

Childhood Asthma Management and Environmental Triggers



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KEYWORDS

- Childhood asthma • Asthma exacerbations • Prevention • Management
- Environmental triggers • Trigger remediation

KEY POINTS

- The causes of asthma development are not known and thus asthma cannot be prevented based on the current level of understanding.
- Home environmental intervention strategies can reduce asthma morbidity in sensitized children but are probably not effective in children not sensitized to the specific allergen.
- Interventions tailored to the allergen sensitization of the child coupled with education and appropriate severity-specific asthma medication may be the most effective strategy to reduce asthma morbidity.
- Efforts to prevent environmental tobacco smoke exposure are important for everyone in the household.

INTRODUCTION

Asthma is the most common chronic disease of children, affecting more than 6.8 million children in the United States (9.3% of all children).¹ Asthma cannot be cured. Asthma cannot be prevented. However, asthma can be controlled. This article first reviews asthma epidemiology and the current understanding of the genetics of asthma. It then discusses the various proposed hypotheses for the continuing increase in asthma prevalence and risk factors for asthma. In addition, it discusses emerging work on asthma prevention and strategies to prevent asthma exacerbations.

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EPIDEMIOLOGY

In industrialized countries with Western lifestyles, lifetime asthma prevalence is high and has increased approximately 2.7 percentage points per year since 1997.² In the United States, the lifetime reported asthma prevalence in individuals of all ages is 13.0% (2012). Lifetime prevalence is higher in children (14%) than in adults and increases from early childhood (7.0% at 0–4 years of age) to adolescence (18.4% at 15–19 years of age), with current asthma prevalence showing a similar trend.¹ Asthma is a major public health problem costing the health care system nearly \$56 billion annually, with direct health care costs estimated at \$50.1 billion and indirect costs (lost productivity) contributing an additional \$5.9 billion.²

Asthma in childhood disproportionately affects more boys than girls and under-represented minority populations with African Americans and (some) Hispanic people having higher rates than other racial and ethnic groups. Children of Puerto Rican origin have the highest asthma prevalence of all ethnic and racial groups, whereas Mexican children have one of the lowest reported rates, making it difficult to examine prevalence when all individuals of Hispanic origin are grouped together.^{2–4}

Asthma morbidity is high but hospitalization rates for asthma decreased 24% between 2003 and 2010 (National Health Interview Survey, 2001–2011).² Compared with adults, children are disproportionately hospitalized for asthma. Approximately 29% of the asthma hospital discharges in 2010 occurred in children less than 15 years of age even though only 21% of the US population is less than 15 years of age.² In 2010, asthma was responsible for 2.1 million emergency room visits, 10.6 million physician office visits, and 1.2 million hospital visits.²

Asthma deaths are rare in children but increase with age. In 2009, 157 children less than 15 years of age (0.2 per 100,000) died of asthma compared with 617 adults older than 85 years.² Black adult women have the highest mortality from asthma (2.5 per 100,000), with an age-adjusted death rate in black people that is 3.1 times higher than the rate in the white population.²

Genetics of Asthma

Asthma is a complex and chronic disease that depends on the interplay of genetic and environmental triggers. More than 100 candidate genetic loci have been identified using epidemiologic linkage studies.⁵ This finding suggests that individuals with asthma may have many susceptibility loci, each of small effect. Multiple genome-wide association studies using population cohorts have identified several regions associated with asthma, including the 17q21 locus (ORMDL3/GSDML), IL33 on chromosome 9p24, HLA-DR/DQ on 6p21, IL1RL1/IL18R1 on 2q12, WDR36/TSRP on 5q22, and IL13 on 5q31.⁵ Many of the associations have not been replicated in other populations, suggesting a role of population-specific variants in the causation of asthma and showing an important role for regulatory genes. Genomic studies using human fetal tissue suggest a complex interaction between environmental factors such as in utero smoke exposure, maternal diet, folate and vitamin D, lung structural genes, and lung function growth trajectory.⁶

African ancestry has been found to affect lung function and asthma severity. Using ancestry informative markers, lung function is inversely correlated with the percentage of African ancestry in 3 independent African American populations.⁷ Genetic variation leading to an increased risk for exacerbations is also more common in African individuals.⁸ Results from the GALA (Genetics of Asthma in Latino Americans) study show that individuals who are Puerto Rican have a higher degree of African and European ancestry than Mexican American individuals. It has been suggested that this

difference may contribute to the high morbidity and mortality experienced by Puerto Rican compared with Mexican American individuals.⁹

Variable responses to specific therapeutic asthma medications have been reported in different ethnic groups and this variable response may also relate to the extent of African ancestry.¹⁰ African ancestry might introduce genetic variation associated with a greater likelihood for alteration in the therapeutic response to inhaled short-acting and long-acting beta agonists (LABAs). In the SMART (Salmeterol Multicenter Asthma Research Trial) study, African American participants treated with salmeterol experienced an increase in asthma life-threatening exacerbations and death but they were also less likely to have been treated with an inhaled corticosteroid (ICS) and more likely to have been hospitalized than the other study participants.¹¹ Additional studies and a large meta-analysis have consistently shown that the combination of a LABA and an ICS is safe and efficacious, but the SMART study resulted in the boxed warning for all LABA-containing inhalers.^{12,13}

Other studies have shown that African American individuals respond differently to combination therapies. In the BADGER (Best Add-on Therapy Giving Effective Response) trial from the Childhood Asthma Research and Education Network, African American children did not show a preferential response to a step-up from low-dose ICS to LABA and ICS combination therapy and thus the addition of a LABA to ICS therapy was no more efficacious than increasing the ICS dose.¹⁴ In contrast, Hispanic and non-Hispanic white children responded to the addition of a LABA to their ICS therapy. In addition, Puerto Rican participants in the GALA study were less bronchodilator responsive after administration of a short-acting bronchodilator.¹⁵

Hypotheses on the Origins of Asthma

Epidemiologists have long sought to determine the underlying causes of childhood asthma. Since the early 1990s, asthma rates have increased worldwide and observational studies have tried to explain this increase in prevalence.¹⁶ Proposed reasons for this increase in prevalence have included increasing pollution levels,¹⁷ obesity, dietary changes, the hygiene effect,¹⁸ low vitamin D levels,¹⁹ and early exposure to acetaminophen (APAP).²⁰ Three of the currently most popular hypotheses are discussed here.

The hygiene hypothesis

The largest increase in asthma prevalence over the past 30 years has been observed in the Western world.²¹ Given the short time frame, genetic changes are unlikely to explain this observation but improvements in public health measures, treatment of diseases, vaccination programs, and hygiene strongly associate with the increase in asthma. These improvements in public health have occurred with a corresponding decrease in exposure to noninfectious microorganisms. In 1989 Strachan²² hypothesized that the increase in asthma and allergic disorders in industrialized nations was caused by the absence of early life exposure to viral and bacterial organisms and their products (eg, endotoxins). This theory is referred to as the hygiene hypothesis. Early life exposure to viruses and bacteria primes and trains the immune system. Elimination of this training results in a shift toward a more inflammatory immune response that has been associated with asthma and allergic disease. Studies have found that farm exposures and larger family size are associated with these early life exposures and are also associated with lower rates of asthma and atopy. In addition, the increased asthma prevalence parallels the increase in autoimmune diseases and corresponds with decreases in rates of infectious diseases. These data suggest that, in the absence of exposure to foreign microbes, the immune system sustains a hypervigilant state that results in a mismatch between the host and innocuous environmental challenges.

Because of this mismatch, the immune system turns on itself, resulting in increases in autoimmune diseases and asthma.

Although microbial exposure (such as bacterial endotoxin) is associated with protection against asthma, the hygiene hypothesis does not reconcile the observed higher asthma prevalence in inner-city, urban environments, where endotoxin exposure has been shown to be a risk factor for asthma.²³ Inner-city housing conditions have unlikely become more hygienic in the United States but asthma prevalence has increased significantly among racial and ethnic minorities living in poverty. To explain these observations, the narrow version of the hygiene hypothesis has evolved, which focuses on early life microbial exposure protecting against allergic asthma by suppressing TH₂ immune responses. It is now suggested that it is the diversity of microbial exposure that is particularly protective against asthma²⁴ and that this diversity, rather than endotoxin per se, may explain the protective effect of farm living.

The vitamin D hypothesis

Hypovitaminosis D is prevalent worldwide and increasing. Multiple studies have shown an increase in asthma prevalence and severity in children with asthma in association with low levels of vitamin D.^{25–27} However, a recent systematic review of childhood cohort studies concluded that there was only a potential association between low vitamin D levels and asthma.¹⁹ Vitamin D is both a hormone and a nutrient; levels of vitamin D are determined primarily by environmental mechanisms such as exposure to the sun, latitude, and skin color. Vitamin D has both in utero and postnatal effects on lung and immune system development and function, and vitamin D is thought to have an immunomodulatory role in both the innate and adaptive immune response. Several genome-wide association studies have uncovered genetic variants that associate with serum vitamin D levels in children with asthma.^{28,29} Overall, studies examining the relationship between vitamin D and asthma have problems with selection bias, inadequate measuring of outcomes, and confounding.¹⁹

The acetaminophen hypothesis

APAP is a widely used antipyretic and analgesic that has recently been identified as a possible cause for the current increase in asthma prevalence.³⁰ APAP replaced aspirin in the 1990s as the antipyretic of choice when aspirin was thought to be associated with Reye syndrome. Since then, several longitudinal studies have reported an association between increased APAP use and the increased prevalence of childhood asthma.²⁰ Induction of asthma by APAP is biologically plausible, because APAP decreases airway antioxidant defenses through depletion of glutathione.³¹ However, an alternative explanation for the APAP/asthma association may be confounding by indication. APAP is commonly used to treat fever and pain caused by respiratory tract infections, which are a known risk factor for childhood asthma. Children with asthma may have a longer duration of fever in association with respiratory tract infections, and this may have resulted in greater APAP exposure.^{32,33} According to a recent systematic review and meta-analysis, there currently is insufficient evidence to support an association between APAP use in childhood and incidence of asthma.²⁰

ASTHMA PATHOPHYSIOLOGY

Asthma is a chronic inflammatory disease of the airways that results from the combination of environmental exposures and genetic/biological susceptibility. Asthma has 3 major characteristics: (1) chronic airway inflammation; (2) airway obstruction that, for the most part, is reversible; and (3) airway hyperresponsiveness to a variety of stimuli. Although airway eosinophil inflammation is typical, many patients, especially those

with mild asthma, have noneosinophilic disease.³⁴ Airflow obstruction is usually reversible but some patients develop irreversible airflow obstruction, which has been attributed to remodeling of the airway wall.

Symptoms of asthma include recurrent wheezing, cough, and shortness of breath. A diagnosis of asthma is based on the presence of these symptoms and objective confirmation of (at least partially) reversible airflow obstruction. However, some children and adults with asthma only cough and never wheeze, whereas others experience shortness of breath and never wheeze.³⁵ Diagnosing asthma in these individuals can be difficult unless the clinician has a high index of suspicion. Triggers for cough-variant asthma and asthma-related dyspnea are the same as for individuals with wheezing, and are discussed later.

Asthma diagnosis and approach to treatment are discussed in a 2013 article in the *Pediatric Clinics of North America*.³⁶

Risk Factors and Natural History

Brief periods of a loss of asthma control, manifested by cough, wheezing, and/or shortness of breath, are the result of exposure to nonspecific triggers such as strong smells or exercise, whereas moderate or severe exacerbations are usually caused by exposure to allergens or viruses, with human rhinovirus being the most important. More than 80% of children who are diagnosed with asthma at 6 years of age have a history of wheezing in the first 3 years of life.³⁷ The opposite is not true; half of all children who wheeze in the first year of life are wheeze free and do not go on to have recurring episodes.³⁸ In general, children who have mild asthma rarely progress to severe disease, but severe and frequent wheezing is a well-established risk factor for persistence and disease severity in adulthood. Boys with wheezing illnesses in early childhood are more likely to outgrow their asthma, probably because of a smaller airway structure that predisposes boys to wheezing illnesses in early life.³⁹

PREVENTION STRATEGIES

Asthma Prevention

There are no effective strategies to prevent the development of asthma in children. In order for an agent/exposure to be determined to have a causal relationship, there must be evidence of a strong and consistent association, a biological gradient, biological plausibility and coherence, and a temporally correct association. At present, no agent or exposure reaches this level of evidence. The last systematic summary of the evidence supporting a causal relationship for the development of asthma was published in 2000 (Committee on the Assessment of Asthma and Indoor Air of the Institute of Medicine [IOM]).⁴⁰ House dust mite and environmental tobacco smoke (ETS) had the strongest association with asthma development but neither reached the level of causation.

Dust mite exposure and asthma development

Exposure to dust mite is associated with dust mite sensitization and dust mite sensitization is a risk factor for the development of asthma.⁴¹ Three large studies have implemented house dust mite avoidance measures during pregnancy, at birth, and later in childhood and assessed asthma development in childhood.^{42–44} Strategies to reduce house dust mite exposure, such as impermeable mite mattress covers, anti-dust mite spray, and carpet removal reduced dust mite levels and dust mite sensitization in children but effects on wheezing outcomes were short-term with no long-term benefit on the development of asthma.^{45–48} Some investigators have suggested that these same strategies might also have reduced endotoxin exposure, which has been found to be protective against asthma in several studies.⁴⁹

Respiratory tract infections and asthma development

The role of viral infections in the development of asthma has long been debated. Viral infections, particularly respiratory syncytial virus (RSV) and rhinovirus, are associated with wheezing episodes in children and children with asthma are at greater risk for more severe infection and thus greater morbidity with these infections.⁵⁰ Emerging evidence suggests that prevention of RSV infection might be protective against asthma. In a randomized controlled trial, use of a highly specific monoclonal immunoglobulin G antibody directed against the RSV fusion protein (palivizumab) glycoprotein reduced recurrent wheezing in healthy preterm infants by 50% in the first year of life.⁵¹ Similar reductions in recurrent wheezing and the diagnosis of asthma have been observed in infants receiving ribavirin antiviral therapy and in premature infants treated with palivizumab.^{52–54} These data suggest that preventing RSV lower respiratory tract infections in the first year of life may prevent asthma or wheezing.

Environmental tobacco smoke and asthma development

Multiple studies have linked ETS and asthma, and several systematic reviews of the literature have concluded that ETS exposure is a risk factor for the development of asthma in children.⁵⁵ The Surgeon General's 2006 report concluded that there was a causal relationship between parental smoking and ever having asthma in school-aged children and between parental smoking and wheezing illness in early childhood.⁵⁶ However, the evidence was only sufficient to show an association between parental ETS exposure and the onset of childhood asthma. In a survey of more than 11,000 children 4 to 6 years of age in the United Kingdom, the odds ratio for childhood wheezing in the previous 12 months increased with each additional smoker in the home. Lewis and colleagues⁵⁷ suggested that 8% of asthma in children 4 to 6 years of age could be attributable to ETS exposure at home. Quitting smoking before pregnancy reduced the risk of asthma to that of the nonsmoking population, and this is the only known effective prevention strategy.

Multiple other intervention strategies to reduce asthma development have not been successful. These strategies include breastfeeding during the first 4 to 6 months of life, maternal avoidance of allergenic foods during pregnancy, antioxidant supplementation (vitamins A and C) during pregnancy, and delayed introduction of solids.⁴¹

Asthma Exacerbation Prevention

In 2000 the Committee on the Assessment of Asthma and Indoor Air of the IOM reviewed and summarized the scientific evidence for the relationship between indoor air exposures and asthma exacerbations.⁴⁰ This report was updated in October 2014⁵⁸ and the results are summarized in **Box 1**. Several important new findings related to exposures that cause asthma exacerbations are highlighted here.

Dust mite and asthma exacerbations

In children sensitized to dust mite (Der p1 and Der f1 are the 2 common dust mite allergens), a dose-related association between dust mite antigen and wheeze has been found.⁵⁹ Both intervention studies⁶⁰ and prospective studies^{61–63} have reported associations between dust mite exposure and asthma exacerbations. In children of unknown dust mite sensitization, most studies have found associations with exacerbations,^{64,65} but not all.⁶⁶ Dust mite exposure has also been associated with fraction of exhaled nitric oxide (FeNO) measurements, suggesting a direct role in airway inflammation.

Box 1**Summary of 2014 scientific evidence for exposures and asthma exacerbations***Exposures with sufficient evidence to show causation of asthma exacerbations*

House dust mite allergens in sensitized individuals

Cat allergen in sensitized individuals

Cockroach allergen in sensitized individuals (especially adults)

Outdoor culturable fungal exposure in sensitized individuals

Dampness or dampness-related agents in children

Exposures associated with asthma exacerbations but with insufficient evidence to show causation

Chronic ETS exposure in preschool-aged children

Dog allergen in sensitized individuals

Brief high-level exposures to NO₂ in conjunction with a nonspecific chemical irritant or inhaled allergen

Indoor endotoxin exposure

Exposures with limited or suggestive evidence of an association with asthma exacerbations

Chronic ETS exposure in older children and adults

Indoor culturable *Penicillium* in individuals with any fungal sensitization

Formaldehyde

Fragrance exposure

Rodent and mice exposure in the home in rodent-sensitized children

Synthetic bedding

Exposures with inadequate or insufficient evidence of an association with asthma exacerbations

Pesticides

Houseplants

Plasticizers

Residential volatile organic compounds

Indoor pollen exposures

Low building ventilation rates

Cat allergen exposure and asthma exacerbations

Cat allergen exposure in children with asthma sensitized to cat is associated with increased asthma severity, greater rescue medication use, increased asthma symptom frequency, and/or increased FeNO.^{59,61,67} This association has not been reported in cross-sectional studies^{65,66} but it has been suggested that the findings were biased by cat-allergic subjects not owning cats. Other studies have found no association between cat exposure and asthma exacerbations in individuals who were atopic but not sensitized to cat.⁶⁸

Cockroach exposure and asthma exacerbations

There is strong evidence of a causal relationship between exposure to cockroach antigen and asthma exacerbations in cockroach-sensitized adults^{69,70} but the evidence

in children for this association is less consistent. Bedroom cockroach exposure in sensitized children is consistently associated with asthma exacerbations in prospective studies,^{71,72} whereas results from cross-sectional studies have been mixed for bedroom exposure^{59,66} but positive for kitchen exposure.⁶⁴ Cockroach allergen can induce allergic sensitization and inflammation,⁷³ and expression of inflammatory cytokines,^{74,75} suggesting a potential mechanism for asthma morbidity in sensitized and nonsensitized individuals.

Fungi and asthma exacerbations

Outdoor fungal exposures cause exacerbations of asthma in sensitized individuals, including children.^{76,77} Outdoor fungal concentrations are associated with admissions to emergency rooms even after adjustment for pollen and air pollutants.⁷⁶ Two studies have reported an association between culturable airborne indoor *Penicillium* exposure and severe asthma exacerbations and asthma severity even after adjustment for outdoor fungal levels.^{61,77} Indoor *Penicillium* levels have been associated with increased asthma symptoms in several other studies^{78,79} but the sampling strategy was suspect because of high temporal variability so the IOM was unable to conclude that there was an association between indoor cultural *Penicillium* exposure and asthma exacerbations in children.

Dampness and asthma exacerbations

Multiple studies published in the past 15 years have shown a positive association between evident or measured dampness or mold and asthma severity or exacerbations,^{80–83} and remediation of dampness sources and visible mold has been shown to reduce severe asthma exacerbations.^{80,84} The specific causal agents for asthma exacerbations associated with dampness have not been identified but are thought to include fungal agents and/or other biological exposures, such as bacteria or dust mites, that thrive in dampness.

Environmental tobacco smoke exposure and asthma exacerbations

One of the major changes in the recently released update to the IOM report was the downgrading of the evidence in support of a causal relationship between ETS exposure and asthma exacerbations.⁵⁸ Citing 19 recent studies on ETS exposure and asthma exacerbations, the update concluded that the “weight of evidence no longer supports a causal relationship.”⁵⁸ In preschool children for whom the evidence is the strongest and formed the basis for the 2000 IOM conclusion, more recent studies have found that high ETS exposure is not related to increased wheezing episodes or unscheduled medical visits.^{85,86} Other investigators have reported an inverse relationship between current ETS and FeNO, with ETS exposure at age 4 years associated with lower forced expiratory volume in 1 second at age 7 years but not concurrent exposure at age 7 years. Other studies have also found no association between FeNO and ETS.^{65,87–90} In contrast, multiple other studies in children have continued to show an association between ETS exposure and reduced lung function, increased wheezing, nocturnal symptoms, and emergency department visits.^{91–96}

Asthma Exacerbation Prevention Strategies

There is significant evidence that 3 groups of intervention strategies are effective in reducing asthma symptoms and possibly asthma exacerbations. These groups are (1) a tailored in-home education and remediation of asthma triggers in sensitized individuals; (2) integrated pest management in sensitized individuals; and (3) combined elimination of moisture intrusion and leaks, and removal of mold items.⁹⁷

Asthma Trigger Remediation

Dust mite

Multiple studies have shown the effectiveness of a comprehensive dust mite mitigation strategy on dust mite exposure in homes. The most effective strategies have included dust-impermeable pillow, mattress, and box spring covers; use of a high-efficiency particulate air (HEPA) vacuum cleaner; and removal of the carpets.⁹⁸ Sophisticated (and high-cost) interventions have included installation of central heating and use of a whole-home mechanical ventilation system with heat recovery unit, which significantly reduced humidity levels and resulted in a significant reduction in house dust mite counts. Bedroom and living room air cleaners have been shown to reduce cat and dog allergens but do not reduce dust mite levels in homes.⁹⁹ Reductions in dust mite exposure using either multiple bedroom strategies and/or sophisticated interventions have been associated with decreases in asthma symptoms. In contrast, isolated interventions, such as dust-impermeable pillow and mattress and box spring covers, have not been effective.^{46,48}

Environmental tobacco smoke

Although comprehensive smoke-free laws prohibiting smoking in public places correlated with declines in smoking rates among adults, ETS exposure has declined more slowly among children.¹⁰⁰ In a cross-sectional study, using National Health and Nutrition Examination Survey 2003 to 2010 data, 53.3% of nonsmoking children 6 to 19 years of age with asthma were exposed to ETS.¹⁰¹ Several interventions have targeted tobacco smoke cessation and reduction of secondhand smoke exposure in the home. However, most interventions designed to reduce children's ETS exposure have been ineffective.¹⁰² The most effective strategy among children, who have minimal control over ETS exposure, was reported by Lanphear and colleagues,¹⁰³ in which HEPA filters reduced the number of unscheduled asthma visits. However, there was no difference in serum or hair cotinine between the intervention and control groups. Children are more vulnerable than adults to the effects of third-hand smoke, which can persist for weeks to months on surfaces and in settled dust. Studies of smoking outside the home have shown small decreases in urine cotinine among infants living in homes of smokers who smoked outside.¹⁰⁴ This finding suggests that even smoking outside the home is not an effective strategy for remediating ETS exposure.

Integrated pest management

Integrated pest management (IPM) is a prevention-based approach to pest control that reduces the need for pesticides. It is a safer, and often more effective, long-term means of reducing the presence of pest allergens in homes compared with traditional pest control methods. IPM focuses on eliminating the root causes of pests (**Table 1**) and includes (1) using small, sticky traps or glue boards in areas of the house that are more susceptible to pests, such as the kitchen, basement, or bathroom; (2) preventing pest access by caulking cracks and crevices that pests use to move or hide; (3) reducing clutter to remove pest hiding places; (4) preventing food sources by using plastic or glass containers with tight-fitting lids, washing and drying dirty dishes, storing pet foods in pest-proof containers, and using a trash can with a tight-fitting lid; and (5) removing water sources by fixing any water leaks, wiping up spills, and removing pets' water dishes at night. In New York City, IPM involves a 3-hour intervention including a home inspection, vacuuming, steam cleaning, pest exclusion activities (sealing holes), low-toxicity pesticide application, and tenant education, and costs from \$400 to \$500 per unit.¹⁰⁵

Table 1 Supplies needed to implement asthma exacerbation prevention strategies	
Dust mites	Dust-impermeable pillow, mattress, and box spring covers HEPA vacuum cleaner Carpet removal
IPM	Cockroach glue traps Mouse glue traps Door sweeps Caulk for cracks Plastic containers with tight lids Trash can with tight lid Roller mop Copper mesh to fill holes

Adapted from Asthma Regional Council of New England. The role of pest control in effective asthma management: a business case. 2009. Available at: <http://asthmaregionalcouncil.org>. Accessed January 26, 2015.

Moisture and mold interventions

In children with sensitization to mold, a comprehensive asthma program consisting of evaluation by an asthma specialist with development of a written asthma treatment plan, asthma education, and skill building in individualized problem solving was coupled with household interventions designed to reduce dampness and mold.⁸⁴ Specific interventions were directed at reducing water infiltration, removing water-damaged building materials, alterations to the heating/ventilation/air conditioning, lead hazard control, and environmental cleaning. Mold was cleaned from hard surfaces, mold exposure pathways were moved, rainwater intrusion was stopped, water vapor was exhausted from kitchens and bathroom, and plumbing leaks were repaired. The cost for the intervention was \$3458 ± \$2795 and resulted in a reduction in asthma symptoms and mold levels, and a modest reduction in health care use.

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