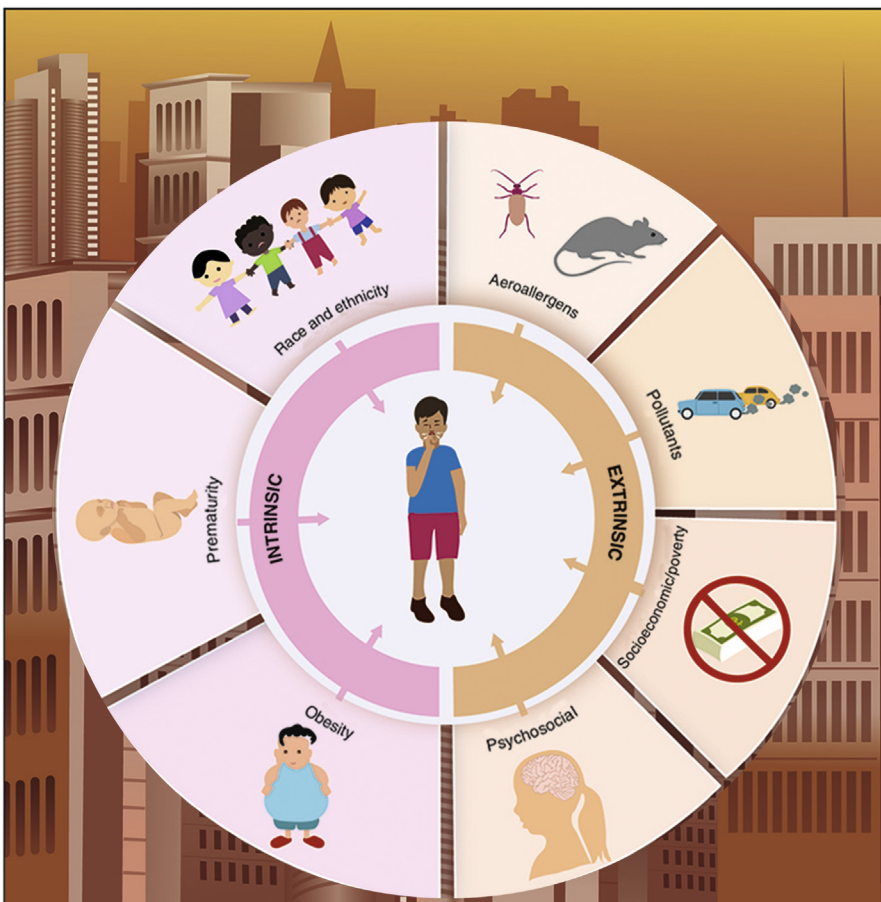


Fig. 1. Risk factors for inner-city asthma in childhood.

SUMMARY

Residing in the inner city is an established and important risk factor for asthma. The prevalence of asthma remains high in the inner city compared with nonurban areas. This prevalence has been shown to be related not only to the inner-city locale, but also to both extrinsic and intrinsic factors, such as race, ethnicity, and a lower household income. Prematurity and obesity are additional intrinsic risk factors that are common in the inner city. Regarding extrinsic inner-city risk factors for childhood asthma, cockroach, mouse, and mold remain the most relevant aeroallergens contributing to disease burden. Indoor pollutants such as nitrogen dioxide and environmental tobacco smoke are common in the inner city and significant risk factors for increased asthma severity. Living in the inner city also exposes children with asthma to more outdoor pollutants such as carbon monoxide, nitrogen dioxide, ozone, and particulate matter. Poverty, stress, and psychosocial factors also contribute to increased morbidity in the inner-city population (Fig. 1). With increasing knowledge of risk factors associated with inner-city childhood asthma, investigators and clinicians have been able to implement interventions, including indoor environmental control measures, smoking cessation, and educational and psychological support. Medical interventions based on asthma phenotype have also shown to be beneficial in inner-city childhood asthma. More studies aimed at identifying and targeting risk factors and implementing interventions and therapies will be pertinent for decreasing disparities in this high-risk vulnerable population of children with asthma.

REFERENCES

1. Merriam-Webster. Inner-city. Available at: [https://www.merriam-webster.com/dictionary/inner city](https://www.merriam-webster.com/dictionary/inner%20city). Accessed February 2, 2018.
2. Urban settlement. Encyclopedia britannica. Available at: [https://www.britannica.com/place/United-States/Impact-of-the-motor-vehicle - ref77981](https://www.britannica.com/place/United-States/Impact-of-the-motor-vehicle-ref77981). Accessed February 2, 2018.
3. Weiss KB, Gergen PJ, Crain EF. Inner-city asthma. The epidemiology of an emerging US public health concern. *Chest* 1992;101(6 Suppl):362S–7S.
4. Togias A, Fenton MJ, Gergen PJ, et al. Asthma in the inner city: the perspective of the National Institute of Allergy and Infectious Diseases. *J Allergy Clin Immunol* 2010;125(3):540–4.
5. Akinbami LJ, Simon AE, Schoendorf KC. Trends in allergy prevalence among children aged 0-17 years by asthma status, United States, 2001-2013. *J Asthma* 2016;53(4):356–62.
6. Bryant-Stephens T, West C, Dirl C, et al. Asthma prevalence in Philadelphia: description of two community-based methodologies to assess asthma prevalence in an inner-city population. *J Asthma* 2012;49(6):581–5.
7. Keet CA, McCormack MC, Pollack CE, et al. Neighborhood poverty, urban residence, race/ethnicity, and asthma: rethinking the inner-city asthma epidemic. *J Allergy Clin Immunol* 2015;135(3):655–62.
8. Keet CA, Matsui EC, McCormack MC, et al. Urban residence, neighborhood poverty, race/ethnicity, and asthma morbidity among children on Medicaid. *J Allergy Clin Immunol* 2017;140(3):822–7.
9. Gergen PJ, Teach SJ, Togias A, et al. Reducing exacerbations in the inner city: lessons from the inner-city asthma consortium (ICAC). *J Allergy Clin Immunol Pract* 2016;4(1):22–6.

10. Akinbami LJ, Moorman JE, Simon AE, et al. Trends in racial disparities for asthma outcomes among children 0 to 17 years, 2001-2010. *J Allergy Clin Immunol* 2014; 134(3):547–553 e545.
11. Akinbami LJ, Rhodes JC, Lara M. Racial and ethnic differences in asthma diagnosis among children who wheeze. *Pediatrics* 2005;115(5):1254–60.
12. Carter-Pokras OD, Gergen PJ. Reported asthma among Puerto Rican, Mexican-American, and Cuban children, 1982 through 1984. *Am J Public Health* 1993; 83(4):580–2.
13. Ledogar RJ, Penchaszadeh A, Garden CC, et al. Asthma and Latino cultures: different prevalence reported among groups sharing the same environment. *Am J Public Health* 2000;90(6):929–35.
14. Steinberg DM, Serebrisky D, Feldman JM. Asthma in children of Caribbean descent living in the inner-city: comparing Puerto Rican and Afro-Caribbean children. *Psychol Health Med* 2017;22(6):633–9.
15. Akinbami LJ, Moorman JE, Garbe PL, et al. Status of childhood asthma in the United States, 1980-2007. *Pediatrics* 2009;123(Suppl 3):S131–45.
16. He H, Butz A, Keet CA, et al. Preterm birth with childhood asthma: the role of degree of prematurity and asthma definitions. *Am J Respir Crit Care Med* 2015; 192(4):520–3.
17. Crump C, Winkleby MA, Sundquist J, et al. Risk of asthma in young adults who were born preterm: a Swedish national cohort study. *Pediatrics* 2011;127(4): e913–20.
18. Martin JA, Hamilton BE, Osterman MJ, et al. Births: final data for 2012. *Natl Vital Stat Rep* 2013;62(9):1–68.
19. Gergen PJ, Togias A. Inner city asthma. *Immunol Allergy Clin North Am* 2015; 35(1):101–14.
20. Martin JA, Osterman MJ, Centers for Disease Control and Prevention (CDC). Pre-term births - United States, 2006 and 2010. *MMWR Suppl* 2013;62(3):136–8.
21. Dombkowski KJ, Leung SW, Gurney JG. Prematurity as a predictor of childhood asthma among low-income children. *Ann Epidemiol* 2008;18(4):290–7.
22. Robbins JM, Benson BJ, Esangbedo IC, et al. Childhood obesity in an inner-city primary care population: a longitudinal study. *J Natl Med Assoc* 2016;108(3): 158–63.
23. Elliott JP, Harrison C, Konopka C, et al. Pharmacist-led screening program for an inner-city pediatric population. *J Am Pharm Assoc* (2003) 2015;55(4):413–8.
24. Vo P, Makker K, Matta-Arroyo E, et al. The association of overweight and obesity with spirometric values in minority children referred for asthma evaluation. *J Asthma* 2013;50(1):56–63.
25. Jensen ME, Gibson PG, Collins CE, et al. Diet-induced weight loss in obese children with asthma: a randomized controlled trial. *Clin Exp Allergy* 2013;43(7): 775–84.
26. Eggleston PA, Rosenstreich D, Lynn H, et al. Relationship of indoor allergen exposure to skin test sensitivity in inner-city children with asthma. *J Allergy Clin Immunol* 1998;102(4 Pt 1):563–70.
27. Rosenstreich DL, Eggleston P, Kattan M, et al. The role of cockroach allergy and exposure to cockroach allergen in causing morbidity among inner-city children with asthma. *N Engl J Med* 1997;336(19):1356–63.
28. Ahluwalia SK, Matsui EC. Indoor environmental interventions for furry pet allergens, pest allergens, and mold: looking to the future. *J Allergy Clin Immunol Pract* 2018;6(1):9–19.

29. Ahluwalia SK, Peng RD, Breyse PN, et al. Mouse allergen is the major allergen of public health relevance in Baltimore City. *J Allergy Clin Immunol* 2013;132(4):830–5.e1-2.
30. Torjusen EN, Diette GB, Breyse PN, et al. Dose-response relationships between mouse allergen exposure and asthma morbidity among urban children and adolescents. *Indoor Air* 2013;23(4):268–74.
31. Matsui EC, Eggleston PA, Buckley TJ, et al. Household mouse allergen exposure and asthma morbidity in inner-city preschool children. *Ann Allergy Asthma Immunol* 2006;97(4):514–20.
32. Phipatanakul W, Eggleston PA, Wright EC, et al. National Cooperative Inner-City Asthma Study. Mouse allergen. II. The relationship of mouse allergen exposure to mouse sensitization and asthma morbidity in inner-city children with asthma. *J Allergy Clin Immunol* 2000;106(6):1075–80.
33. Sheehan WJ, Rangsihienchai PA, Muilenberg ML, et al. Mouse allergens in urban elementary schools and homes of children with asthma. *Ann Allergy Asthma Immunol* 2009;102(2):125–30.
34. Chew GL. Assessment of environmental cockroach allergen exposure. *Curr Allergy Asthma Rep* 2012;12(5):456–64.
35. O'Connor GT, Walter M, Mitchell H, et al. Airborne fungi in the homes of children with asthma in low-income urban communities: the Inner-City Asthma Study. *J Allergy Clin Immunol* 2004;114(3):599–606.
36. Pongracic JA, O'Connor GT, Muilenberg ML, et al. Differential effects of outdoor versus indoor fungal spores on asthma morbidity in inner-city children. *J Allergy Clin Immunol* 2010;125(3):593–9.
37. Ziska LH, Gebhard DE, Frenz DA, et al. Cities as harbingers of climate change: common ragweed, urbanization, and public health. *J Allergy Clin Immunol* 2003;111(2):290–5.
38. Ziello C, Sparks TH, Estrella N, et al. Changes to airborne pollen counts across Europe. *PLoS One* 2012;7(4):e34076.
39. Kattan M, Gergen PJ, Eggleston P, et al. Health effects of indoor nitrogen dioxide and passive smoking on urban asthmatic children. *J Allergy Clin Immunol* 2007;120(3):618–24.
40. Hansel NN, Breyse PN, McCormack MC, et al. A longitudinal study of indoor nitrogen dioxide levels and respiratory symptoms in inner-city children with asthma. *Environ Health Perspect* 2008;116(10):1428–32.
41. O'Connor GT, Lynch SV, Bloomberg GR, et al. Early-life home environment and risk of asthma among inner-city children. *J Allergy Clin Immunol* 2018;141(4):1468–75.
42. Liu AH, Babineau DC, Krouse RZ, et al. Pathways through which asthma risk factors contribute to asthma severity in inner-city children. *J Allergy Clin Immunol* 2016;138(4):1042–50.
43. Milligan KL, Matsui E, Sharma H. Asthma in urban children: epidemiology, environmental risk factors, and the public health domain. *Curr Allergy Asthma Rep* 2016;16(4):33.
44. Guarneri M, Balmes JR. Outdoor air pollution and asthma. *Lancet* 2014;383(9928):1581–92.
45. Gauderman WJ, Urman R, Avol E, et al. Association of improved air quality with lung development in children. *N Engl J Med* 2015;372(10):905–13.
46. Ruffin J. A renewed commitment to environmental justice in health disparities research. *Am J Public Health* 2011;101(Suppl 1):S12–4.

47. Cureton S. Environmental victims: environmental injustice issues that threaten the health of children living in poverty. *Rev Environ Health* 2011;26(3):141–7.
48. Ierodiakonou D, Zanobetti A, Coull BA, et al. Ambient air pollution, lung function, and airway responsiveness in asthmatic children. *J Allergy Clin Immunol* 2016; 137(2):390–9.
49. Bloom B, Jones LI, Freeman G. Summary health statistics for U.S. children: National Health Interview Survey, 2012. *Vital Health Stat* 10 2013;(258):1–81.
50. Department of Health and Human Services, Office of the Assistant Secretary for Planning and Evaluation. Information on poverty and income statistics: a summary of 2014 current population survey data. Washington, DC: ASPE Office of Human Services Policy; 2014. p. 1–9. Available at: <https://aspe.hhs.gov/report/information-poverty-and-income-statistics-summary-2014-current-population-survey-data>.
51. Lynch SV, Wood RA, Boushey H, et al. Effects of early-life exposure to allergens and bacteria on recurrent wheeze and atopy in urban children. *J Allergy Clin Immunol* 2014;134(3):593–601.e12.
52. Kopel LS, Gaffin JM, Ozonoff A, et al. Perceived neighborhood safety and asthma morbidity in the school inner-city asthma study. *Pediatr Pulmonol* 2015;50(1): 17–24.
53. Shams MR, Bruce AC, Fitzpatrick AM. Anxiety contributes to poorer asthma outcomes in inner-city black adolescents. *J Allergy Clin Immunol Pract* 2018;6(1): 227–35.
54. Ramratnam SK, Visness CM, Jaffee KF, et al. Relationships among maternal stress and depression, type 2 responses, and recurrent wheezing at age 3 years in low-income urban families. *Am J Respir Crit Care Med* 2017;195(5):674–81.
55. Bellin MH, Collins KS, Osteen P, et al. Characterization of stress in low-income, inner-city mothers of children with poorly controlled asthma. *J Urban Health* 2017;94(6):814–23.
56. Coordinated federal action plan to reduce racial and ethnic asthma disparities. Available at: http://www.epa.gov/childrenstaskforce/federal_asthma_disparities_action_plan.pdf. Accessed May 1, 2018.
57. Bellin MH, Newsome A, Land C, et al. Asthma home management in the inner-city: what can the children teach us? *J Pediatr Health Care* 2017;31(3):362–71.
58. Morgan WJ, Crain EF, Gruchalla RS, et al. Results of a home-based environmental intervention among urban children with asthma. *N Engl J Med* 2004; 351(11):1068–80.
59. Rabito FA, Carlson JC, He H, et al. A single intervention for cockroach control reduces cockroach exposure and asthma morbidity in children. *J Allergy Clin Immunol* 2017;140(2):565–70.
60. Phipatanakul W, Matsui E, Portnoy J, et al. Environmental assessment and exposure reduction of rodents: a practice parameter. *Ann Allergy Asthma Immunol* 2012;109(6):375–87.
61. Pongracic JA, Visness CM, Gruchalla RS, et al. Effect of mouse allergen and rodent environmental intervention on asthma in inner-city children. *Ann Allergy Asthma Immunol* 2008;101(1):35–41.
62. Matsui EC, Perzanowski M, Peng RD, et al. Effect of an integrated pest management intervention on asthma symptoms among mouse-sensitized children and adolescents with asthma: a randomized clinical trial. *JAMA* 2017;317(10): 1027–36.

63. DiMango E, Serebrisky D, Narula S, et al. Individualized household allergen intervention lowers allergen level but not asthma medication use: a randomized controlled trial. *J Allergy Clin Immunol Pract* 2016;4(4):671–679 e674.
64. Expert Panel Report 3. Guidelines for the diagnosis and management of asthma 2007. Available at: https://www.nhlbi.nih.gov/sites/default/files/media/docs/asthgdln_1.pdf. Accessed April 5, 2018.
65. Szeffler SJ, Mitchell H, Sorkness CA, et al. Management of asthma based on exhaled nitric oxide in addition to guideline-based treatment for inner-city adolescents and young adults: a randomised controlled trial. *Lancet* 2008;372(9643):1065–72.
66. Busse WW, Morgan WJ, Gergen PJ, et al. Randomized trial of omalizumab (anti-IgE) for asthma in inner-city children. *N Engl J Med* 2011;364(11):1005–15.
67. Teach SJ, Gill MA, Togias A, et al. Preseasonal treatment with either omalizumab or an inhaled corticosteroid boost to prevent fall asthma exacerbations. *J Allergy Clin Immunol* 2015;136(6):1476–85.
68. Rabe KF, Nair P, Brusselle G, et al. Efficacy and safety of dupilumab in glucocorticoid-dependent severe asthma. *N Engl J Med* 2018;378(26):2475–85.
69. Castro M, Corren J, Pavord ID, et al. Dupilumab efficacy and safety in moderate-to-severe uncontrolled asthma. *N Engl J Med* 2018;378(26):2486–96.
70. Brown KR, Krouse RZ, Calatroni A, et al. Endotypes of difficult-to-control asthma in inner-city African American children. *PLoS One* 2017;12(7):e0180778.
71. Pongracic JA, Krouse RZ, Babineau DC, et al. Distinguishing characteristics of difficult-to-control asthma in inner-city children and adolescents. *J Allergy Clin Immunol* 2016;138(4):1030–41.