
Housing and Child Health

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The connection between housing and health is well established. Physical, chemical, and biological aspects of the child's home, such as cleanliness, moisture, pests, noise, accessibility, injury risks, and other forms of housing environmental quality, all have the potential to influence multiple aspects of the health and development of children. Basic sanitation, reduced household crowding, other improvements in housing and expanded, and improved housing regulations have led to advances in children's health. For example, lead poisoning prevention policies have profoundly reduced childhood lead exposure in the United States. This and many other successes highlight the health benefits for families, particularly children, by targeting interventions that reduce or eliminate harmful exposures in the home. Additionally, parental mental health problems, food insecurity, domestic violence, and the presence of guns in

children's homes all are largely experienced by children in their homes, which are not as yet considered part of the Healthy Homes agenda. There is a large movement and now a regulatory structure being put in place for healthy housing, which is becoming closely wedded with environmental health, public health, and the practice of pediatrics. The importance of homes in children's lives, history of healthy homes, asthma, and exposures to lead, carbon monoxide, secondhand/third-hand smoke, radon, allergy triggers is discussed, as well as how changes in ambient temperature, increased humidity, poor ventilation, water quality, infectious diseases, housing structure, guns, electronic media, family structure, and domestic violence all affect children's health.

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Introduction

Importance of Homes in Children's Lives

For most children, the home and its immediate surroundings are the first and major environments they experience throughout their early years. Young children spend the majority of their time in the home. On average, children spend ~15 h a day indoors at home. Infants average nearly 20 h/day indoors.^{1,2} The connection between housing and health, meanwhile, is well established.³ Physical, chemical, and biological aspects of the home, such as cleanliness, water quality, lead-based paint hazards, secondhand and thirdhand smoke (SHS and THS), ventilation, mold and moisture, pests, noise, accessibility, injury risks, and other forms of housing

environmental quality, all have the potential to influence multiple aspects of the health and development of children.⁴

Children are particularly vulnerable to housing-related pollutants because they spend proportionally more time indoors than adults. They also have increased exposure due to physiological and behavioral factors, such as hand-to-mouth activity. Air and settled dust levels of pesticides and lead, for example, also have been found to be higher closer to the floor, increasing exposure. Children have increased surface area to total body mass and higher respiratory rates, pound for pound drink more water and consume more food, thereby contributing to increased exposure especially during "critical windows of exposure."⁵

In the case of air pollutants, infants and young children constitute a special risk group due to the fact that their respiratory system is not yet completely developed until the age of 6.⁶ Children and infants have a higher resting metabolic rate and rate of oxygen consumption per unit of body mass. Therefore, their intake of any air pollutant is likely to be greater. In addition to an increased need for oxygen relative to their size, children have narrower airways than do adults.⁶ Thus, irritation caused by air pollution that would produce only a slight response in an adult can

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result in potentially significant inflammation, obstruction, and portals of entry for antigens and infectious agents in the airways of a young child.

Since children in the developed world now spend most of their time indoors, their principal exposure to air pollutants is from breathing the air inside their homes, child care centers, and schools. In some communities, and where it is cold, indoor exposure may be for a much longer period each day. Depending on the materials used in the building itself, the condition of the building, the chemicals used inside the building, as well as on its ventilation system, various pollutants can be found in higher concentrations indoors than outside.⁷

For all these reasons, the first years of life constitute a critical period for a child's exposure to indoor pollution. Basic sanitation, ventilation, reduced household crowding, other improvements in housing, and expanded and improved housing regulations have led to advances in children's health. Multiple research studies have demonstrated improved child health outcomes with policies targeting living conditions, especially homes. For example, lead poisoning prevention policies have profoundly reduced childhood lead exposure in the United States.^{8,9} This and many other successes highlight the health benefits for families, particularly children, by targeting interventions that reduce or eliminate harmful exposures in the home.

This paper includes aspects of children's lives that may have profound influences on their health and development that to date are not often considered as part of discussions about healthy homes. Such issues as parental mental health problems, food insecurity, domestic violence, and the presence of guns in children's homes all are largely experienced by children in their homes, and thus are discussed in this paper in the hope of expanding the thinking about the importance of homes in children's lives.

History of Healthy Homes

The strong relationship between health and the home has long been well recognized. Since the 19th century, physicians and public health officials have implemented housing standards that improved ventilation, sanitation, structural stability, and reduced crowding in an effort to reduce the deaths and illnesses among the poor who are concentrated in slum housing around factories and big

cities.^{3,10} In recent years, the public health community has renewed its interest in improving and promoting healthy, safe, affordable, accessible, and environmentally friendly homes through a comprehensive and coordinated approach. In 2009, the Surgeon General of the US Public Health Service issued *The Surgeon General's Call to Action to Promote Healthy Homes* in an effort to focus attention on the public health impact of housing hazards and to provide an overview of issues that contribute to the nation's unhealthy housing situation. Factors discussed include the structural and safety aspects of the house, quality of indoor air, water quality, chemicals, residents' behavior, and the house's immediate surroundings. Additionally, the *Call to Action* described housing-related health and safety issues for which interventions are available and made suggestions for future areas of research.³

The Healthy Homes concept began to take shape in the US during the 1990s with the administration of the childhood lead hazard control program. In 1991, the

Lead Hazard Control program was implemented by the US Department of Housing and Urban Development's (HUD) Office of Healthy Homes and Lead Hazard Control in an effort to reduce the number of childhood lead poisoning cases. Through the utilization of grants, research, enforcement, and outreach, this program helped to substantially decrease the number of lead-poisoned children. The Federal

Residential Lead-Based Paint Hazard Reduction Act was passed in 1992, creating a national approach to preventing lead poisoning from housing hazards through the development of lead dust and soil standards as well as requirements for lead hazard control in federally assisted housing and precautions during renovation work.⁸ These actions supplemented the Federal ban of lead from new paints in 1978, gasoline and food canning.⁸ These collective policy changes and enforcement efforts led to an over 70% reduction in the number of cases since the program's inception.¹⁰ Although lead exposure is still a serious environmental health concern, the US lead poisoning prevention program is considered to be a major public health success. The prevention program made much progress and the policy lessons and experience that were gained from this endeavor provided a framework and necessary infrastructure for other housing-related health

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hazards,¹¹ such as carbon monoxide poisoning, radon, safety hazards, and electrocution.

The success of the lead poisoning prevention program validated the need for other healthy homes activities that include primary prevention, exposure assessment, hazard control techniques, surveillance, targeted public investment, national action plan, cost-benefit analysis, enforcement, and policy-relevant scientific research in other areas of important housing hazards.¹⁰ In 1999, the HUD recognized that targeting building deficiencies that contribute to many health and safety hazards was a cost-effective intervention and proposed the Healthy Homes Initiative. The aim of this program, led by HUD and the Centers for Disease Control and Prevention (CDC), is to develop a holistic approach to healthy housing. It seeks to reduce disparities in the availability of healthy, safe, affordable, accessible, and environmentally friendly homes by building upon existing activities and establishing a comprehensive national healthy homes program that promotes efforts to decrease housing-related health hazards,³ and reduces long-standing environmental health disparities related to housing. HUD formulated a preliminary plan that established focus areas and objectives and assessed the scientific links between housing and health hazards.¹² Initially, the important focus areas included moisture reduction, dust control, improving indoor quality, and targeting education and outreach. In 2002 rodent and cockroach exposures, injuries, chemicals, and others became critical points of interest. The objectives of the Healthy Homes Initiative were the identification of homes where interventions were appropriate, development of efficient intervention strategies, and the evaluation of such intervention strategies. The Healthy Homes Demonstration grants and the Healthy Homes Technical Studies grants enabled the implementation of local healthy homes programs; training of public health officials, housing professionals, the private sector; development of effective practices and programs related to healthy housing; and support for research in improving health in homes. In 2003, the CDC joined HUD in the effort to improve housing conditions in the United States by developing a holistic approach to healthy housing through its own Healthy Homes Program. The CDC developed programs to train environmental health practitioners, public health practitioners and others who were interested in creating healthy homes, and also put forth guidelines on diminishing hazard exposures in the home.³ There is an ongoing commitment of the HUD, the CDC, and other government agencies to work

together, fund important healthy homes activities, and provide local authorities with the tools to address housing-related health hazards.¹⁰

The release of *The Surgeon General's Call to Action to Promote Healthy Homes* in 2009 was in reaction to the mounting interest within the public health community to bring attention to unhealthy home hazards and to promote a coordinated, comprehensive, and holistic approach to eliminating substandard housing conditions. The *Call to Action* says, "A healthy home is sited, designed, built, renovated, and maintained in ways that support the health of residents." This was a significant departure from existing practices, which responded only after housing conditions caused illness or injury. In order to support and maintain this goal, research needs to be conducted to identify hazards and mechanisms within the home environment that positively and negatively affect the residents' health and interventions need to be developed to reduce the harmful effects.³ Effective housing-related interventions were identified and a review of the literature was published.¹³⁻¹⁷ The nation's interest in the Healthy Homes Initiative is echoed in the *Healthy People 2020* Environmental Health Agenda. *Healthy People 2020* is a 10-year national plan to improve the health of all Americans by achieving health equity and eliminating health disparities. The Environmental Health goals seek to eliminate the hazards that affect health and safety, such as indoor air pollution, inadequate heating and sanitation, structural problems, electrical and fire hazards and lead-based paint hazards, and also seeks to maintain healthy housing. The objectives of *Healthy People 2020* target reductions in problems, such as blood lead levels in children and indoor allergen levels. Various Healthy Homes programs in different government agencies address the objectives of this national agenda. Recognition of the critical role that housing-based hazards play in affecting health is recognized both in the US and more generally. The World Health Organization (WHO) recently published a book quantifying the environmental burden of disease associated with inadequate housing.¹⁸

Connection Between Child Health and the Home

Lead Exposure

Please note that lead is also discussed under [Importance of Homes in Children's Lives](#), [History of Healthy Home](#), and [Indoor Air Quality](#).

The near elimination of acute childhood lead encephalopathy represents one of the truly great pediatric public health success stories in the US. Almost no children in the US die from this disease any longer, and most child health clinicians practicing today have never treated or seen a child who has overt symptoms from acute lead encephalopathy. Despite this success, large numbers of US children continue to have levels of lead exposure that adversely affect their health and function, and severe toxicity and even deaths still occur. More commonly, however, children often are exposed to so-called “low” levels previously thought to be harmless but that are now recognized to impair cognition and behavior. Thus, continued efforts in the areas of primary prevention, public education, removal of sources of and exposure to lead, and screening of children for lead exposure are needed.

Recent research clearly indicates that there is *no safe level* of lead exposure in children, which was first recognized by the CDC in 1991.^{19–22} A summary of the remarkable array of US policies and subsequent reductions in children's blood lead levels are shown in Figure. Despite these efforts, the CDC estimates that approximately 530,000 children between the ages of 1 and 6 years have blood lead levels $>5 \mu\text{g/dL}$,^{9,23,24}

and HUD estimates that 24 million housing units contain significant lead hazards in the form of deteriorated paint and contaminated dust and soil as of 2000.²⁵

Sources of Lead Exposure

While lead is ubiquitous in the environment and potential sources of exposures are numerous, including air, bare soil, drinking water, toy jewelry, and home remedies, far and away the major source of exposure in children is through ingesting lead-contaminated dust and lead-based paint that has chipped, peeled, or flaked in homes where children live or in other indoor spaces that they frequent.^{26–28}

Older homes typically contain higher levels of lead, correlating with the percentage of lead used in paints at the time that the house was built.²⁹ Exposure to lead-based paint and dust increases when the surface encounters friction or impact, commonly exacerbated by housing renovations.³⁰ Rental units are more likely to have lead-based paint hazards than owner-occupied housing.²⁵ Many studies have shown that African-American children are at higher risk for lead-related morbidities than non-Hispanic white children, and this is corroborated by studies showing that the concentration of lead-contaminated dust is significantly higher

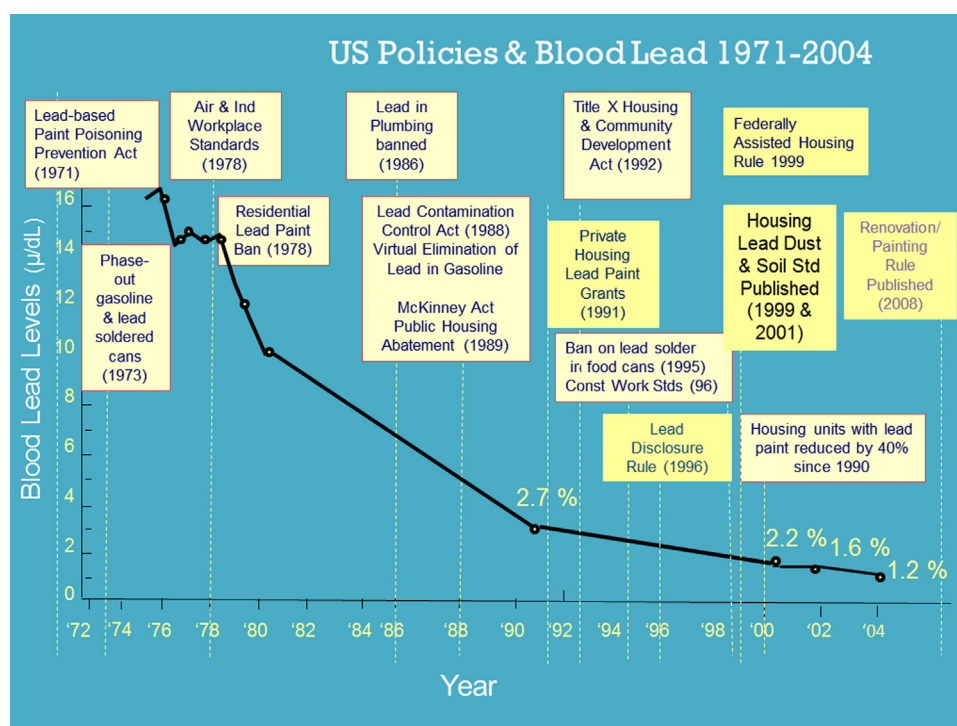


FIG. US policies and blood lead (1971–2004).

in homes occupied by non-Hispanic blacks.²³ Although the differences in rates of elevated blood lead levels and in children's mean blood lead levels have declined in recent years, minority children who live in poverty still have higher rates and higher mean blood lead levels than non-poor children and white children.^{9,23} Exposure of children to SHS and THS is discussed at length later in this review, and it is not surprising that blood lead levels increase in children living in homes with smokers. SHS and THS contain lead, which become deposited in dust thereby establishing a significant route of exposure for children.^{31,32}

In addition, soil continues to be a source of lead exposure for some children, largely due to settling of lead from prior use of leaded gasoline, which peaked in the early 1970s but has since been banned, and because of the decay of lead-contaminated paint on the exteriors of homes.³³

Blood Concentrations of Lead in Children

The mean blood lead concentration of children has fallen dramatically since the 1970s. The National Health and Nutrition Examination Surveys (NHANES) have estimated that the mean blood lead levels in children aged 1–5 years has dropped from 15 µg/dL in 1976–1980 to 1.3 µg/dL in 2007–2010.⁹ Similarly, 77.8% of children had blood lead levels greater than 10 µg/dL in 1976–1980 compared to 0.8% in 2007–2010.^{9,34} At the same time as these declines have occurred, a large, consistent and widely accepted research literature has emerged demonstrating adverse neurodevelopmental and behavioral consequences of lead exposure in children at levels previously believed to be safe, and the new reference level for elevated blood lead levels of children is 5 µg/dL or higher, although *the CDC has recently stated that there is no known threshold below which adverse effects of lead are absent*. It is thus important to consider both the percentage and absolute number of children in the US with blood lead levels ≥ 5 µg/dL, and how this has changed over time. Currently, 2.6% of all US children have blood lead levels ≥ 5 µg/dL as compared to 8.6% in 1999–2002 and 4.1% in 2003–2006, and it is estimated that approximately 535,000 children aged 1–5 years have levels of lead of this magnitude (see Fig.).

Cognitive and Behavioral Outcomes

Lead is the most widely studied of all known potential neurotoxins and its toxicity has been reviewed elsewhere.³⁵ Even at very low levels of

exposure, lead has adverse effects on intelligence, attention, vigilance, language development, transfer of information from short-term to long-term memory, aggression, and antisocial behavior.^{36–40}

Poor cognitive outcomes have been recognized with lead exposure in children for some time. Less than 50% of IQ can be attributed to heritable causes⁴¹; the remaining influences on IQ are largely environmental and social in etiology. Elevated blood lead levels in children have been recognized as a significant cause of decreased IQ for decades.⁴² However, more recent research has shown that blood concentrations of lead below the previously recognized threshold of 10 µg/dL are also associated with cognitive deficits in children.^{21,43,44} As blood lead levels increase from 2.4 to 10 µg/dL, there appears to be an approximate 3.9 IQ-point decrease; between 10 and 20 µg/dL, there is an additional approximate 1.9 IQ-point decrease; and between 20 and 30 µg/dL, there is still another additional 1.1 IQ-point decrease.⁴³ Other studies have shown even more drastic reductions in IQ by over 7 points when blood lead levels increase from 1 to 10 µg/dL.⁴⁵

In addition to decrements in intelligence, there is a dose-dependent relationship between lead exposure and other neurocognitive functions and behaviors, including hyperactivity, distractibility, impulsivity, disorganization, non-persistence, inability to follow simple instructions, and overall poor functioning. Examined later in childhood, these same children are at increased risk of exhibiting reading difficulties, not graduating high school, having a low class standing in high school, increased absenteeism, lower vocabulary and grammatical reasoning scores, and slower reaction times.^{46–48} Some investigations suggest that childhood lead exposure explains almost 90% of the variation in the violent crime rates from 1960 to 1998.^{49,50} The trend in crime and arrest rates suggests that blood lead levels not only affect violent crime, but also may affect repeat offending. Even murder rates over previous decades have been found to be correlated with levels of lead exposure beginning in preschool.⁵¹ Neurohormonal alterations caused by lead exposure in children contribute to increased rates of attention-deficit/hyperactivity disorder (ADHD). Children with blood lead levels on the higher end of the 2–5-µg/dL spectrum show a 4-fold increased risk for having the diagnosis of ADHD. In addition, it has been estimated that approximately 20% of ADHD cases among children may be attributable to having a blood lead level > 2.0 µg/dL.^{52–54}

Motor Function

Elevated blood lead levels in children are associated with marked impairments in both fine motor and visual motor function,⁵⁵ with alterations in reaction time, sway oscillations, alternating arm movements, and action tremor, even among children with blood lead levels <10 µg/dL.⁵⁶ A study following children exposed to elevated lead at birth over the course of 6 years showed balance impairment that persisted throughout childhood among children exposed to low levels of lead.^{57,58} Children with elevated blood lead levels acquired later in childhood exhibit deficits in postural sway, body balance, and visuo-motor integration,^{59,60} as well as finger tapping speed and pattern recognition.⁶¹

Interestingly, males may be more susceptible to motor impairments due to lead exposure than are females in both human and animal models.^{61–63} The mechanism underlying this finding has not yet been elucidated, but it has been postulated that elevated blood lead levels exacerbate the same neurological pathways that impart an increased risk for males to develop behavioral problems, such as ADHD.⁶³

Screening for Elevated Blood Levels

Primary prevention has proved to be the most effective means of lowering children's lead exposure in the US, and even more intensive large-scale primary preventive measures, such as more housing lead hazard control, have been advocated.⁶⁴ To identify children who need individual interventions to reduce such exposure, however, blood lead screening remains an essential tool. Guidance from the CDC has been pivotal in defining national standards for screening programs. CDC guidelines advise state health officials to develop universal or targeted screening programs (or both) based on the risk characteristics of their local communities. State- and locale-specific screening strategies are available on the CDC Web site at: www.cdc.gov/nceh/lead/grants/contacts/clppp%20map.htm.

To be optimally effective, screening policies are not enough. Healthcare providers must comply with recommendations. Also, effective treatment of children with elevated blood lead levels requires that primary care clinicians work closely with local health officials, licensed exposure risk assessors, public and private housing providers, and social services to help identify sources of a child's exposure and ways to eliminate them or to provide the child with alternative housing when necessary.

It is essential that families receive education about potential sources of lead exposure, means to reduce exposure, and housing and public health regulations concerning lead. A detailed history to help identify potential sources of lead exposure is indicated whenever children have elevated blood lead levels. Families should be counseled to (a) have lead-based paint hazard control performed by a properly licensed contractor and, if possible, with supervision of the local health department; (b) relocate children and pregnant women to another site while work is being performed; and (c) have a thorough cleanup of dust and dust testing before allowing children to reinhabit the home. Detailed procedures for identification and control of lead-based paint hazards have been published⁶⁵ and found to be effective.¹⁷

Indoor Air Quality

Indoor air quality has a major impact on various aspects of children's health. Air quality is of particular importance in children because they spend an estimated 80–90% of their time indoors whether it is in their homes, child care settings, or at school. Sources of indoor air pollutants include tobacco smoke, gas and wood stove emissions, water-damaged building materials, furnishings, unvented portable fossil fuel heaters, radon, and construction materials. Furthermore, children are exposed to many different allergens and biological agents in the air in their homes.

Carbon Monoxide

Carbon monoxide (CO) is a colorless, odorless gas that can be found in homes, resulting from combustion appliances (gas stoves/heating), smoking, and living in high rise buildings (which is a reflection of higher local population and traffic density). CO exposure causes approximately 450 deaths and more than 15,000 emergency department visits annually; 64% of these occur in the home.^{66,67} These data likely reflect an under estimate of CO exposures, as lower level exposures do not result emergency department visits. Both the acute and chronic toxicities of CO result from its increased binding capacity, compared to that of oxygen, with blood hemoglobin (Hb).⁶⁸ Because children and infants have higher metabolic and respiratory rates than adults, they are more susceptible to CO toxicity.⁶⁹ These effects begin in utero as the fetal oxyhemoglobin dissociation curve is shifted to the left of the adult curve and shifted further to the left after

CO exposure. This leftward shift results in impaired release of oxygen from hemoglobin to tissues and ultimately to tissue hypoxia. After maternal exposure to CO, fetal carboxyhemoglobin (COHb) levels continue to rise for several hours, equilibrate at a COHb level 10% higher than maternal COHb, and have a half-life of 15 h.⁶⁹ Elevated CO levels have been associated with increased low birth weight and smaller mean head circumference; moreover, this is one of the mechanisms by which prenatal smoking exposure is believed to result in infants with smaller head circumference.⁶⁸

It is often difficult to evaluate for CO toxicity as there are no pathognomonic signs or symptoms associated with it. Fetal deaths, developmental disorders, and cerebral anoxic injuries may occur when pregnant women are exposed to CO, however, the severity of fetal intoxication cannot be assessed by the mother's clinical status.⁷⁰ More specifically, retrospective studies indicate fetal mortality of 35–67% following maternal CO exposure (average COHb level was 19%; for reference, heavy smokers have COHb levels of 5–10%). Autopsy evidence of basal ganglia and gray matter lesions, poor tone, and mental deterioration in children following in utero exposure also support significant fetal morbidity and mortality.⁷¹ Similarly, maternal smoking and thus increased levels of COHb that lead to fetal hypoxia with resultant poor intra-uterine growth have been shown to have a lasting effect on subsequent growth and development in children, including increased risk of emotional and behavioral problems, lowered cognitive abilities, and hyperactivity.^{72–75}

Among adults, CO exposure is associated with increased neuropsychologic deficits, such as cognitive and personality changes, amnesia, apathy, distractibility, and gait disturbance.⁶⁹ Unfortunately, there is a paucity of research literature related to comparable issues in children. One study found delayed neuropsychologic sequelae in children following CO exposure, including chronic headaches, memory difficulties, and decline in school performance.⁶⁹ Additionally, children are more likely than adults to experience syncope and lethargy when acutely exposed to CO.⁶⁹

As such, it is important to be aware of the dangers that CO toxicity poses to children and make efforts in primary and secondary prevention to decrease the household CO exposure.

Currently, more than half of the states in the US have statutes that require CO detectors in residential buildings. This includes family homes, child care centers, group child care homes, and schools.⁷⁶ CO detectors must be in the proper place (i.e., in the vicinity of bedrooms, on ceilings, or walls) and replaced every 5–6 years, as needed. They are often combined with or co-located with smoke alarms. Five studies show that working smoke alarms installed in the home reduce death and injuries from residential fires.^{77–81} Homes with working smoke alarms have a 40–50% lower fire death rate than homes without working smoke alarms.⁸¹ Furthermore, 70% of all home fire deaths occur in homes without working smoke alarms.⁸¹ Parents should be informed of this and of their rights to have functional CO detectors in rental units, as well as their responsibility to have them in their own homes.

Tobacco

As of 2000, approximately 1.22 billion people actively smoke tobacco products worldwide, and it is predicted that the number of smokers will reach 1.9 billion by 2025.⁸² The WHO recently reported that the yearly mortality rate from tobacco-related deaths is nearly 6 million, costing hundreds of billions of dollars annually.⁸³ Exposure to tobacco smoke exposure can occur: prenatally (due to maternal smoking or secondhand exposure); as secondhand smoke; as thirdhand smoke; and during adolescence as firsthand smoking.

Secondhand Smoke. Please note that secondhand smoke is also discussed under [Childhood Asthma](#).

Despite increasing awareness about the dangers of tobacco exposure not only to the smoker also to others exposed to SHS, tobacco use remains the leading cause of preventable death in the United States.⁸⁴ Exposing children to the chemicals in tobacco smoke has been shown to have deleterious effects as early as the in utero period and extending throughout their lives. The

major mechanism by which children are exposed to SHS is in homes with users of tobacco products.

SHS, also known as “environmental tobacco smoke (ETS)” or “passive cigarette smoke,” refers to the smoke discharged from the lit end of a cigarette in addition to the

smoke exhaled by an active smoker.⁸⁵ Over 4000 chemicals are present in SHS, greater than 250 of

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which have been shown to be toxic or carcinogenic.⁸⁶ A small fraction of the chemicals present in SHS include hydrogen cyanide (used in chemical weapons), carbon monoxide (found in car exhaust), butane (used in lighter fluid), ammonia (used in household cleaners), toluene (found in paint thinner), arsenic (used in pesticides), lead (formerly found in paint), chromium (used to make steel), and cadmium (used to make batteries).⁸⁶ Other known carcinogens include polycyclic aromatic hydrocarbons (PAHs), tobacco-specific *N*-nitrosamines (TSNA), as well as numerous other hydrocarbons, aldehydes, metals, and organic compounds.^{84,85}

Critical Periods of Exposure in the Prenatal and Postnatal Periods. There are specific periods during development, often referred to as critical windows of exposure, during which exposure to toxic chemicals, such as those present in tobacco smoke, are particularly deleterious. Prenatally, exposure is associated with deficits in almost every developing organ system, including the lungs, brain, heart, and ears.^{87,88}

Postnatally, the risk of respiratory, neurological, and immunological morbidity appears to be highest during infancy because these systems are not fully developed at birth.^{75,88,89} The risk of bronchitis and pneumonia from SHS exposure peaks during the first year of life,⁷⁵ and early postnatal exposure to SHS is associated with bronchial hyperresponsiveness and hospitalization for respiratory illness within the first 6 months of life.⁹⁰ The rates of these complications decline as children grow older, possibly because they spend less time in the home as they age, thereby decreasing SHS exposure.⁹¹

Biochemical Effects of Prenatal Tobacco and SHS Exposure. Exposure to tobacco smoke causes physical alterations in fetal blood flow, alterations of protein metabolism, and certain chemical concentrations in both the mother and the fetus that are independently associated with many adverse consequences in children. Prenatal maternal smoking or SHS exposure increase levels of COHb in both maternal and fetal blood, which leads to fetal hypoxemia, and subsequent chronic hypoxic stress in the fetus.⁹² Chemicals in cigarette smoke transiently cause vasospasm of the vessels supplying the placenta, increasing placental vascular resistance, and further reducing blood flow to the fetus.⁹³⁻⁹⁷

Nicotine has been shown to have teratogenic effects on neurodevelopment in animal models,^{98,99} resulting in profound alterations in neurotransmitter disposition

that alter neuronal pathways both before and after birth.⁷⁵ These effects are caused by alterations of the developmental trajectory of synaptic function rather than one neurotoxic injury to the brain.¹⁰⁰ This results in a phenomenon called synaptic dysregulation, in which presynaptic neurons are juxtaposed to incorrect target cells, impairing neuronal communication.¹⁰⁰⁻¹⁰⁵ These alterations leave the fetus susceptible to increased cholinergic effects, including tachycardia and fetal hypoxia, which has previously been implicated as increasing the risk of sudden infant death syndrome (SIDS) and other fetal morbidities.^{103,106} Prenatal nicotine exposure also impairs the development of noradrenergic presynaptic projections and the postsynaptic beta-receptor binding capabilities, causing a compensatory increase of noradrenergic receptor sites in the cerebral cortex.¹⁰⁷⁻¹⁰⁹

The deleterious effects of only a fraction of the chemicals found in tobacco smoke have been studied, and the spectrum of potential adverse health consequences of the thousands of harmful substances in SHS will likely never be fully appreciated.

Sudden Infant Death Syndrome. The link between prenatal tobacco and childhood SHS exposure and SIDS has been thoroughly investigated. Parental tobacco use is the *most common* preventable cause of SIDS, with the majority of exposure occurring within the home.¹¹⁰ Epidemiologic evidence supports a causal relationship between SIDS and both prenatal and postnatal tobacco exposure, and the risk of SIDS has been reported to be 6-fold higher when mothers smoke.⁷⁵ Smoking cessation during pregnancy decreases the incidence of SIDS.¹¹¹

The leading hypothesis explaining the mechanism linking tobacco exposure and SIDS is called the "brainstem hypothesis."¹¹² The brainstem is a region responsible for controlling breathing, temperature control, blood pressure, chemosensitivity, and upper airway reflexes during sleep. The brainstem hypothesis postulates that SIDS is due, at least in part, to impairment of these basal functions, which "impairs the infant's response to life-threatening, but often occurring, stressors during sleep (e.g., hypoxia, hypercarbia, asphyxia, and hyperthermia) and leads to sudden death in a vulnerable developmental period."¹¹³

One hallmark of SIDS is upregulation of serotonin receptors in the brain, and it has been shown that prenatal SHS exposure elicits hyperactivity of the serotonin, dopamine, and norepinephrine pathways,

resulting in deficits of these neurotransmitters.¹¹⁴ Consequently, cardiac sympathetic innervation is decreased, increasing the vulnerability of the fetus and infant to hypoxia during times of stress. Interestingly, these neurological changes have been shown in one study to be offset by prenatal administration of vitamin C.¹¹⁴

Preterm Labor and Low Birth Weight. Tobacco smoke exposure is the most important determinant causing low birth weight after adjusting for gestational age (small for gestational age babies).^{115,116} Nearly twice as many mothers who smoke or are exposed to SHS experience term low-birth-weight deliveries compared to mothers who are not exposed.⁶⁸ Pregnant nonsmokers who are exposed to SHS have an increased risk of giving birth to a child with low birth weight, albeit with less severity than prenatal maternal smokers.^{117–120} Studies suggest that birth weight can be improved by reducing or eliminating smoking during pregnancy.^{121,122} Complications involved with these low-birth-weight children cost almost \$6 billion in 2001.¹²³ Reduced birth weight has been associated with an increased risk for a number of behavioral problems, including hyperactivity, learning disabilities, anxiety, and decreased IQ.^{73,124,125}

Asthma, Otitis Media, and Upper Respiratory Infections. Exposure of children to SHS is associated with an increased incidence of middle ear disease, asthma, wheezing, bronchitis, bronchiolitis, pneumonia, impaired pulmonary function, snoring, adenoid hypertrophy, tonsillitis, pharyngitis, and increased severity and risk of respiratory syncytial virus in infants.^{75,126} This in turn results in increased use of and exposure to antibiotics, increased incidence of tonsillectomies, and a greater incidence of hospitalization for respiratory illness.⁷⁵

The association between SHS exposure and respiratory tract infections in children has been well established.¹²⁷ However, smoking during pregnancy imparts an additional risk compared to postnatal exposure, and maternal smoking during pregnancy is independently associated with an almost 4-fold increase in infant respiratory disease.⁷⁵ SHS exposure impairs immunological function in children predisposing them not only to respiratory infection also to allergy and bronchial hyperresponsiveness.¹²⁸

Children exposed both prenatally and postnatally to SHS have decreased pulmonary function.^{129,130} The adverse effects on the lungs of children begin as early as 33 weeks of gestation, and persist after birth.¹²⁸

Children exposed to SHS experience an average of a 1.4% reduction in forced expiratory volume in 1 s, a 5% decrease in mid-expiratory flow rate, and a 4.3% decrease in end-expiratory flow rate.¹³¹ Despite these deficits, the mechanism of damage has not fully been elucidated.¹²⁹

Asthma prevalence and severity are also increased in children exposed to SHS,¹³² and these children have a greater number of visits to the emergency department¹³³ and a greater risk of intubation.¹³⁴ Although the direct mechanism has not fully been elucidated, studies have shown that higher blood cotinine levels in children are associated with increased bronchial hyperresponsiveness.¹²⁸ It is believed that the relationship between SHS exposure and asthma is causal.^{88,135,136} If either parent is a smoker, the risk of developing asthma is increased by 37%.^{126,131,136,137} In addition, when exposure to SHS is reduced, the severity of asthma is also decreased.¹³⁸

The association between SHS exposure and otitis media is extensive and conclusive.^{86,139,140} In fact, SHS exposure is the leading preventable cause of children's middle ear infections.⁸⁶ The morbidity associated with the ear is not limited to otitis media, but also includes tympanic membrane perforation, cholesteatoma, and sensorineural hearing loss (SNHL).^{141,142} One study showed that the risk of otitis media with effusion was increased 4-fold after the insertion of a tympanostomy tube in children exposed to SHS.¹⁴³ A large meta-analysis suggests a causal relationship between SHS exposure and otitis media, middle ear effusion, and surgery for these conditions.¹³¹ Repeated episodes of otitis media increase the risk for SNHL, and a dose-dependent relationship has been demonstrated between SHS exposure and SNHL.¹⁴²

Behavioral Problems. It has been well documented that children exposed prenatally to tobacco smoke are more likely to have behavioral problems. Recent studies have shown that these children exhibit overall worse behavior, including specific problems like hyperactivity, oppositional defiant disorder, delinquency, and internalizing and externalizing behaviors.¹⁴⁴ In fact, children exposed to SHS have a 50% increased risk of having at least 2 of these neurobehavioral disorders,¹⁴⁵ an association that has been shown to be dependent on the dose of SHS exposure per child.¹⁴⁶

In children exposed either prenatally or postnatally to tobacco smoke, behavioral problems can be seen very early in life. Newborns exposed in utero have

been shown to exhibit heightened startle responses, tremors, and hypertonicity,¹⁴⁷ and have more severe reactions to bowel movements and diapering, and tend to cry more and be more fussy.¹⁴⁸ Children exposed to tobacco in utero show symptoms as early as 18 months, manifested by increased externalizing behaviors, including defiance, not responding to punishment, inability to pay attention, and hyperactivity.¹⁴⁹

During preschool years, children exposed to prenatal or postnatal tobacco smoke show more externalizing behavioral problems than unexposed children.^{150,151} Some of the more common problems include arguing, demanding attention, changes in mood, emotional instability, aggression, and destructive behavior.^{151,152}

The adverse effects seen in early childhood have been shown to persist into adolescence.^{153–158} Children exposed prenatally to SHS are more likely to break rules, exhibit aggression, and display other behavioral problems.¹⁵⁹

Studies have attempted to separate the effects of prenatal and postnatal maternal smoking and child behavior. The 2006 Surgeon General's Report points out that this is a formidable challenge, because many women who smoke during pregnancy continue to do so after the birth of the child.⁸⁶ Postnatal smoking alone, and prenatal and postnatal smoking together have been shown to be independently associated with behavioral problems in children in a dose-dependent fashion.¹⁴⁴ Although both prenatal and postnatal exposure increase the likelihood of being classified as having abnormal behavior, children only exposed prenatally were 90% more likely to be classified as abnormal, and children exposed only postnatally 30% more likely.¹⁶⁰ Children born to mothers who smoke more than a half pack of cigarettes per day during pregnancy are approximately 4 times more likely to have conduct disorder, and experience increased rates of oppositional defiant disorder and delinquency.^{161–163} However, this relationship between tobacco smoke exposure and conduct disorder could be affected by multiple confounders, including increased prevalence of smoking among young people, poorer education of mothers of lower socioeconomic status, higher prevalence of smoking among women with antisocial traits, depression, and/or anxiety disorders, and the possibility that prenatal smoking may be a marker of genetic risk for antisocial behavior.¹⁶⁴ Further research needs to be done on this topic to account for all of these potential confounders.

The association between SHS exposure and ADHD was reported as early as 1975 in a study that found that

mothers who smoked were 3 times more likely to have “hyperkinetic” children.¹⁶⁵ Recent reviews examining almost 40 years of research show that in utero exposure to tobacco smoke is a risk factor for ADHD and similar behavioral disorders,¹⁶⁶ and the risk of developing ADHD has been reported from 2 times to 3 times higher than among children not exposed.^{167,168} Of all of the factors implicated in causing ADHD, maternal smoking during pregnancy was found to be the most important risk factor.¹⁶⁸ New studies are examining the interaction between dopaminergic genes and SHS exposure in the etiology of ADHD in children. One study showed that children with 2 copies of a dopamine transporter gene polymorphism are more likely to develop ADHD in the presence of maternal smoking.^{169,170} Children with the DAT1 440 allele, or DRD4 7-repeat allele, plus a history of prenatal tobacco smoke exposure were 1.8 and 2.1 times more likely, respectively, to be diagnosed with DSM-IV combined subtype ADHD.¹⁷¹ Children with one allele plus prenatal smoke exposure were shown to be 3 times more likely to have ADHD, and children with both alleles plus prenatal smoke exposure were 9 times more likely to have “population-defined” ADHD diagnosis than children with neither risk factor.¹⁷¹ Contrary to these studies, a recent study suggested that there is no gene–environment interaction between children with the DRD4 7-repeat allele, prenatal SHS exposure, and the diagnosis of ADHD.¹⁷² A different study showed that only males containing the DAT1 genotype showed a gene–environment interaction with prenatal smoke exposure and ADHD; they found no such correlation in females.¹⁶⁹ Although further research is needed to clarify the aforementioned discrepancies, these studies represent a novel approach to discerning the relationship between behavioral problems like ADHD and prenatal tobacco smoke exposure. Importantly, rates of ADHD have been found to be even higher among children exposed to both SHS and lead than to either agent alone.¹⁷³

School Performance. Another consequence of SHS exposure appears to be impaired cognitive function, which is manifested as lower scores on intelligence tests and achievement tests, and in poor school performance. Children born to smoking mothers appear to have an approximate 6.2 point decrease in IQ at 18 years of age compared to children born to non-smoking mothers.¹⁷⁴ Academic achievement suffers in children exposed to SHS prenatally even after adjusting

for many potential confounders.^{175,176} Impaired academic performance has been demonstrated even among children with serum cotinine levels less than 0.5 ng/mL.¹⁷⁷ In fact, the association between SHS exposure and lower scores on intelligence tests is dose dependent; test scores decrease in children with increasingly elevated cotinine levels.¹⁷⁷ These findings are similar to those that have been well established with low levels of lead, with a dose-dependent decrease in test scores beginning with blood lead levels less than 5 µg/dL and worsening with increasing blood lead levels.^{20,21,23,24,49}

A hypothesis attempted to bridge the link between children's exposure to tobacco smoke and cognitive impairments, showing that sleep fragmentation is often seen in children exposed to SHS, which could explain or contribute to the decrease in IQ seen in these individuals.¹⁷⁸ An increase in arousal frequency of snoring infants, as well as an inverse relationship between respiratory arousal index (central apnea, desaturation, and snoring) and scores on the Mental Developmental Index of the Bayley Scales of Infant Development, has been observed in smoking households.¹⁷⁸ Other researchers have corroborated this finding, showing that after accounting for confounders such as socioeconomic status, marital status, physical abuse, prenatal medical care, and postnatal cigarette smoke exposure, there is a positive correlation between prenatal nicotine exposure and children's sleep problems persisting throughout the first 12 years of life,¹⁷⁹ including longer sleep-onset delay, sleep-disordered breathing, parasomnias, daytime sleepiness, and overall sleep disturbance.¹⁸⁰

There have been numerous studies conducted regarding the association between tobacco exposure in children and performance in school. Children exposed to SHS via their parents have been found to be 50% more likely to repeat kindergarten or first grade.¹⁷⁶ Maternal smoking is also correlated with lower scores on mathematics and spelling tests, but not reading tests.¹⁸¹ In addition, children prenatally exposed to tobacco smoke appear to be at higher risk for failing to learn to regulate physical aggression.¹⁸² It is clear that many questions remain regarding the validity of studies regarding the relationship between maternal prenatal smoking and cognitive impairments in children, but the preponderance of evidence to date clearly indicates a robust association.

Parental Mental Health Problems. Compounding the effects of SHS on child behavioral and emotional

outcomes, SHS exposure in children has been linked with mental health in general and increased rates of depressive symptoms in both parents. Mental health problems in parents are associated with poor behavioral or emotional outcomes in their children, although this association is most likely bidirectional.^{183–185}

Dental Caries and Food Insecurity. Children exposed to SHS, as well as impoverished children, have been shown to have increased rates of dental caries.¹⁸⁶ Numerous explanations have been proposed to explain this finding, including (a) nicotine has been found to promote the growth of *Streptococcus mutans*, which is known to increase the risk of developing dental caries; (b) SHS is a known risk factor for other craniofacial infections, such as otitis media. Hence, it would not be surprising that the risk of dental caries, which are also caused by an infectious etiology, would be increased; (c) SHS directly reduces the production of saliva and indirectly increases the risk of dry mouth by causing inflammation in the respiratory tract that increases mouth breathing¹⁸⁶; (d) households with smokers also have decreased discretionary income, leading to increased rates of food insecurity. This leads to a number of poor child health and functional outcomes, including increased amounts of high sugar foods consumed by children, thereby increasing the risk of dental caries.¹⁸⁷

Thirdhand Smoke. Please note that thirdhand smoke is also discussed under [Childhood Asthma](#).

Thirdhand smoke refers to residual particulate matter from tobacco smoke that remains on surfaces and in dust.¹⁸⁸ Many of the components of THS are the same as those in SHS. Still other bioactive chemicals are found in THS and are formed from the reaction between SHS particles with chemicals, including ozone and gaseous oxide.^{140,188}

In 2006, the same year that the term “thirdhand smoke” was coined,¹⁸⁹ the Surgeon General of the US Public Health Service noted that the most important environmental tobacco smoke exposure for children occurs in the home.⁸⁶ Exposure to THS can occur even in households without any active smokers. Homes of former smokers contain THS particles that can be measured in new occupant's urine and blood samples for up to 2 months after the homes were vacated, even after cleaning.¹⁹⁰

In addition to the known dangers of many of the chemicals present in SHS that are also present in THS,

there is emerging evidence that novel chemicals present in THS cause lung damage as early as the in utero period. Exposure to chemicals, such as 1-(*N*-methyl-*N*-nitrosamino)-1-(3-pyridinyl)-4-butanal (NNA) and 4-(methylnitrosamino)-1-(3-pyridyl)-1-butanone (NNK), induce pulmonary damage via a number of mechanisms, including disrupted homeostatic signaling, stimulation of surfactant production and protein synthesis, and breakdown of alveolar epithelial-mesenchymal cross talk.¹⁴⁰ Evidence of the increased toxicity of SHS and THS is supported by analyses of secret, unpublished research from Philip Morris that shows that SHS is approximately 4 times more toxic than direct smoke exposure, and that THS is 2–4 times more toxic than SHS.^{191,192} Children are at particularly high risk for accumulating the harmful chemicals present in THS. Environmental dust containing THS particles are present in higher concentrations and in larger particles lower to the ground and in areas, such as floors and carpets, where children play.¹⁹³

Asthma and Respiratory Complications. THS particles have a larger molecular weight than SHS particles, with greatly elevated asthma hazard index values.¹⁹⁴ Studies measuring markers of asthma severity, such as exhaled nitric oxide, indicate that exposure to even low levels of THS cause significant airway inflammation.^{194,195} One study examining the risk of carcinogenesis from exposure to THS found that preschool exposure to high concentrations of PAHs, one component of THS in house dust, results in an excess lifetime cancer risk greater than 1:1000.^{196,197}

Smoke-Free Policies. According to 4 studies of nonresidential smoke-free policies^{198–201} and reports from the Institute of Medicine (IOM)²⁰² and the International Agency for Research on Cancer,²⁰³ 100% smoke-free policies or rules are effective in reducing exposure to SHS. The IOM concluded that there was sufficient evidence for a causal relationship between smoke-free laws and decreases in acute coronary events.²⁰² The panel further determined that eliminating smoking in indoor spaces fully protects nonsmokers from SHS exposure. Separating smokers from nonsmokers, ventilating buildings, and cleaning the air, however, cannot eliminate exposures of nonsmokers to SHS. In addition, the available evidence on the effects of interventions to reduce SHS exposure in the home was reviewed by the

International Agency for Research on Cancer report, *Evaluating the Effectiveness of Smoke-free Policies*. This report concluded that smoke-free home policies reduce exposure of children to SHS and reduce adult smoking. There also is strong evidence that smoke-free home policies may reduce youth smoking.²⁰³

Radon

Radon gas exposure is the leading cause of lung cancer among nonsmokers and the second leading cause of lung cancer overall, causing 21,000 deaths annually in the US.²⁰⁴ Combined data from several previous residential studies show definitive evidence of an association between residential exposure to radon gas and lung cancer.^{205–207} Radon is one of the leading causes of ionizing radiation exposure in homes. It is released into the air from decaying radium or uranium but is quickly diluted in the atmosphere. However, it can enter homes through cracks in basement floors or walls, or from diffusing out of building materials. When inhaled, the decaying radionuclides irradiate the bronchial epithelium.²⁰⁸ The highest concentrations to which people are exposed occur underground workers in uranium mines. Studies of miners have consistently found associations between radon and lung cancer.²⁰⁵

A recent population-based case-control study found a positive dose-response trend for both large cell and small cell lung carcinomas.²⁰⁹ Additionally, an analysis of data from 13 European case-control studies demonstrated strong evidence of an association between residential radon and lung cancer.²⁰⁵ Interestingly, cohort studies suggest that lung cancer risk as an adult is not increased due to radon exposure during childhood, and there have not been any studies to date exploring childhood radon exposure and lung cancer specifically.²¹⁰

Radon in homes currently accounts for 9% of deaths from lung cancer (and hence 2% of all cancer deaths in Europe). Overall concentrations can be reduced in existing homes at a moderate cost and low concentrations can be achieved at a low cost in newly constructed homes, as will be discussed later in this section.

Acute Lymphocytic Leukemia, Lymphoma, and Gastric Cancer. Since the 1990s, several studies have suggested that radon inhalation may deliver a small amount of irradiation to the bone marrow, thus increasing the risk of leukemia and lymphoma.^{211,212}

There is also concern for cancer risk from radon in the drinking water. The stomach is the critical organ for ingested radon, with doses at least one order of magnitude higher than for other organs, and studies have correlated stomach cancer occurrence with water radon levels.²¹³ One study, however, found little indication of increased risk of stomach cancer associated with radon in drinking water in a population with extraordinarily high exposure levels.²⁰⁵

Radon Guidelines and Interventions. Currently there are different guidelines for radon levels in new and existing homes in most developed countries throughout the world. For example, many European countries have national guidelines in the range of 200–400 becquerel (Bq)/m³, Canada has a guideline of <800 Bq/m³, and the US Environmental Protection Agency (EPA) has established a national radon guideline of 4 pCi/L (~150 Bq/m³).²¹⁴ In 2009, the WHO estimated that as many as 14% of the lung cancer cases in many countries (including the United States) are caused by exposure to radon gas and in response, the WHO established a new standard for action of 2.7 pCi/L (100 Bq/m³) for indoor radon levels.²¹⁵ The EPA estimates that 100 million US homes need to be tested for radon and 6 million will likely exceed the EPA action guideline of 4 pCi/L. For families living in existing homes, a radon test can cost anywhere between \$10 and \$50 with a do-it-yourself kit to be mailed in or \$75–\$350 to have a professional home inspector perform the test.²¹⁴ In new homes, one of the best opportunities for testing radon is during real estate transactions, as many states require radon to be included in mandatory property condition disclosures.²¹⁴ The EPA panel concluded that according to evidence from 7 studies,^{216–222} active radon mitigation strategies are effective in reducing radon exposure in the air to less than 4 pCi/L. Each of these studies enrolled a large number of housing units, ranging from 73 to 238 units.

Volatile Organic Compounds

The health effects of volatile organic compounds (VOCs) are varied. The IOM report found insufficient evidence of an association between residential indoor VOC exposures and the development or exacerbation of asthma. At higher levels of exposure, however, the threat of sensitization, respiratory problems, cancer, and other conditions can be pronounced.¹⁶ Common household items that release VOCs include paint,

varnish, and wax, as well as cleaning, disinfecting, cosmetic, and degreasing products. Additionally, products containing particle board and plywood, so-called air fresheners, and hobby products also release VOCs. Formaldehyde is a VOC that is a component of particular building materials, such as particle board and plywood adhesives, and may be found at high levels in many new buildings.

Childhood Asthma

Please note that asthma is also discussed under [Secondhand smoke](#), [Thirdhand smoke](#), [Changes in Ambient Temperature](#), [Increased Humidity](#), and [Poor Ventilation](#).

Asthma prevalence and morbidity have increased dramatically in the past 2 decades.²²³ According to recent basic research, it has been suggested that asthma develops as a result of gene–environment interactions.²²⁴ The contribution of environmental factors to the observed increase in asthma incidence and prevalence has been the focus of many investigations.^{225–229} Biologic agents, including allergens from cockroaches, rodents, dust mites, and fungi are among the prominent environmental factors implicated in asthma morbidity, in addition to respiratory irritants, such as fungal cell wall components.²²⁶ Housing conditions are associated with exposure to these biologic agents that induce asthma.²³⁰ Excess moisture in a home supports mold growth and provides an environment favorable to dust mites, cockroaches, and rodents. Common sources of moisture and water in homes include condensation, structural membrane leaks, damp foundations and crawl spaces, leaking pipes, inadequate ventilation, and activities such as bathing and cooking. Asthma is an extremely common childhood illness that is affected by household exposures, including SHS and THS. Changes in temperature, humidity, and ventilation also play roles in the development or exacerbation of asthma. Studies as early as the 1980s indicated that residential exposure to dust, dust mites, and other allergens can increase the risk of asthma and cause asthma exacerbations in those who are already diagnosed with this condition.

Dust Mites. Dust mites are often found in house dust. Case–control studies have shown an increased relative risk and clear dose–response relationship between mites in house dust and newly diagnosed asthma.²³¹ Moreover, higher levels of exposure to dust mite allergen are associated with higher airway hyper-

sensitivity.²³² This suggests that reducing exposure to these allergens can reduce the severity of asthma and perhaps even result in a large public health benefit in terms of asthma prevention. A body of clinical and epidemiologic evidence suggests that exposure to Der-p or Der-f antigens at levels greater than 2 µg/g is associated with sensitization; levels above 10 µg/g are associated with exacerbation of established asthma in mite-sensitized persons.^{233–235} These set points are often used to assess exposure risk in field studies. One survey found that more than 80% of US homes had detectable levels of house dust mite allergen in the bedroom, 46% had levels above 2 µg/g, and 24% had levels above 10 µg/g.²³⁴

Other Allergens. Most children with asthma tend to be both exposed and sensitized to multiple different allergens. One study sought to describe allergen sensitivities and home characteristics of a national sample of inner-city children with asthma, to better explore comprehensive interventions to reduce home allergens. This study found that the highest allergen sensitivities were to cockroaches (69%), dust mites (62%), cats (44%), rodents (33%), and dogs (21%). The study then looked at the relationship between exposure to an allergen in the home and sensitization to that allergen group. They found that for cockroaches and rodents, children were significantly more likely to be sensitized if they were exposed, whereas this was not the case for exposure to cats or dogs.²³⁶

A cross-sectional study was conducted over 6 years to identify risk factors and estimate the population-attributable risk to residential exposures in children diagnosed with asthma.²³⁷ The study indicated that about 39% of the millions of cases of asthma among US children could be prevented by eliminating exposures to indoor pollutants and allergens in houses.²³⁷

Effects of HEPA Filters. One intervention that has been explored to decrease exposure to allergens in the home is the high-efficiency particulate air (HEPA) filter. These filters work to remove almost 99.96% of particles >0.3 µm in diameter. A double-blind study with use of air filters and placebo filters was performed to assess the use of room air filters and patients' symptoms. Patients who used the air filters were found to have a significant decrease in 24-h symptoms and specifically nighttime symptoms, such

as congestion; eye irritation; and ear, nose, and throat itching.²³⁸

Changes in Ambient Temperature

Due to the increased frequency of extreme weather patterns occurring globally, changes in ambient temperature are a growing concern for children, especially those under 1 year of age.²³⁹ A number of proposed etiologies for this increased vulnerability have been described, including (a) children have an increased surface area-to-mass ratio compared to adults, resulting in a greater rate of heat transfer between the body and the environment²³⁹; (b) the temperature regulation system is not fully developed in children²³⁹; (c) the increased metabolic rate in children may increase temperature sensitivity²⁴⁰; (d) children have a decreased cardiac output and increased heart rate compared to adults²⁴¹; (e) children spend more time engaged in outdoor physical activities, resulting in increased exposure to temperature extremes²⁴²; and (f) children are dependent on others to provide households that are protective from temperature extremes.

Numerous studies from many countries have reported an increased morbidity and mortality among children during periods of temperature extremes.²⁴³ Some studies have suggested a significant increase in hospital admissions caused by fever, electrolyte imbalances, gastroenteritis, renal disease, and infections.²⁴³

Temperature changes inside the home also have also been implicated in poor outcomes in children. Lack of air conditioners or heaters pose similar dangers for children as do outdoor temperature extremes. In addition, the use of gas burning ovens and burning wood for heat increase the risk of exposure to deleterious chemicals, including many of the same compounds present in SHS that are implicated in the numerous aforementioned poor outcomes in children.²⁴⁴

Multifaceted Tailored In-Home Asthma Interventions. Home-based interventions using a multifaceted approach to help residents decrease exposure to multiple asthma triggers are effective in reducing exposure to triggers,¹⁵ decreasing asthma symptoms and short-term healthcare use, and improving quality of life. These interventions tailor activities to triggers found in an individual's home and/or to which the individual is sensitized. Interventions include home environmental assessment, education, use of HEPA (or equivalent) vacuums and HEPA air filters, use of

mattress and pillow covers, cockroach and rodent management, minor repairs, smoking cessation and reduced SHS exposure, and intensified household cleaning. The strongest evidence comes from studies that examine the impact of interventions on control of existing asthma.^{227,245–249} The Inner City Asthma Study was a large, multisite randomized trial that targeted interventions to reduce exposure to asthma triggers to which a child was sensitized.^{245–247} The findings showed a large and clinically significant reduction in asthma symptoms and a modest and significant reduction in emergency department and urgent clinic use.²⁴⁵ Eggleston et al.²⁴⁶ showed that in-home interventions reduced concentrations of airborne particulate matter and dustborne cockroach allergen and decreased daytime asthma symptoms but not other measures of morbidity. Krieger et al.²²⁷ found that home visits by community health workers to support families in decreasing exposure to asthma triggers led to significantly reduced use of urgent health services and to improved quality of life for caretakers. Carter et al.²⁴⁵ found that home visits by community health workers also decreased short-term visits for asthma among children with dust mite allergy.

Fever, Electrolyte Imbalances, and Renal Failure. Increases in maximum daily temperature is a risk factor for fever,²⁵⁰ and numerous studies have shown an increase in emergency room visits and hospitalizations during heat waves.²⁵¹ One reason for this increase in healthcare visits appears to be due to increased rates of electrolyte imbalances, which have been shown to increase emergency room visits in children aged 0–4 years by approximately 20%.²⁵² Another extreme consequence of increased temperature is acute renal failure. The risk of hospitalization due to renal disease increases by more than 2.6 times during heat waves.²⁵³ This complication is most common and most severe in children under the age of 5 years.²⁵⁴

Energy Conservation and Weatherization of Homes. Current sources of energy are being depleted, with profound concern about climate change, both contributing to the development of the field of weatherization (making homes more energy efficient). Energy conservation and weatherization of homes are likely to have important health outcomes. While many earlier studies have documented how energy conservation practices in the 1970s and 1980s could contribute to

mold and moisture problems, only a few studies have demonstrated how modern energy conservation in the home (a key part of green rehabilitation) can improve health. One of these was a Canadian study that examined new homes built with green energy-efficient practices.²⁵⁵ It demonstrated that green energy-efficient homes were associated with significant improvements in throat irritation ($p < 0.004$), cough ($p < 0.002$), fatigue ($p < 0.009$), and irritability ($p < 0.002$). Another study in New Zealand²⁵⁶ determined that improved insulation was associated with a reduced odds ratio in the insulated homes of persons with fair or poor self-rated health, with an adjusted odds ratio of 0.50; self-reports of wheezing in the past 3 months, with an adjusted odds ratio of 0.57; self-reports of children taking a day off school, with an adjusted odds ratio of 0.49; and self-reports of adults taking a day off work, with an adjusted odds ratio of 0.62. This study also showed that visits to medical practitioners were reported less often by occupants of insulated homes, with an adjusted odds ratio of 0.73. In addition, hospital admissions for respiratory conditions were reduced, with an adjusted odds ratio of 0.53, but this finding was not statistically significant ($p = 0.16$). The study showed that insulating existing houses led to a significantly warmer, drier indoor environment and resulted in improved self-rated health, days off school and work, self-reported wheezing, and visits to general medical practitioners. The “Heat-or-Eat” study found that families with reduced costs for energy as a result of receiving fuel assistance were 20% less likely to be underweight for age or length, and 30% less likely to require admission on the day visiting an emergency room.²⁵⁷ In addition, a 10-year-old report on the US Weatherization Assistance Program briefly mentioned health improvements such as reduced incidence of flu, the common cold, and arthritis due to weatherization; however there is no description of methods, the number of participants, or the exact type of weatherization employed.²⁵⁸

Lastly, there are mental health benefits of improved energy efficiency. A New Zealand study reported that energy upgrades improved “happiness,” “vitality,” and “emotion” when compared to the control group (OR 0.56, 95% CI 0.41–0.77; OR 0.51, 95% CI 0.41–0.64; +10.9% improvement in “emotion,” $p < 0.001$).²⁵⁶ Other studies show that improved housing quality is associated with a 30–60% improvement in mental well-being.²⁵⁹

One important set of interventions to control heat and cold extremes is green building design and weatherization. The Moving into Green Healthy Housing (MIGHHTY) study showed that housing conditions and self-reported general health, headaches, sinusitis, asthma, respiratory allergy, hay fever, angina, child behavior, and mental health (sadness, nervousness, and restlessness) all were statistically significantly better in the green healthy housing group compared to both the control group and the public housing from which participants moved.²⁶⁰ Children with asthma required significantly lower use of urgent care and lower frequencies of asthma symptoms, difficulty staying asleep, and use of a prescription inhaler to stop an asthma attack compared to children with asthma in the control group ($p = 0.020$, $p = 0.043$, and $p = 0.014$, respectively). Air contaminant levels were lower than applicable guidelines among the green healthy housing group.

The Wheeler Terrace study also showed that excellent, very good, or good general health in adults significantly improved from 59% to 67% ($p = 0.026$) with moving to green healthy housing. These apartments had large statistically significant improvements in water/dampness problems (80% at baseline vs. 16% at 1-year post-intervention; $p < 0.001$) and mildew odor/musty smells were eliminated (61% vs. 0%; $p < 0.001$). Additionally, cockroach problems significantly improved (56% vs. 8%; $p = 0.003$) as well as rodent problems (64% vs. 12%; $p = 0.002$), with resulting reductions in pesticide use. Geometric mean cockroach (Bla g1) and mouse (Mus m1) allergen dust loadings were significantly reduced from baseline to 3-months post-intervention ($p = 0.002$ and $p < 0.001$, respectively), and the low levels were sustained through 1-year post-intervention (both $p < 0.001$). Finally, the Watts To Well-Being study showed that adult respondents reported a 0.29-point improvement in mean general health score (1 = excellent, 2 = very good, 3 = good, 4 = fair, and 5 = poor) (3.07–2.78, $p < 0.001$); hypertension, overweight, sinusitis, and reduced use of asthma medication during asthma attacks showed 14%, 11%, 5%, and 20% differentials between improvement and worsening ($p < 0.001$, $p < 0.001$, $p = 0.038$, and $p = 0.077$, respectively). Collectively, these results show that using modern green healthy housing principles during rehabilitation or construction of low-income housing produces substantial health benefits.^{261–263}

Gastrointestinal Issues. The incidence of both infectious and non-infectious diarrhea increases dramatically with both increases and decreases in ambient temperature.^{250,264,265} Diarrheal illness in children increases by about 5.7–8% per Celsius degree increase in temperature above normal temperature.^{266,267} A study in Taiwan found that approximately 50% of diarrheal illness in children occurs during times of increased temperature.²⁶⁸

Eczema and Asthma. Decreased ambient temperature is associated with both increased incidence and severity of eczema due to inflammatory and irritant dermatoses.²⁶⁹ In addition, children with winter-type eczema are more sensitive to changes in ambient temperature. Eczema symptoms improve with increases in ambient temperature, with a 22% decrease in itching and a 65% decrease in extent of eczema with an increase of outdoor temperature of 15 °C.²⁶⁹

Infections. Numerous infections are more common when ambient temperatures rise. For example, the incidence of hand, foot, and mouth disease, commonly caused by the Coxsackie A virus, increases by greater than 11% for each degree Celsius increase in temperature.²⁶⁴ Other enteric viruses, including the Coxsackie B virus and the Hepatitis A virus, survive longer as temperature decreases. The maturation and infectivity of certain water-borne bacteria, including the *Vibrio* species, and certain protozoa, increase with increases in ambient water temperatures.²⁷⁰

Respiratory Infections and Asthma. Respiratory diseases in children are more common with both increases and decreases in ambient temperature. Decreases in temperature result in an increase in the incidence and morbidity from viral respiratory infections, an effect most pronounced in children under the age of 5 years.^{265,271}

Studies investigating the effects of changes in ambient temperature on asthma have been somewhat inconsistent. Some studies indicate that asthma symptoms worsen with increases in temperature, reflected by increases in hospital admissions during heat waves.²⁷² Other studies have shown the opposite finding, with an inverse relationship between monthly temperature and hospital admissions for asthma.^{273,274}

However, other studies hypothesize that the rate of temperature change, not the absolute temperature, is more responsible for increases in asthma symptoms.

Asthma-related healthcare visits increase during periods of rapid temperature change over the course of 1–3 days.^{272,275}

Increased Humidity

Increased humidity is a well-recognized public health concern, and recent statements from the Institute of Medicine and the WHO highlight the association between indoor humidity and respiratory complications, including asthma exacerbations and respiratory infections.^{276,277}

Mold

Asthma exacerbations in children are commonly linked to increased humidity and exposure to mold in the home. Children in humid homes are at a 7.6-fold increased risk for developing asthma symptoms.²⁷⁸ Current data are highly suggestive of a causal relationship between mold exposure and asthma symptoms.²⁷⁸ In addition, when dampness and visible mold are removed from the home, children's acute care visits decrease by up to 90%.²⁷⁹

Visible mold in the home increases the risk of children developing upper respiratory infections and otitis media.²⁸⁰ The mechanism increasing the risk of these infections in children include repeated inflammatory insults and immunosuppressive responses to organisms, spores, and other chemicals found in mold that both directly injure the respiratory mucosa and result in a diminished barrier to future infections.²⁷⁷ Furthermore, a synergistic relationship has been described between different organisms typically found in humid buildings, including different species of fungi, amoebae, and actinomycetes.²⁸¹

Multiple meta-analyses have estimated the increased risk of children developing bronchitis in homes with visible mold to be approximately 1.4 compared to children in homes without visible mold.^{280,282} The population-attributable risk in this population of children has been reported between approximately 8% and 20%.²⁸⁰ In Europe, the WHO estimates that the population-attributable fraction of asthma related to housing with mold or damp conditions is between 6% and 26%.^{18,283}

In addition to the asthma-inducing consequences of mold exposure, significant amounts of certain mold species are considered mycotoxic. One such mold, *Stachybotrys chartarum*, which grows on indoor materials such as wood, paper, and ceiling tiles, has been strongly linked with pulmonary bleeding in

infants.^{284–288} This particular mold has also been associated with rash and upper respiratory tract irritation.²⁸⁹ Aflatoxin, another type of mycotoxin, has been speculated as a cause of kwashiorkor²⁹⁰ and even Reye's syndrome.²⁹¹

Poor Ventilation

Together with source control, adequate ventilation in homes is paramount in reducing exposure of all members of the household to particulate matter and other contaminants. The American Society of Heating Refrigeration and Air Conditioning Engineers has established standards for ventilation of both single and multifamily housing.²⁹² Exposure to many of the chemicals that have been previously discussed, including carbon monoxide, tobacco smoke particles, and radon each can reach elevated concentrations when ventilation is poor. Concentrations of particulate matter can reach as high as 20–80 mg/m³ in homes with inadequate ventilation using open fires for cooking, with particle sizes as small as 2.5 µm, which are able to penetrate deeply into the lung. A substantial proportion of the global burden of disease in the developing countries results from increased exposure to these chemicals in the home due to poor ventilation.²⁹³

Asthma. Poor ventilation in the home increases children's exposure to chemicals, particles, and organisms that have been shown to increase the risk of asthma exacerbations and respiratory infections.²⁹⁴ Decreased ventilation can potentiate the effects of many of the previously discussed chemicals due to the resultant increased concentrations and duration of exposure. Furthermore, improvement of ventilation in the home decreases humidity (discussed in section “Increased Humidity”) and reduces the concentration of mites, organisms, and other particles that exacerbate the inflammatory process preceding exacerbation of asthma symptoms.²⁹⁵

Bronchitis. Children living in conditions with poor ventilation and high levels of pollutants in the home are at high risk for developing respiratory infections, and are at an increased risk of developing long-term complications, including bronchiectasis and bronchiolitis obliterans.²⁹⁶ Children living in homes with adequate ventilation are at a decreased risk for a number of respiratory complications, including a 15% reduction in the risk of developing bronchitis.²⁹⁷

Water Quality

Among the possibly greatest human achievements is the widespread implementation, availability, and regulation of clean water (free of bacteria, viruses, and parasites), as well as monitoring and regulating chemicals and pollutants, such as lead, throughout the developed world. Water quality is essential to normal child development. While there are many water purification systems in place to ensure better quality water in homes, there are still many adverse effects secondary to water contamination with chemicals such as pesticides, bacteria or viruses, and heavy metals.

Pesticides/Fertilizers/Rodenticides

Pesticides have long been known to pose dangers to humans yet have remained an important part of agriculture in America. Home environments in the US are commonly contaminated with pesticides, such as organophosphate (OP), carbamate, organochloride, pyrethroid, and herbicide compounds.²⁹⁸ Children often are more likely to be exposed to these pesticides because they tend to explore their environments orally and spend more time close to contaminated floors and other surfaces.

Rodenticides also pose an important threat to child health. A case-series study found that nearly a fifth of poisonings was due to rodenticides.²⁹⁹ About 90% of rodenticide cases involved dispersed granules or pellets and did not involve children accessing the rodenticide from the package itself.²⁹⁹ As such, a specific solution for decreasing child poisoning with rodenticides would be to create child-resistant bait stations and widely implement them.

Cognitive Development. Prenatal exposure to organophosphate pesticides negatively affects child neurobehavioral development. Prenatal pesticide exposure is associated with smaller head circumference and abnormal primitive reflexes.^{300,301} Additionally, children with mothers with higher urinary levels of the OP metabolite, dialkylphosphate (DAP), have decrements in mental development at 12 months and decreased perceptual reasoning later in childhood.³⁰² A birth-cohort study among farmworker families from an agricultural community that examined associations between prenatal and postnatal exposure to OP pesticides and cognitive abilities in school-age children found that children with mothers who were in the

highest quintile of DAP levels had an average deficit of 7.0 IQ points compared to the lowest quintile. Postnatal exposure to OP pesticides have not yet, however, been associated with cognitive scores.³⁰³

Reproductive Issues. Pesticides known as xenoestrogens (i.e., non-steroidal man-made chemicals that can enter the body by ingestion, absorption, or transplacental transfer) have also been explored recently with concern for disturbances in intrauterine reproductive development. The most common examples of these, which can be found in surface waters, include chlorinated hydrocarbons (e.g., DDT, the use of which was discontinued in 1972), polychlorinated biphenyls (PCBs), methoxychlor (MXC)—which has been shown in animal studies to decrease sexual arousal—and endosulfans. In particular, prenatal exposure of the male fetus to endocrine disruptors may lead to congenital abnormalities such as hypospadias and cryptorchidism, as well as reduced semen quality.³⁰⁴

One review of in utero exposure to estrogens and reproductive health assessed the biological plausibility and evidence connecting environmental chemicals with adverse reproductive outcomes. A systematic review of human studies was carried out concerning the direct effect of exogenous estrogens on reproductive disorders. The conclusion of the study was that the data lend strong support that estrogens contribute to reproductive disorders.³⁰⁴

Integrated Pest Management. Integrated pest management (IPM) is an effective intervention in reducing pests and pesticides.^{246,305} IPM methods include carefully assessing the presence and location of pests, such as rodents and roaches (both produce allergens that exacerbate asthma), removing food sources through proper food storage and cleaning, repairing structural defects that allow roaches to gain access to homes, applying low-toxicity pesticides as needed, monitoring and continuing intervention until pests are eliminated, and educating residents. Randomized controlled studies have demonstrated that IPM is effective in reducing exposure to cockroaches.^{306–309} Arbes et al.³⁰⁸ conducted a 6-month study and found that roach allergen levels were significantly reduced in beds and kitchens after IPM interventions; the levels in the beds dropped below the thresholds for both sensitization and exacerbation. In addition, Wang and Bennett³⁰⁶ showed a significantly greater decrease in cockroach counts with IPM than

with gel bait alone. Miller and Meek³⁰⁷ found that IPM was initially more costly but also significantly more effective in reducing roaches than with traditional pesticide treatment. Of note, these 3 studies did not report on health outcomes.

A study by Eggleston et al.²⁴⁶ showed a modest benefit on clinical outcomes but the study employed a multifaceted intervention that addressed other allergens besides cockroaches. Additional research, using less rigorous methods, has also found IPM to be effective. One study by Levy et al.²⁴⁸ showed reduced cockroach allergen and improved clinical outcomes in a single-group prepost study. McConnell et al.³⁰⁹ conducted a randomized trial of IPM methods that showed decreased dust allergen levels and cockroach counts in the IPM group relative to the control group. This study also showed that intensive cleaning can significantly reduce allergen levels in homes with initially high levels; however clinical outcomes were not reported. There are other studies^{310,311} that have also demonstrated improvements, but their conclusions were limited by small sample sizes, lack of control groups, inclusion of multiple interventions in addition to IPM, use of nonstandard and self-reported measures of cockroach exposure, or interventions that would be difficult to replicate. In contrast, evidence of the effectiveness of IPM for reducing exposure to rodent allergens is less well developed. A small study showed no significant improvement in forced expiratory volume or asthma symptoms but did show a significant decline in mouse allergen levels in the homes.³¹² The evidence that IPM is effective in reducing exposure to cockroach allergens is strong, but further evaluation of its role in reducing exposure to other pests is needed.

Infectious Diseases

Another common source of illness via water supply is bacterial and other infectious agent contamination. Drinking water, water used in food production or irrigation, water for fish farming, surface water, and recreational water are all recognized vectors for the transmission of pathogenic bacteria.

Escherichia coli O157:H7. Particularly in rural families using well-water, *E. coli* contamination is significantly associated with gastrointestinal illness in family members. This relationship was noted to also be related to the distance between the well and the household septic tank, with a distance between the 2 of less than 20 m being more strongly associated

with GI illness than if they were greater than 20 m apart.³¹³

Cryptosporidium. *Cryptosporidium* is a cause of diarrheal illness that can be particularly severe in immune-compromised individuals. Infection with *cryptosporidium* is more commonly reported in young children. It has been noted to be secondary to contaminated drinking water supplies with inadequate water treatment.³¹⁴ With stricter drinking water regulations and improved water treatment regimens there has been a decline in *cryptosporidium* cases.³¹⁴ Improvement in *cryptosporidium* surveillance, such as detection, recording, and reporting cases, will help to recognize outbreaks and intensify interventions.

Norovirus. *Norovirus*, which falls in the family of human caliciviruses, is a common bacterial cause of diarrheal illness, particularly in children. Infection with *Norovirus* can occur in all children worldwide, regardless of their level of hygiene, quality of water, food or sanitation, or type of behavior. While most enteric viral infections early in life provide immunity from severe disease upon re-infection, *Norovirus* represents an important cause of diarrhea in developed countries because it has large antigenic variation and only provides short-lived immunity thus permitting repeated episodes throughout life.³¹⁵

Housing Structure and Design

Structural Deficiencies

There are many environmental causes of childhood morbidity and mortality. It is important for both pediatricians and parents to understand the variety of risks children can be exposed to in their homes and how to prevent the potential harmful effects of these exposures. Residential injuries result in thousands of deaths and millions of emergency department visits each year; in 2009 more than half of all injury-related deaths resulted from injuries in the home.³¹⁶ The rates of death from unintentional home injury are highest in the youngest and oldest age groups.^{317,318} For infants, children, and young adults aged 0–19 years, at least 55% of unintentional deaths (excluding motor vehicle crashes) occur in the home.^{319–321} Overall, preventable and unintentional residential injuries among US children younger than 19 years result in more than 4 million visits to US emergency departments and 74,000 hospitalizations each year.^{320,321} Important

causes of fatal and nonfatal injuries involve structural and other deficiencies in housing. These involve factors related to design, construction, installation, and lack of monitoring or maintenance.

Falls/Window Guards. Trauma from falls can lead to serious injury in children of any age, but particularly during the first year of life. Pediatricians should counsel parents about falls from strollers, walkers, down the stairs, off the bed/crib, or falls into sharp-corners in furniture.³²² This can be particularly serious if the fall results in head injury. Falls are the fifth most common cause of accidental death in children aged 1–4 years.³²² This includes falls from second-story windows, stairs, trees, garage roofs, and ladders. This group is more prone to falls as they have a more risk-taking behavior.

As many as 90% of falls from windows can be prevented by use of window guards.³²³ Given the high mortality rate among children who fell from windows in New York City, in 1972 the Department of Public Health began an initiative known as Children Can't Fly.^{324,325} This involved reporting falls from windows, community education, and free installation of window guards. After only 2 years, a 50% decline in falls from windows was noted and since then there has been legislation passed which mandates window guards. In a 10-year follow-up study, falls from windows decreased by 96% since passage of the law, which has been widely adopted nationwide.³²⁵

Scald Burns. Scald burns are the most common type of thermal injury in children.³²⁶ They account for 7–17% of childhood burns that require hospitalization; toddlers and preschool children are most likely to be injured.³²⁶ In about 45% of instances, the child is unsupervised and turned on tap water and in almost 30% abuse is suspected. A chart review study was performed to analyze whether the characteristics of victims or circumstances of their injuries suggested ways to prevent such burns. This involved surveillance of home water temperatures; 80% of homes tested had unsafe bathtub water temperatures of 130 °F or higher that can result in full-thickness burns after only 30 s of exposure. These burns can be prevented passively by limiting household water temperatures to less than 125 °F.³²⁶

Additionally, new water heaters can be preset at this temperature and families can be educated on how to turn down the temperature on existing heating units.

The evidence that preset safe temperature hot water heaters to reduce scald burns came primarily from Feldman et al.³²⁶ and Erdmann et al.³²⁷ Feldman et al.³²⁶ determined that 80% of children hospitalized for scald burns lived in homes with unsafe bathtub water temperatures of 130 °F or higher. Erdmann et al.³²⁷ found that 5 years after a 1983 Washington State law required new water heaters to be preset at 120 °F at the factory, 77% of homes tested had safe tap-water temperatures and the frequency, morbidity, and mortality of tap-water burn injuries in children were significantly reduced. The effect of requesting manufacturers to voluntarily comply with the presetting of water-heater temperatures to a safe level, in the absence of legislation, has not yet been evaluated. Such voluntary compliance, with appropriate monitoring, is likely to be a promising approach that deserves field testing.³²⁸

Fires/Electronic Burns. Burns from heated items, hot water, fires, or electric burns are also very dangerous. The kitchen is an especially dangerous place in the home, as children can easily be burned by pulling things from the stove, microwave, toaster, or tables. Hot water from both the kitchen and bathroom can result in burns, as well.

Fires occur in houses secondary to adults smoking tobacco and dropping the cigarette, children playing with matches, poor household wiring, defective heating systems, and electric or kerosene room heaters.³²² As such, it is essential to have working smoke alarms and fire extinguishers in an easy to reach location in the home to reduce deaths and injuries from residential fires.^{77–81,329}

Electrocution and electric burns can be life threatening to children despite initial presentations that seem very benign. Parents should be advised to keep electric outlets blocked with plastic inserts, replace frayed or brittle electric cords to appliances, and warn children never to bite these cords.³²² As children grow older, it is important to warn them about the dangers of handling power tools or fuse boxes that can also cause electrocution.

Drowning. The incidence of drowning varies by region. Florida and California, which have the highest number of swimming pools, have higher rates of childhood drowning. Among young children, however, drowning also can occur in homes in bathtubs, hot tubs, or wading pools with only 6 in of

water. Floatation devices may promote drowning as children are more likely to be left unattended if they are wearing one. It is essential for guardians to be attentive when children are near water and to keep children away from large bodies of water until they know how to swim. Moreover, pools, hot tubs, and wading pools must be fenced or covered to prevent drowning incidents.³²²

Evidence from 3 studies and 1 systematic review demonstrate that fencing that completely encircles the pool and isolates it from the house (4-sided pool fencing) is effective in preventing drowning.^{330–334} Four-sided isolation pool fencing is much more effective than methods in which children can still gain access to the pool through the house (3-sided perimeter fencing). Fergusson and Horwood³³⁰ reported that the risk of drowning in a fenced pool was about 3 times lower than drowning in an unfenced pool. Another study showed that 4-sided isolation fencing is about 5 times more effective than 3-sided perimeter fencing.³³¹ The last study³³² reported findings similar to those reported by Thompson and Rivara³³³ in their systematic review. In conclusion, the evidence shows that a 4-sided isolation pool fencing considerably reduces childhood drowning and performs significantly better than a 3-sided perimeter fencing.

Suffocation and Strangulation. Hundreds of infants die each year from choking, strangulation, and suffocation. This can occur from becoming entangled in drapery, cradles, or in window blind cords. Additionally, children may be suffocated by bed clothes or linens, or become trapped between crib/playpen slats that are too wide. They may also choke on inappropriate food (e.g., raisins, raw carrots, peanuts, or popcorn), toys (e.g., toys with small parts), or balloons.³²²

Noise

Environmental pollutants, such as noise, may impair early childhood development and education and ultimately lead to effects on lifelong achievement.³³⁵ Children may be more susceptible to environmental stressors as they have yet to develop coping strategies and may not be able to anticipate stressors as well as adults can. One of the most well-studied sources of noise is that from aircraft. Over the past 2 decades, studies have been performed in children living near Los Angeles, Heathrow, and Munich Airports.³³⁵ The most consistent effects of aircraft noise exposure are cognitive impairments. Tasks that involve central

processing and language comprehension, including reading, attention, problem solving, and memory, seem to be most affected.

School Performance/Impaired Reading. Although the underlying causal mechanisms are not known, it is suggested that speech perception may play a role in the detrimental effects of noise on reading.³³⁶ The main theory guiding research into noise-related cognitive impairments has been that noise restricts attention to central cues during complex language-related tasks.³³⁷ Children may adapt to noise interference by filtering out sounds, including both relevant auditory stimuli and unwanted noise. This may in turn lead to noise-exposed children having poorer ability to sustain attention in classrooms. Additionally, noise exposure has been linked to annoyance and diminished quality of life in children. Annoyance could interfere with school performance and lead to poor cognitive performance.³³⁵

Impaired Memory. Strong evidence shows that noise affects long-term memory recognition.³³⁶ Specifically, children appear to have problems with long-term recognition but not recall. In contrast, short-term memory has not been found to differ between high and low noise exposure.³³⁵

Stress. The Munich Airport study also examined neuroendocrine indices in an attempt to assess chronic stress in people exposed to chronic noise.³³⁸ Overnight resting levels of catecholamines were significantly higher among children chronically exposed to aircraft noise than among those unexposed to noise.³³⁸ Interestingly, however, chronic noise exposure has not to date been associated with child mental health problems (e.g., anxiety, depression, hyperactivity, and conduct problems).³³⁵

Hearing Loss. Noise has also been implicated in progressive hearing loss. In particular, exposure to continuous noise of 85–90 decibels (e.g., sounds similar to a blow dryer, kitchen blender, or food processor) can lead to hearing loss and increased threshold of hearing sensitivity.³³⁹ These impairments are due to a direct consequence of the effects of sound energy on the inner ear.

Hypertension/Tachycardia. Noise exposure can also cause several short-term physiological changes via activation of the autonomic nervous system.³³⁹ These

include increases in heart rate and blood pressure, peripheral vasoconstriction and thus increased peripheral vascular resistance. In particular, studies have found a significant increase in systolic blood pressure after chronic noise exposure. Moreover, people have lower reactivity of systolic blood pressure after presented with a cognitive task under acute noise exposure.³³⁹ This finding has not been shown with diastolic blood pressure nor studied in children.

Access to Safe and Healthy Homes/ Homelessness

Most people in the US take for granted the importance of good housing on their well-being. The majority have stable safe housing that they can afford and tend to move only by choice. Though it may seem contrary to common belief, however, families make up over a third of the homeless population in the US. In many large cities, such as New York, Philadelphia and Portland, families may represent the majority of the homeless population.³⁴⁰ The growth of the homeless family population may be due to increased poverty among families, as well as rising costs of homes and family dysfunction.

Previous studies may have underestimated the proportion of 2-parent families that are homeless. Two-parent families often are less eligible for programs such as Medicaid, the Homeless Family Assistance Programs, and Aid to Families with Dependent Children.³⁴⁰ Prior to becoming homeless, families often spend an extremely high proportion of their income on housing, such that they struggle to meet other basic necessities such as food or clothing. Often these families report more family problems than families that do not experience homelessness. These problems include spousal abuse, drug abuse by spousal partners, and even child abuse.³⁴⁰ Homeless mothers additionally are more likely to have required hospitalization for mental illness.

Many families lack housing stability; this can lead to changing schools and can have significant implications for students' academic success.³⁴¹ Federal investment in low-income rental housing assistance and rental housing production could be an important resource to such families. This would be greatly enhanced by the development of a standardized housing security scale, which currently does not exist. Many studies show both racial and ethnic disparities in homelessness and disparate health outcomes.^{12,342,343} One study showed that homeless individuals with HIV/AIDS are at an

increased risk of negative physical and mental health outcomes, are more likely to be uninsured, use emergency rooms more often, and less likely to take prescribed medication.³⁴² Children who experience housing instability or homelessness have a 25% greater risk of poor health in adulthood and have higher mortality rates in adulthood than individuals who reside in stable housing as children.³⁴⁴

Other Harmful Household Exposures Not Related to Housing Structures

Residential Chemicals and Poisoning

In the vast majority of cases, accidental poisoning is attributed to easy access to drugs and chemicals by the child who can crawl, stand, or walk. Household items include medications, drain cleaners, solvents, herbicides, or poisonous plants. Rarely, poisoning with drugs or chemicals is committed by a caregiver or parents, which is a form of child abuse known as Munchausen Syndrome by Proxy.³²² As adolescents, there is concern for involvement with illegal drugs that could result in an overdose with resultant illness or death to the adolescent or younger sibling.

Fatal child poisonings involving drugs or other household substances have decreased within the past decade; however they still pose an important public health concern as they account for a large number of deaths in children younger than 5 years. Based on the number of phone calls received by US poison control centers, more than 1 million children <5 years of age experience toxic ingestions each year, the vast majority of which occur in their homes.³⁴⁵

Approximately 60% of the poisonings involve ingestion of prescription or nonprescription oral medications, such as acetaminophen, aspirin, or diphenhydramine. Other household products involved in poisoning include cleaning products (e.g., drain openers, oven cleaners, windshield washer fluid, and anti-freeze) which constitute approximately 13% of poisonings; personal care products such as perfumes, soaps, and hair and nail care products which make up 5%; and low-viscosity hydrocarbons such as lighter fluid, paint solvents, and furniture polishes, make up approximately 2%.³⁴⁵

Of note, more than half of these poisonings are from products that are packaged in child-resistant (CR) packaging.³⁴⁵ While this may seem surprising, explanations may involve greater risk exposure associated with these regulated products and greater toxicity of

regulated products. Moreover, CR packaging regulations may be less effective than hoped for since they do not require 100% childproofing (i.e., the testing protocol requires only that 80% of children <5 years of age be unable to open CR packages), CR packages are often left open at the time of ingestion, and CR packaging does not prevent dosing errors.^{346–348} Despite the limitations listed above, CR packaging regulations have been shown to reduce fatal and nonfatal poisoning rates by 40%; therefore it may be prudent to apply regulations to additional toxic household substances.^{346–348}

Guns

Effects on Child Mortality. Over 6500 children were victims of gun-related deaths in 2010 in the United States, translating to 7 child deaths per day.^{349,350} Estimates have shown that almost 85% of homicides among children are related to firearms.³⁵¹ In addition to the astounding and tragic number of deaths, including 114 unintentional deaths, over 15,000 children suffered nonfatal firearm-related injuries in a single year.³⁵¹

Effects on Violent Behavior in Children. A 2011 survey found that over 5% of children in grades 9–12 had carried a firearm within the past month.³⁵² Characteristics that increase the risk of a child or adolescent carrying a firearm include gang membership, use of illicit substances including drugs and alcohol, and exhibiting violent behavior.³⁵³ A majority of gun-related morbidity and mortality occurs during the adolescent years, a time during which children are in a developmentally vulnerable place and are at high risk for conflict and therefore gun violence, especially when access to guns is common.³⁵¹ In the US, 38% of all families own at least one gun, and over 40% of gun-owning families with an adolescent leave the gun unlocked in the home,³⁴⁹ greatly increasing the risk for firearm-related morbidities.

Electronic Media Use and Child Health

Discussion of the association between electronic media and child outcomes has become popular over the past decade, but the first paper describing the association between television and obesity was published in 1985.³⁵⁴ The US Department of Health and Human Services specified a national objective of reducing television viewing to combat obesity in its *Healthy People 2010* target goals.¹³ Since this time, analyses have been performed to examine the time

children spend using electronic media, as well as the content to which children are exposed.

Sedentary Behavior. It was once thought that the association between poor dietary outcomes and electronic media use was because heavy media users devote insufficient time to exercise. This theory has been replaced in part by the current view that the major cause of poor dietary outcomes in children is related to food marketing through various media sources, including television.

From 2005 to 2010, media use among children aged 8–18 years increased by more than an hour a day, from almost 6.5 to over 7.5 h/day, accounting for more time than any other waking activity. Among children of all ages, most screen time is devoted to television. Older children and teens are more likely to engage in multiple media venues simultaneously, as well as engaging in activities such as homework while also using mass media.^{355,356}

The directionality of the relationship between sedentary behavior and media usage is still under investigation. Although it seems plausible that overweight individuals may be more likely to stay home and use media more than physically active people, many studies have argued against this hypothesis.³⁵⁷ An experimental intervention that reduced screen time over a 6-month period found that body mass index (BMI) increased significantly less than a control group, suggesting that increased exposure to electronic media leads to weight gain and the risk of obesity.³⁵⁸

Dietary Outcomes. The first study to describe the association between television use and obesity found that the prevalence of obesity increased by 2% for each hour of television watched per day, even when controlling for prior obesity, region, season, population density, race, socioeconomic class, and a variety of other family variables.³⁵⁸

Given the extended amount of time that children spend watching television, they inevitably encounter large amounts of commercials for food products, which are dominated by high-density, low-nutrient products. In addition to television, the exposure to these products is also increasing by Internet advertisements.³⁵⁸ Before 7–8 years of age, children believe that advertisements are fun, entertaining, and unbiased; this period of vulnerability may lead to poor dietary outcomes, especially since almost 50% of television commercials are related to food products, many of

which are high in carbohydrates and low in vitamins.³⁵⁹

One study examined television viewing by children with and without commercials. The amount of time that children spent viewing commercials was significantly associated with increased BMI, whereas time watching noncommercial television was not.³⁶⁰ One study estimated that the impact of banning food advertisements on television would reduce the baseline rate of childhood obesity in the United States from 17% to somewhere in the range of 10.5–14.5%.³⁶¹

Exposure to these “junk foods” through various media outlets has an impact on the food preferences, requests, diet, and ultimately a child's health. Some scientists believe that advertising exposure is the primary mechanism explaining why screen time is significantly correlated with childhood obesity, rather than the widely accepted “couch-potato hypothesis.”³⁵⁸

Educational Outcomes and ADHD. Children regularly exposed to television at an early age are at an increased risk for impaired vocabulary,³⁶² a finding that is more pronounced if children have significant exposure before 30 months of age.³⁶³ Studies have shown that even watching informative programs designed to be educational such as *Sesame Street* do not increase child vocabulary significantly compared to children taught vocabulary through direct interaction with an adult speaker.³⁶⁴ Television exposure is also independently associated with both obesity and ADHD, which have both been shown to be associated with poor educational outcomes.^{365,366} The American Academy of Pediatrics, therefore, discourages television and other media use by children under the age of 2 years, and recommends less than 1–2 h of educational, nonviolent media use for older children.³⁶⁷

Family Structure and Design

Family Structure

Income and Access to Healthcare. Family income has a profound impact on the physical and mental health outcomes of all members of the family.^{368–371} Family socioeconomic status (SES) is only one of the many interacting environmental factors that contribute to the overall health of a family. In children, these effects begin as early as the in utero period and extend into adulthood. Children from low-SES families are at an increased risk for developing growth retardation,

premature birth, low birth weight, and impaired neurobehavioral development.^{372,373} Later in childhood, these children are at an increased risk for health-related issues including obesity, dental caries, elevated blood lead levels, nutritional deficiencies, growth stunting, sensory impairment, and poor academic achievement.³⁷⁴

Children are particularly vulnerable to the effects of family SES. Multiple hypotheses have been developed to explain this observation. The first hypothesis proposes that children in lower SES families may experience similar rates of illness/injury, but families with higher SES are more likely to be able to better ameliorate the consequences of these issues by utilizing health services, social supports, and making healthy life decisions.^{375–377} This hypothesis is supported by data showing children with chronic diseases, such as asthma, have improved outcomes throughout life if the child is raised in a higher SES family.^{369,378,379}

The second hypothesis proposes that socioeconomic disadvantaged children have higher rates of illness/injury related to their environment and housing situation. Due to this increased incidence of healthcare incidents, as opposed to the management of the conditions, children in low-SES households have worse outcomes.^{379,380}

Interestingly, the relationship between SES and child health differs among countries with alternative healthcare systems. Some studies show that the disparity between income and child health is decreased in England, where the healthcare system is largely based on equal access and free services, compared to countries such as United States and Canada. These studies suggest that the similar outcomes in American and Canadian children implies that the universal healthcare system in Canada would not improve SES-related health disparities among children.³⁷⁸

Attempts by the government to improve poverty and many of its associated morbidities have benefitted children's access to healthy food. Efforts such as the National School Lunch and School Breakfast Programs, The Supplemental Nutrition Assistance Program (SNAP), and the Special Supplemental Nutrition Assistance Program for Women, Infants, and Children (WIC) have aimed to provide low-SES households with extra money for groceries and supplies to improve the quality of life inside the home. In 2012, the maximum benefit for a 3-person household was \$526 per month. SNAP has been shown to reduce the depth,

severity, and prevalence of poverty, with a particularly strong effect on children.³⁸¹ While not extensively documented, these food supplement programs probably contribute to increased family discretionary income and thus increased housing stability.

Housing Stability and School Performance. The environment in which a child is raised has a major impact on mental and physical health outcomes. The United States Department of Health and Human Services defines housing insecurity as high housing costs in proportion to income, poor housing quality, unstable neighborhoods, overcrowding, or homelessness.³⁸² Crowding has been associated with numerous morbidities among all members of the family, including impaired mental health, stress coping, child and parent interaction, social relationships, sleep, and increased risk of medical conditions such as hypertension, respiratory conditions, and infections.³⁸²

Multiple moves from home to home also are associated with poor child outcomes. Families that move often are less likely to participate in preventative services for their children and are less likely to seek out a medical home.^{382,383} These children are at an increased risk for mental health and behavioral problems, substance abuse, teen pregnancy, lower global health ratings in adulthood, and poor school performance.³⁸² Children in low-SES families that receive public housing subsidies are less likely to show signs of malnutrition.³⁸⁴

There have been numerous studies that documented adverse health consequences associated with living in highly segregated neighborhoods. For example, analysis using NHANES data showed significant variation in body mass index by neighborhood and ethnicity.³⁸⁵ Inequalities in mortality between residents of poor and very poor (i.e., public housing) neighborhoods in New York City showed clear disparities in age-standardized all-cause mortality rates, with preventable diseases, such as diabetes, chronic lung disease, and malignancies, contributing to the disparity.³⁸⁶ Repeated hospitalizations for childhood asthma are associated with residence in census tracts with the highest proportion of crowded housing conditions, highest neighborhood-level poverty, and largest number of racial minorities.³⁸⁷ Reid et al.³⁸⁸ examined housing instability using 4 nationally representative surveys and found that worsening economic standing was associated with poorer healthcare access, being uninsured, postponing needed care, and higher hospitalization rates. In a large

cohort of more than 12,000 households in New York City, asthma was most prevalent in Puerto Rican households, followed by other Hispanic and African-American households. Exposure to deteriorated housing conditions and low social cohesion in the neighborhood significantly elevated the odds of asthma.³⁸⁹ Indicators of housing deterioration in the study included maintenance problems such as heating and toilet breakdowns; need for additional heat; the presence of rodents; broken plaster; and leaks, cracks, or holes in floors, walls, or ceilings. This study not only determined factors associated with increased odds of asthma but also demonstrated that multiple housing deficiencies are found together, thus further magnifying the asthma risk. Interestingly, the analysis found that these housing and neighborhood factors were independent of the influence of socioeconomic status (but not of race and ethnicity). These findings are consistent with those of another large study that found housing to be an important mediator of the pathway from social/physical conditions to pollutants to health outcomes.³⁹⁰

Mental and Physical Health. Research has repeatedly shown the connection between mental health, physical health, and the consequences of poor health on all members of the family. Of the numerous factors that contribute to poor mental health, housing problems such as inadequate housing, crowding, poor lighting,³ exposure to SHS, and living with smokers each significantly increase the risk of mental health problems and depressive symptoms.^{183–185} Recent studies have shown that unemployment, a major contributor to poverty and housing problems, is the biggest risk factor for fathers exhibiting depressive symptoms, and paternal depressive symptoms is the biggest risk factor for mothers exhibiting depressive symptoms.^{183,184} Fuel poverty (e.g., paying more than 10% or 15% of a family income for fuel) has also been linked to stress and declines in mental health. Studies in Ireland and elsewhere have documented that when many other contributory factors were controlled for statistically, fuel poverty had highly significant effects on adolescent risk taking (e.g., early alcohol and tobacco abuse) and truancy. Living in a home that was inadequately heated emerged as the only housing quality factor to be associated with 4 or more negative outcomes in an adolescent's mental health status. Among adolescents who had lived for long periods in poorly heated homes, 28% were at significant mental

health risk, compared with 4% of similar children who lived in homes that were adequately heated.^{391,392}

Domestic Violence

Domestic violence has a negative influence on children, both physically and mentally. An estimated 2.2 million children witness violence against their mothers in their homes.³⁹³ Several reviews of the effects of domestic violence on children have been performed over the past decade. These studies indicate that domestic violence has an adverse impact across a range of child functioning, produces different effects at different ages, increases the risk of child abuse, and is associated with other risk factors such as poverty and parental substance abuse.³⁹⁴ Notably, home visiting services have shown to be very effective in reducing domestic violence as well as in reducing rates of preterm labor and low birth weight.³⁹⁵

Preterm Labor/Low Birth Weight. Domestic violence has an impact on children even before they are born. Domestic violence during pregnancy is associated with several health problems for mothers and infants, including more health problems during pregnancy, higher likelihood of premature labor, later entrance into prenatal care, lower infant birth weight, and more prenatal substance abuse.³⁹³ This is particularly of concern because in the US and other developed countries, preterm birth and low birth weight contribute significantly to infant mortality and childhood morbidity.^{396,397}

Childhood Mental Health. As children grow up, studies show that those in homes with domestic violence are more likely to exhibit both internalizing and externalizing behaviors compared to those in nonviolent households. This includes more aggression and behavioral problems at school (ranging from temper tantrums to fights), depression, anxiety, phobias, insomnia, and low self-esteem.³⁹⁴ Additionally, children exposed to domestic violence demonstrate impaired ability to concentrate, difficulty in their schoolwork, and lower scores on measures of verbal, motor, and cognitive

skills.³⁹⁴ Similarly, there is emerging evidence that there is a link between exposure to domestic violence and post-traumatic stress disorder (PTSD). Analyses show that PTSD symptoms appear to occur more in younger children.³⁹⁸ On the other hand, a 1996 review study pointed out that there was no significant relationship between exposure to violence and lower levels of social competence.³⁹⁹

Interventions. The above findings suggest the need for domestic violence screening during pregnancy, as well as clinical intervention for battered, pregnant women in order to prevent serious physical and emotional problems for both mothers and their infants.³⁹³ Additionally, children who witness domestic violence may benefit from therapy such as age-determined group therapy that incorporated play and art therapy, cognitive behavioral therapy. This can help children identify and change destructive belief patterns, identify and express emotional residue from the violence, exercise personal control, and make plans for the future without feeling isolated.⁴⁰⁰ A recent randomized controlled trial found that women who were visited by paraprofessionals were less likely to report domestic violence. As such, home visits should be encouraged and discussed with mothers so they may experience significant benefits and decreases in domestic violence.^{395,401}

Conclusions

There are many aspects of homes and home life that have profound impacts on child well-being and development. There are multiple connections between child health and the homes in which they reside or visit, including lead-based paint, indoor air quality, water quality, products in homes, family composition, and various aspects of housing structure and quality.

The growth in recognition of home conditions on child health and the development and implementation of large numbers of regulations and programs to address home conditions so as to improve child health is one of the truly great advances in public health that has only been

There are multiple connections between child health and the homes in which they reside or visit, including lead-based paint, indoor air quality, water quality, products in homes, family composition, and various aspects of housing structure and quality.

possible because of voluminous research, advocacy, and governmental responsiveness driven by scientific advances and consumer activism.

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