The Effects of Housing
Interventions on Child Health

It may come as a surprise to many pediatricians that housing is one of the leading causes of morbidity and mortality among children in the United States. The problems historically associated with poor housing conditions, such as tuberculosis and typhus, are now uncommon. However, three leading contemporary pediatric public health concerns are intimately linked with housing. More than 4 million children in the United States have asthma, and it is estimated that more than 40% of doctor-diagnosed asthma cases among US children are due to residential exposures.1 More than 400,000 children have blood lead levels greater than 10 μg/dL; the vast majority of lead exposure is from the home environment.2 Each year, more than 4 million children have an emergency visit for injuries, and more than 2,800 die from unintentional injuries in their home.3

The cost of residentially induced disease and disability is substantial. Asthma is the most common chronic disease of childhood, occurring in more than 5% of US children, a rate that has more than doubled in the past 20 years.4 Given the lifelong effects of lead poisoning, estimates of the economic gain in lowering lead levels during the past 3 decades have exceeded $110 billion.5 Even so, it is estimated that the annual cost of childhood lead poisoning is more than $40 billion.6

This article provides a review of the literature focusing specifically on interventions for hazards found inside the home that have been linked to asthma, lead poisoning, and unintentional injury. Goals include enhancing pediatricians’ levels of understanding of common lessons learned from housing interventions concerning asthma, lead poisoning, and unintentional injury and informing pediatricians about future programs for intervention in housing hazards.

SEARCH METHODS

For this article, studies were identified using Medline. Keyword searches were done using unintentional injury, asthma, lead poisoning, housing, public housing, environmental intervention (with subheadings in asthma, allergens, and lead), environmental exposures (with subheadings in prevention and control), prospective studies, and child. Some studies not listed on Medline were identified through references of papers originally identified through Medline searches. Studies were reviewed if they were randomized controlled trials, had a majority of children as subjects, and had some health measurement associated with environmental intervention, home visitation, or anticipatory guidance regarding the home. Studies did not have to be blinded to be reviewed, and could take place outside the United States.
States. Meta-analyses and systematic reviews, if available, were also discussed.

ASTHMA

Epidemiology

Asthma is the most common chronic disease of childhood. A recent study by the Institute of Medicine found sufficient evidence to implicate indoor allergens as factors that exacerbate or cause asthma. This study showed sufficient evidence that dust mites cause asthma in children and that other indoor exposures, such as those of cats, dogs, molds, cockroaches, and environmental tobacco smoke, exacerbate asthma.

Environmental Interventions

The majority of interventions to improve or prevent asthma have attempted to reduce household dust mite exposure. This article focuses specifically on environmental intervention studies in asthma, because no studies in home visitation or anticipatory guidance regarding dust mites or cockroaches were found during searches. Most randomized, controlled trials of dust mite control involve adult patients, but some studies focused on children.

In a limited number of studies, similar interventions were conducted for both children and adult subjects. Most studies focused on secondary prevention of dust-mite allergy and asthma in sensitized patients. Only a few studies focused on primary prevention.

Most intervention studies introduced impermeable covers over mattresses and pillows, treatment of carpet and bedding with pesticides (ascaricides) to kill dust mites, or both; fewer studies used air filtration or cleaning. Only one intervention actually changed where participants were living and measured the effects on asthma. This study used census tracts to randomize families from high-poverty regions (more than 40% poverty) and public housing to receive vouchers to pay for rental housing from private landlords in areas with less than 10% poverty.

Researchers found families with asthmatic children who moved to apartments in better neighborhoods (ie, lower levels of economic deprivation) had almost a 50% decreased likelihood of asthma attack, independent of other risk factors.

Studies that focused on mattress covers or chemical applications alone to reduce allergen load were largely unsuccessful. Only studies that used more intense environmental or physical interventions, such as carpet removal and old bedding replacement, reduced dust-mite levels and improved subjective or objective outcomes.

Thus, it may be necessary to eliminate the source of exposure to reduce asthma exacerbations. Because carpets can act as a reservoir for allergens, carpet removal may be necessary to effectively reduce exposure to indoor allergens. Other intensive interventions, such as central ventilation and humidity control, showed moderate benefit in dust mite reduction, but these studies were limited by their extremely small sample size.

Table 1 shows investigators’ efforts to reduce other common allergens for asthma, such as cockroach allergen or molds. Three studies were unsuccessful at reducing cockroach allergens below proposed levels of 8 IU/g, despite intense cleaning and extermination efforts. One randomized trial involving 32 families led to a persistent reduction in allergen concentration in the bedroom, but it consisted of an intensive 6-month cleaning and extermination protocol.

Other studies have attempted to reduce mold and dampness in the home environment, but most studies to reduce humidity were aimed at other allergens that prosper in high humidity, namely dust mites.

These intervention studies suggest intense interventions to reduce the source of indoor allergens are necessary to control or eliminate allergen exposure. Clinical trials of physical and chemical interventions that employed only a single method, such as mattress covers, found little or no difference in mite levels or clinical improvement. Some successful primary and secondary trials in dust-mite allergen reduction required multiple interventions, including changing carpet to linoleum.

However, the intensity of home interventions necessary to improve asthma outcomes is unclear. In some cases, multiple intensive home visits with supplies such as vacuums and HEPA filters may be sufficient, whereas some children may require physical changes to their home to see clinical improvement in asthma. Studies in England and Malawi demonstrated amelioration of asthma and respiratory illnesses after such housing improvements, but considering the cost of these improvements, further study is required.

Limitations

Most of the randomized, rigorous trials to control asthma had fewer than 50 participants, and power calculations rarely were reported. Most studies to reduce dust mites failed to reduce major sources in the home, such as carpet. Moreover, because blinding is inherently difficult for these types of trials, few studies were blinded. Most studies failed to use objective outcome, versus parent-reported symptoms or exposures, or validated asthma surveys.

LEAD

Epidemiology

Despite dramatic reductions in lead exposure, low-level lead toxicity is one of the most prevalent environmental hazards in childhood. Mortality from lead poisoning has decreased dramatically since the 1960s, and fatal lead poisoning
<table>
<thead>
<tr>
<th>Problem</th>
<th>Approach (by levels of intensity)</th>
<th>Type of Prevention</th>
<th>Study (positive in bold)</th>
<th>Subjects in Each Group</th>
<th>Ages (years)</th>
<th>Results in Home</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust mites</td>
<td>Covers + ascaricide + laundry service + replaced flooring</td>
<td>Primary</td>
<td>Custovic 2000, 2001</td>
<td>258/291</td>
<td>Birth</td>
<td>Bedtime dust decreased by 26% (CI 24% to 37%) at 1 year (P = .007)</td>
<td>Lower risk of wheezing (OR 0.44, CI 0.2 to 0.8) in interventions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Secondary</td>
<td>Hayden 1997</td>
<td>13/10</td>
<td>5 to 18</td>
<td>Dust levels fell more than threefold</td>
<td>Better peak flows (P &lt; .05) after 6 months</td>
</tr>
<tr>
<td></td>
<td>Ascaricide + plastic covers + laundry service</td>
<td>Secondary</td>
<td>Shapiro 1999</td>
<td>36/44</td>
<td>6 to 16</td>
<td>Lower dust levels in 50% of aggressive homes vs. 12% standard (P = .03)</td>
<td>Doubling PD20 in nine aggressive vs. four standard (P &lt; .05)</td>
</tr>
<tr>
<td></td>
<td>Plastic covers + laundry service</td>
<td>Secondary</td>
<td>Burr 1980a</td>
<td>53/55</td>
<td>4.5 to 14</td>
<td>Dust and antigen amounts reduced but same number of mites</td>
<td>No change in symptoms</td>
</tr>
<tr>
<td></td>
<td>New bedding</td>
<td>Secondary</td>
<td>Burr 1980b</td>
<td>21/21</td>
<td>4.5 to 14</td>
<td>Lowered mite levels (P &lt; .05)</td>
<td>Higher mean peak flows (P &lt; .01)</td>
</tr>
<tr>
<td></td>
<td>Ascaricide + plastic cover versus plastic covers alone</td>
<td>Secondary</td>
<td>Bahir 1997</td>
<td>46/65</td>
<td>6 to 18</td>
<td>Lower dust levels in both groups (P &lt; .001)</td>
<td>Better symptom scores in both groups (P &lt; .001), no change FEV1 or peak flows (P &gt; .05)</td>
</tr>
<tr>
<td>Plastic covers alone</td>
<td></td>
<td>Secondary</td>
<td>Elwert 1992</td>
<td>24/24</td>
<td>7 to 15</td>
<td>No change in dust mite levels</td>
<td>Improved airway hyperresponsiveness in exacerbation group</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Secondary</td>
<td>Gilles 1967</td>
<td>25/26</td>
<td>6 to 16</td>
<td>Lowered levels but no difference from controls</td>
<td>No change in symptoms</td>
</tr>
<tr>
<td></td>
<td>Ascaricide alone</td>
<td>Secondary</td>
<td>Sette 1994</td>
<td>24/24</td>
<td>Mean Age 12.8</td>
<td>No difference in dust levels (P &gt; .05)</td>
<td>No change in bronchial hyper-response (P &gt; .05)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Secondary</td>
<td>Carswell 1996</td>
<td>49/72</td>
<td>Mean age 9.9</td>
<td>Lower levels in bedding (P &lt; .05) vs. 29% (P &lt; .05)</td>
<td>Higher FEV1 after 24 weeks (P &lt; .05)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Secondary</td>
<td>Golde-Bernstein 1995</td>
<td>32/24</td>
<td>4 to 12</td>
<td>Lower dust concentrations in ascaricide (P &lt; .05)</td>
<td>Improved symptom scores (P &lt; .05)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Secondary</td>
<td>Warner 1993</td>
<td>14/20</td>
<td>3 to 11</td>
<td>Decreased mite levels in 13 of 16 intervention homes (P &lt; .001)</td>
<td>Reduced skin test reactivity in intervention (P &lt; .004)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Secondary</td>
<td>Reiser 1990</td>
<td>40/51</td>
<td>5 to 16</td>
<td>No change in mite levels</td>
<td>Improved airway hyperresponsiveness</td>
</tr>
<tr>
<td>Air filtration unit (HEPA)</td>
<td></td>
<td>Secondary</td>
<td>Antonacci 1991</td>
<td>9/9</td>
<td>10 to 28</td>
<td>No difference in mites (P &gt; .05) but both groups dust levels fell (P &lt; .05)</td>
<td>Rhinitis symptom score improved (P &lt; .05), but not peak flows (P &gt; .05)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Secondary</td>
<td>Verall 1983</td>
<td>13/16</td>
<td>7 to 27</td>
<td>No mite assessment</td>
<td>No change in symptoms</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Secondary</td>
<td>Mitchell 1980</td>
<td>10/10</td>
<td>6.9 to 13.5</td>
<td>No mite assessment</td>
<td>No change in peak flows</td>
</tr>
<tr>
<td></td>
<td>Ventilation + vacuum vs. vacuum alone vs. ventilation alone &amp; placebo</td>
<td>Secondary</td>
<td>Warner 2000</td>
<td>40/40</td>
<td>27 children, 4 to 16, 13 adults 20 to 67</td>
<td>Lowest dust concentrations in ventilation and vacuum group (P &lt; .001)</td>
<td>No statistical difference</td>
</tr>
<tr>
<td>Cockroaches</td>
<td>Gelbait/plastic covers vs. placebo-treated vs. education alone</td>
<td>Secondary</td>
<td>Carter 2001</td>
<td>85/104</td>
<td>7 to 14</td>
<td>No difference between active and placebo</td>
<td>No difference between active and placebo</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Primary</td>
<td>(did not test for allergy)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>IPM/cleaning</td>
<td>Secondary</td>
<td>Equaleston 1999</td>
<td>13 homes</td>
<td>Children</td>
<td>No difference</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Secondary</td>
<td>Gergen 1999</td>
<td>265</td>
<td>8 to 12</td>
<td>Difference in allergen levels but still much higher than normal levels</td>
<td>Data reported separately (no statistically significant reduction seen)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Secondary</td>
<td>Arbee 2003</td>
<td>32 homes</td>
<td>Children</td>
<td>Lower level cockroach allergen bedroom (P &lt; .05)</td>
<td>N/A</td>
</tr>
</tbody>
</table>

*Only environmental modification studies qualified. No home education or contingency guideline studies were found for review.

RR = relative risk; FEV1 = forced expiratory volume over 1 second; CI = confidence interval.
is rare. Although the average blood lead concentrations of children dropped by more than 80% in the past 30 years,36 400,000 US children ages 5 and younger still have blood lead concentrations of 10 μg/dL or higher.2 Undue lead exposure remains high in some groups, such as urban, black children. Many Northeast and industrial areas of the United States have exposure rates higher than 20% among urban children.37

Older rental housing often contains the highest levels of lead hazards. In addition to having higher concentration of lead paint, older rental housing is often less well maintained than owner-occupied housing. In a random telephone survey in the United States, parents reported that children younger than 6 were more likely to have an elevated blood lead concentration level if they lived in housing built before 1960, in a rental home, in the Northeast, or in a home with low household income.38 An estimated 14 million US children younger than 6 still live in housing built before 1960, with the highest concentration of lead paint. A recent national survey estimated that 24 million (25%) of the housing units in the United States contain one or more lead dust hazards on floors or windows.39

**Interventions to Improve Morbidity and Mortality from Lead Exposure**

Most reported interventions to control lead exposure have been secondary prevention trials, occurring only after a child was identified with blood lead concentrations greater than 15 μg/dL or 20 μg/dL. These studies examined complete removal of lead-contaminated paint (abatement), encapsulation of lead-based paint using polymers to stabilize paint, replacement of windows or door frames, repainting deteriorated paint, or professional dust control. With the exception of dust control, none of these studies were randomized, controlled trials.

There is inconsistent evidence that paint abatement or stabilization is associated with a significant reduction in blood lead concentrations. Two studies have shown reductions in blood lead levels for children who have blood lead concentrations greater than 25 μg/dL, although one study was retrospective45 and the other was not randomized.46 However, another study did not find significant reductions in blood lead for children with blood lead levels less than 25 μg/dL.47 No randomized trials have tested the efficacy or safety of lead-hazard controls for children who have blood lead concentrations less than 30 μg/dL, with the exception of dust controls.48 Indeed, one controlled trial found that paint abatement was associated with a 6.5 μg/dL increase in blood lead concentration among children in the abatement group, despite using the US Department of Housing and Urban Development's post-abatement clearance testing.42 Existing US Environmental Protection Agency standards and Department of Housing and Urban Development post-abatement standards provide an illusion of safety. These standards are based on both economic considerations and scientific evidence about which levels of lead contamination result in elevated blood lead levels in children. Existing health-based residential lead standards are not set low enough to protect children from undue lead exposure.

**Recommendations to prevent lead exposure typically have focused on education regarding dust control such as dust...**

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**TABLE 2.**

<table>
<thead>
<tr>
<th>Problem Lead</th>
<th>Approach (by levels of intensity)</th>
<th>Type of Prevention</th>
<th>Study (positive in bold)</th>
<th>Subjects in Each Group</th>
<th>Ages</th>
<th>Results in Home</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Professional dust control</td>
<td>Secondary</td>
<td>Rhodes 1999</td>
<td>113</td>
<td>6 to 36 months</td>
<td>Lead dust levels reduced</td>
<td>Statistical difference in blood lead levels (17%)</td>
<td></td>
</tr>
<tr>
<td>Dust control with repair/painting</td>
<td>Secondary</td>
<td>Aschengrau 1998</td>
<td>41</td>
<td>6 to 36 months</td>
<td>Lead dust levels reduced</td>
<td>No statistically significant difference in blood lead level</td>
<td></td>
</tr>
<tr>
<td>Home visitation</td>
<td>Education/dust control supplies</td>
<td>Primary</td>
<td>Landheer 1999, 2000</td>
<td>275</td>
<td>6 months</td>
<td>No difference in dust lead levels</td>
<td>No statistically significant difference in blood lead levels</td>
</tr>
<tr>
<td></td>
<td>Secondary</td>
<td>Landheer 1996</td>
<td>104</td>
<td>12 to 31 months</td>
<td>No difference in dust lead levels</td>
<td>No statistically significant difference in blood lead levels</td>
<td></td>
</tr>
</tbody>
</table>
cleaning, hand washing, and reducing children’s mouthing behaviors to reduce lead exposure, ingestion, and absorption (Table 2). There is no evidence, however, that education alone is adequate to prevent pediatric lead exposure, as measured by blood lead concentration.

Dust control is safe and efficacious at controlling or preventing children’s exposure to lead. There is some evidence that regular visits by professional dust control teams led to greater reductions in lead-containing dust and blood lead concentrations than parental cleaning alone (Table 2). However, the magnitude of the reduction in mean blood lead concentration was modest, and this service is unlikely to be available for most high-risk families who live in substandard housing. Moreover, dust control did not reduce blood lead concentrations to levels low enough to avoid the adverse consequences of low-level lead exposure. Nevertheless, dust control was associated with a greater than 50% reduction in children who had blood lead levels in excess of 15 µg/dL, regardless of whether the intervention was performed by professionals or family members (Table 2).

Remedies to residential lead hazard control have suffered from a lack of evidence-based approaches. There is limited evidence that environmental lead-hazard controls (eg, window treatments, paint stabilization, creating smooth and cleanable surfaces) will reduce children’s blood lead concentrations, yet they remain the most commonly recommended intervention. Haphazard enforcement of existing laws, such as the Residential Lead-Based Paint Hazard Reduction Act (Title X) requiring home sellers to tell buyers of lead hazards prior to purchase, only perpetuates the problem. Only an estimated 9.1% of homes built before 1960 have been tested for lead, and enforcement of lead hazard controls and disclosure about lead in housing have remained largely regional and ineffective. Given new evidence of the lifelong burden of lead exposure in childhood, much more effort should be put forth to prevent lead poisoning before it occurs.

Limitations
There is considerable uncertainty about the effectiveness of many lead-hazard controls. Many educational efforts have been tested and, with the exception of dust control, most recommendations have not been shown to be lower lead levels in children. Still, the benefit of any prevention effort is likely to be underestimated if the study involves children who have high blood lead levels or if they are older than 2 and exhibit few mouthing behaviors.

To protect children from environmental lead exposure, it is likely we need to control or eliminate the source of lead exposure; ongoing dust control without reducing lead air emissions or paint deterioration is unlikely to be successful. Moreover, because major alterations in the physical characteristics of housing must be done to eliminate lead hazards, blinding is inherently difficult for these types of trials. Given the barriers of cost and feasibility of these studies, it is difficult to gather adequate sample sizes to analyze whether a difference has occurred, especially at lower lead levels.

RESIDENTIAL INJURY
Epidemiology
Excluding motor vehicle injuries, the majority of injuries among US children occurs in and around the home. From 1978 to 1984, residential injuries accounted for 60% to 70% of fatal injuries among children younger than age 15. Leading residential mechanisms of injury in children are falls, poisonings, burns, drownings and suffocations, cutting and piercing, and neglect or abuse.

Interventions to Prevent Residential Injuries
Most published research focused on the reduction of residential injury in children through home visitation, anticipatory guidance, and provision of low-cost safety equipment. Although there is high-quality evidence linking counseling to changes in parental behavior, no randomized, controlled trials of clinic-based injury prevention counseling have linked such counseling to changes in the physical environment of the home or reductions in pediatric clinic visits, emergency department visits, or hospitalizations for injury. There is evidence that home visitation with provision of injury prevention counseling and low-cost safety equipment, such as smoke alarms and cabinet locks, may reduce healthcare visits and injury rates. It is probable that interventions directed at modifying the home to reduce the risk of childhood injury across multiple unintentional mechanisms (eg, smoke alarms, window guards, radiator covers) will have a greater effect than interventions that target single mechanisms. Also, interventions that have follow-up, such as maintenance of smoke detectors, will have greater effect as well.

Limitations
Many limitations were found in the injury studies. Many studies did not evaluate whether injury hazards were reduced in the home. Most studies relied on parental report, which may be unreliable and subject to multiple biases. Though most studies had large sample sizes, many studies did not have power...
calculations to support appropriate hypothesis testing.64-67

EXPANDING UNDERSTANDING OF HOUSING AND FUTURE INTERVENTIONS

The relationship between home environment and health involves neighborhood and community factors. Neighborhoods with more boarded-up buildings have higher rates of gonorrhea and premature death.68 Studies of outdoor pollutants such as ozone, which has been associated with increased incidence of asthma among children participating in sports, show seasonal and geographic differences.69 Another outdoor exposure postulated to exacerbate asthma is diesel exhaust particles.70 Violence in neighborhoods and in homes has been associated with increased incidence of wheezing in children and worsening of pre-existing asthma in children.71 More narrowly, housing can be defined by the hazards found inside the home.

A number of additional methodological issues may explain the relative paucity of evidence supporting the interventions examined. While most research on housing hazards has focused on each exposure and specific disease outcomes in isolation, children may be at risk from multiple hazards in their homes. Beyond the cumulative physical exposures related to housing, there are additional effects from housing quality that also need to be considered in future studies. Substandard housing conditions have been shown to have mental health implications.80 Housing quality, including presence of pests and mold, has been strongly associated with psychological distress.81 Other sources of housing-related stress, such as strain of meeting rent payments, overcrowding, and inability to relocate, have been associated with worse health status.82 Taken together, these data underscore the need to consider both the physical and emotional effects of housing quality and area of residence on disease. Social inequality is often associated with housing inequality as well.

SUMMARY

Housing hazards contribute to considerable morbidity and mortality among millions of children each year in the US, but few interventions are proven to control asthma and lead poisoning. Moreover, there is little evidence that many of the current recommendations to control residential hazards are safe and efficacious. The only interventions that have been found to work consistently are home visitation programs and home modifications, such as installation of window guards and carpet removal.

Altering the environment to protect the health of children requires pediatrician intervention. New models of cooperation between pediatricians and public health agencies must deal with residential hazards in an integrated manner and cannot be focused on one disease process or one method at a time. With research in more effective environmental interventions and pediatric-public-health partnerships, primary and secondary prevention of diseases from residential hazards may become a reality in the future.

REFERENCES

22. Mitchell EA, Elliot RB. Controlled trial of an