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Indoor Combustion and Asthma

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Combustion indoors produces both gases (eg, nitrogen dioxide, carbon monoxide) and particulate matter that may affect the development or exacerbation of asthma. Sources in the home include both heating devices (eg, fireplaces, woodstoves, kerosene heaters, flued [ie, vented] or nonflued gas heaters) and gas stoves for cooking.

Home heating devices include both those used as the primary heating source and those used as a secondary source. In areas where central heating is the norm (ie, most of the United States), woodstoves, kerosene heaters, or gas space heaters may be used as a secondary source, allowing the family to heat a specific room or to lower the thermostat and reduce the cost of central heating. Some sources may be used only occasionally, such as fireplaces used for ambiance or space heaters used in case of power failure. In other parts of the world such as parts of Europe and China, burning wood or coal within the living space of a home may represent a primary method of heating. These differences in source use (eg, daily versus infrequently, primary versus secondary) lead to considerable variability in exposures.

Gas stoves are another common source of indoor combustion. Exposures to emissions from stoves can also vary considerably depending on stove and household characteristics. Older stoves with continuously burning pilot lights produce significantly more exposure to nitrogen dioxide and particulate matter than stoves with electronic ignition. Other gas appliances, including gas dryers and hot water heaters, may also be sources of exposure to nitrogen dioxide and other pollutants, although exposures tend to be lower from these sources. In the Netherlands, exposure to gas geysers (a type of hot water heater) is common and their effect on respiratory symptoms has been studied [1].

Although previous reviews [2] have considered the association of indoor combustion sources with respiratory symptoms in general, this article highlights the recent literature, focusing specifically on exposure to indoor combustion in association with either the development or exacerbation of asthma. Studies of both the incidence and prevalence of asthma in association with indoor combustion sources are included. Severity of asthma will be measured by increases in asthma symptoms (eg, wheeze, persistent cough, chest tightness and shortness of breath) as well as increases in medication use, physician visits, emergency room visits, and hospitalization. Since asthma is a chronic condition affecting both children and adults, both age groups are included in this review. Heating and cooking devices will be considered separately. Generally, exposure in the home has been investigated. The few studies of children exposed at school [3] are also reviewed.

The following questions are considered in this article: Is indoor combustion associated with asthma development, or with exacerbation of symptoms among asthmatics? Is exposure from heating devices more harmful than exposure from cooking devices? Are specific fuels (eg,

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coal), more likely to be associated with risk than others (eg, wood)? Are children more at risk than adults? Is the association of indoor combustion and asthma confounded by poverty or environmental factors associated with substandard housing or older appliances that burn inefficiently?

Heating sources

Woodstoves

Wood smoke includes a vast array of constituents forming a complex mix of particles of varying chemical and physical composition, making it difficult to identify any individual harmful constituent [4]. Thus, some have argued that it is best to examine the entire mixture rather than its individual constituents [4]. Factors such as frequency of use, whether the woodburning stove is a primary or secondary heater, ventilation, age, type and condition of the device, and size of home influence concentrations of emissions within the home.

Four studies examined the association of asthma with exposure to a woodstove [5–8]. Of these, only Thorn and colleagues [5] reported a positive association (odds ratio [OR] = 1.7, 95% CI 1.2–2.5). This study compared 174 cases of adult-onset asthma (after age 16 years) with 870 controls randomly selected from a population sample in Sweden. Additional risk factors related to adult-onset asthma in this study were environmental tobacco smoke (OR = 2.4, CI 1.4–4.1), visible mold growth (OR = 2.2, CI 1.4–3.5), and visible dampness with mold growth (OR = 1.8, CI 1.1–3.1). Information about frequency of stove use was not available. No association with asthma was noted for exposure to an open fireplace, tiled stove, or iron stove, although nearly half of the study population reported these exposures.

Three additional studies did not find any association between woodstove exposure and asthma [6–8]. Eisner and colleagues [7] followed 349 adult asthmatics in northern California for 18 months to assess asthma severity. Woodstove exposure was not associated with any of the health indicators that included: asthma severity; general physical health; asthma quality of life; and medical care (emergency department visits or hospital admissions). More frequent use of the woodstove was also not associated with any particular health outcome.

A survey of 10,667 Finnish university students did not find any association of asthma prevalence with exposure to a woodstove for heating in the first six years of life (OR = 0.99, CI 0.65–1.53) [6]. In this study, woodstove heating was associated with living on a farm. Similarly, a survey of 397 school children in Libby, Montana, did not find an association between using a woodstove as the main source of heat, and prevalence of recent wheeze (OR = 1.07, CI 0.47–2.39) [8]. Recent wheeze was analyzed because half of the children with wheeze in the past four weeks did not have an asthma diagnosis. In both Finland and Montana, woodstoves were identified as the main source of heat, reducing the likelihood that negative findings resulted from infrequent use of the stoves.

Coal stoves

Coal is composed primarily of carbon, but it also contains sulfur, oxygen and hydrogen. Emissions from coal combustion include a large number of air pollutants such as particulate matter, carbon monoxide, sulfur dioxide, nitrogen oxides, and organic toxics. A handful of studies have examined the association between coal stove use and asthma in children.

In Belfast, Northern Ireland, 2574 children whose names were selected from general practitioners' lists were studied [9]. Those exposed to glass-fronted solid fuel fires (GFF) — usually burning anthracite—were compared to children in homes with other heating types (primarily oil fired furnaces). Exposure to GFF was associated with all four of these health outcomes: wheeze during the past 12 months (OR = 2.47, CI 1.83–3.30); cough during the past

12 months (OR = 2.20, CI 1.65–2.80); ever used an inhaler (OR = 1.80, CI 1.30–2.30); and diagnosed asthma (OR = 1.81, CI 1.40–2.40). This study also controlled for exposure to environmental tobacco smoke, deprivation score, and crowding. In Munster, Germany, a small number of children (26 out of 3467) who had coal space heaters in their homes [10] were at increased risk for wheeze and asthma; the correlation was made for both boys and girls, although not consistently due to the small sample size.

Use of coal stoves for heating was recently studied with other potential asthma risk factors in China [11]. The International Study of Asthma and Allergies in Children (ISAAC) questionnaire was distributed to all children 6–10 years of age attending 25 randomly selected schools in suburban Beijing. The survey identified 403 children with asthma; 806 controls were matched for gender, age and class in school. Compared to the use of steam heat, exposure to a coal stove for heating increased the risk of asthma (OR = 1.5, CI 1.1–1.9). Cooking with coal, without a ventilation fan, was associated with an even higher increased risk for asthma (OR = 2.3, CI 1.5–3.5).

A second study investigated household factors and asthma in four Chinese cities (Lanzou, Chongqing, Wuhan, and Gangzhou) [12]. In each city, one urban area with high ambient pollution and one suburban area with low ambient pollution were chosen. Parents of children (n = 7754) attending one school in each area answered a questionnaire. Heating with coal was associated with cough with phlegm (OR = 1.29, CI 1.11–1.50), wheeze (OR = 1.22, CI 1.02–1.45), and asthma, with risks similar to the previous study (OR = 1.52, CI 1.06–2.15). However, cooking with coal was not associated with any health outcome.

Gas heaters

Gas space heaters have nitrogen dioxide (NO₂) emission rates similar to gas stoves. However, because they are used for longer periods of time in living and sleeping areas, there is typically less of a spatial gradient within the home. When they are not vented, use of these heaters can result in NO₂ concentrations four or more times higher than gas stoves used for cooking [13].

A study in Tasmania, Australia investigated exposure to portable or fixed gas space heaters in the first year of life [14]. Data was linked between an infant study of risk factors for SIDS in 1988, and a school study of asthma in 1995. Of 1111 parents who participated in the infant study, 863 also participated in the asthma study. Children exposed to gas heaters in infancy were more likely to develop asthma (RR = 1.95, CI 1.16–3.29) and somewhat more likely to have recent wheeze at age 7 years (RR = 1.63, CI 0.96–2.74), adjusted for smoking in the home and gas cooking. Effects did not differ for children exposed to flued versus nonflued gas heaters. Current exposure to gas heaters at age 7 years was also associated with asthma (RR = 1.33, CI 1.12–1.57) and recent wheeze (RR = 1.41, CI 1.17–1.71). Among infants living in a home with a living room gas heater, those who slept in a room with the door always closed at night had a lower risk of asthma than those who slept with the bedroom door open (RR = 0.26, CI 0.07–0.97). A major strength of this study was the availability of prospective infant data.

The relationship between residential exposures and asthma was also examined in National Health and Nutrition Examination Survey (NHANES) III, a cross sectional study (n = 8257) of a representative sample of children less than six years old in the US [15]. Children in homes where a gas stove or oven was used for heat were more likely to have physician-diagnosed asthma (OR = 1.8, CI 1.02–3.1). Since these stoves are designed for cooking, rather than heating, they are not vented when used as a source of heat.

Fume-emitting heaters

Another study combined different types of heating into two categories: “fume-emitting” and “nonfume-emitting.” In this cross-sectional study of 627 school children (ages 8–11) in Belmont, Australia (a coastal suburb of Sydney), the association between housing characteristics and prevalence of asthma was examined [16]. Questionnaires were completed by parents; airway hyper-responsiveness in the child was measured by histamine challenge; and atopy in the child was measured by skin prick testing to six common allergens. Fume-emitting heating systems included flued gas (4%), nonflued gas (14%), open fire (9%), woodstove (14%), and kerosene (1%); Nonfume-emitting heating systems included central heating (8%), electric heat (47%), and reverse cycle heating (15%). Use of fume-emitting heaters during the first year of the child’s life was associated with airway hyper-responsiveness, (OR = 1.47, CI 1.06–2.03), recent wheeze (OR = 1.44, CI 1.11–1.86), and current asthma (OR = 2.08, CI 1.31–3.31) defined as airway hyper-responsiveness plus recent wheeze. Use of fume-emitting heaters in the first year of life was not associated with asthma when it was alternately defined as a physician diagnosis of asthma (OR = 0.93, 0.74–1.17). In this study, current use of fume-emitting heaters was not associated with any of the asthma-related health outcomes examined. Strengths of this study are: the use of histamine challenge and skin prick testing to obtain objective outcome measures; and adjusting for smoking in the home. In addition, it is unlikely that bias would result in positive associations for exposure in the first year of a child’s life and negative associations with current exposure.

Intervention studies

Two studies have evaluated interventions designed to reduce asthma severity by changing heating systems in children’s homes. In Cornwall, UK, funds from the National Health Service were used to install central heating in the homes of children with asthma to eliminate dampness and increase energy efficiency [17]. Seventy-two children living in 59 homes where the heating system was replaced participated in an evaluation study. There were no control homes. Thirty-three homes previously had coal fires, and 26 homes had other forms of space heating. Central gas furnaces were installed in 37 homes and electric heat in 22. Respiratory symptoms and the number of days lost from school were assessed before and after the intervention. All respiratory symptoms (wheeze, cough, breathlessness) declined after the change in heating system, with the largest decline in cough at night. Days of school lost due to asthma also significantly improved, from a rate of 9.3 per 100 school days to 2.1 per 100 school days. The limitation of this study is the lack of a comparison group, and the possibility that parents were inclined to think their child’s asthma had improved after the change in heating system and report symptoms differently. The authors attributed the improvement in asthma symptoms to a reduction in dampness in the home (children sleeping in a damp bedroom 61% before, 21% after; children sleeping in a moldy bedroom 43% before, 6% after). However, the intervention also removed coal fires from the homes.

Pilotto and colleagues [3] reported a randomized controlled trial from Adelaide, Australia that studied the effect of replacing nonflued gas heaters in schools. Of 18 schools using nonflued gas heaters, eight were randomized to the intervention group that received flued gas (n = 4) or electric heat (n = 4) depending on cost, and 10 were randomized to the control group with no heater replacement. To maintain blinding of teachers, parents and children, changes to the heating system were disguised as routine maintenance. Asthmatic children, who did not have nonflued gas heaters at home, were eligible for the study (n = 118) and they recorded daily symptoms in a diary for the winter period. Lung function tests (before and after the study period) and skin prick tests were also carried out. Children in the intervention group experienced a reduction in the following symptoms: difficulty breathing during the day (RR = 0.41, CI 0.07–0.98), difficulty breathing at night (RR = 0.32, CI 0.14–0.69), chest tightness during the day (RR = 0.45, CI 0.25–0.81), and asthma attacks during the day (RR = 0.39, CI

0.17–0.93). Results of lung function testing did not differ between the two groups. Nitrogen dioxide levels measured in the intervention classrooms (mean 15.5, SD 6.6) were significantly lower than in control classrooms (mean 47.0, SD 26.8). Because this study was both randomized and blinded, it provides some of the strongest evidence of an association between indoor combustion (and NO₂) and symptoms in asthmatic children.

Cooking appliances

Gas cooking stoves

Gas cooking stoves are an important source of indoor NO₂. However, gas stoves tend to be used for shorter periods of time and are limited to the kitchen, resulting in a strong spatial gradient within the home. A large number of studies have investigated the relationship between gas cooking stoves and asthma prevalence or asthma symptoms. Both adults and children have been studied. Results are inconsistent, but exposure of children appears to be more consistent with risk than exposure of adults. Because gas stoves are used in the kitchen, women are thought to have a much higher exposure on average than men; some studies have considered these gender differences.

Adult exposure

Eisner and colleagues reported two studies of adult exposure to gas cooking and asthma [7, 18]. Among 349 adult asthmatics in California, there was no apparent association of gas cooking with any of the health outcomes: asthma severity; physical health status; asthma quality of life; emergency department visits; or hospital admissions [7]. In NHANES III, 445 adult asthmatics completed pulmonary function testing [18]. There was no association between gas cooking and FEV₁, FVC, FEV₁/FVC ratio, or FEF_{25%–75%}, nor was there any association with symptoms (cough, phlegm, dyspnea, or wheeze). However, in a cross sectional study (n = 1159) in East Anglia, UK, gas cooking was positively associated with asthma symptoms and asthma attacks among women: wheeze (OR = 2.07, CI 1.41–3.05); waking with shortness of breath (OR = 2.32, CI 1.24–4.34); asthma attacks (OR = 2.60, CI 1.20–5.65); and use of asthma medication (OR = 2.88, 1.46–5.70) [19]. Women exposed to gas stoves also had lower lung function (% reduction in FEV₁ = 3.51 Standard Error [SE] 1.2, % FEV₁/FVC = 3.07 SE 1.21). No effects were seen in men. The authors argue that women spend more time cooking than men, and short-term “peak” exposures may be more harmful than exposures averaged over longer time periods. Moreover, when all of the European Community Respiratory Health (ECRHS) centers were examined in a subsequent study, the impact of gas stoves was much more variable and inconsistent.

Child exposure

Several studies have examined the impact of gas stove use on asthma in children. A case-control study of Dutch and German children investigated exposure to gas stoves and gas geysers (a type of unvented hot water heater) [1]. Cases (children with asthmatic symptoms) and controls were part of a larger longitudinal study. Parents of 1191 children (age 7–8 years) answered a questionnaire about housing characteristics. Gas cooking with a hood was not associated with asthma status (OR = 0.94, CI 0.60–1.46), but use of an unvented gas geyser significantly increased the risk of asthma symptoms (OR = 3.01, CI 1.21–7.56).

In Victoria, Australia, parents of 148 children (including 53 asthmatics) were interviewed and nitrogen dioxide levels were measured in their homes [20]. Gas stove exposure was associated with asthma diagnosis (OR = 2.23, CI 1.06–4.72) and respiratory symptoms (OR = 2.32, CI 1.04–5.18). The association of gas stoves with respiratory symptoms remained significant (OR = 2.24, CI 1.04–4.82) even after adjusting for measured NO₂ concentration. This suggests several possibilities: that other pollutants from gas stoves are responsible for the health effects;

that metrics other than average exposure are important; or that unmeasured confounders associated with gas stove use explain the association.

As part of the Yale Childhood Asthma Study, exposures to NO₂ and gas appliances were investigated as risk factors for exacerbations of asthma [21]. Children (n = 728) less than 12 years old with active asthma (physician diagnosis and symptom or medication use in the past 12 months) were eligible for the study. At enrollment, research assistants placed Palmes tubes in the home to measure NO₂ and recorded the presence of gas appliances. Mothers reported asthma symptoms in the two months prior to enrollment. To reduce confounding by socioeconomic status and housing characteristics, analyses were stratified by housing type (single family versus multi-family). Asthmatic children living in multi-family housing and exposed to gas stoves experienced increased symptoms of wheeze (OR = 2.27, CI 1.15–4.47), shortness of breath (OR = 2.38, CI 1.12–5.06) and chest tightness (OR = 4.34, CI 1.76–10.69). There was no increase in symptoms associated with exposure to gas dryers, or among children in single-family housing. Exposure to measured NO₂ concentrations confirmed the associations with gas stoves only among children in multi-family housing. The lack of an association of symptoms with exposure in single family homes may be due to the reduced exposure to NO₂ resulting from newer appliances, or it might be due to less personal exposure due to larger homes.

A case control study in Baltimore, MD, specifically looked at exposure to gas stoves among low-income children in the United States [22]. The investigators recruited 150 asthma cases and 150 controls to investigate factors associated with asthma development. All children lived in the inner city and high percentages were from low-income families (88% Medicaid) and were African American (91%). Asthma was not associated with either gas stove exposure or heating systems among these children. Because all subjects were low-income, differences between gas stove users and non-users cannot be attributed simply to poverty or substandard housing.

The effects of ventilation have also been considered to explain the inconsistency in findings about gas stoves. As noted above, Mommers and colleagues [1] specifically analyzed gas stoves with a hood. However, many stoves have hoods that are not vented to the outside, further complicating analysis of the effects of gas cooking. Using birth cohort data from the Netherlands, Willers and colleagues [23] investigated gas cooking, controlling for ventilation. The ventilation variable included an assessment of the effectiveness of an extractor fan, the size of the kitchen, air supply to the kitchen, and use of other ventilation in the kitchen (eg, window fan or ceiling fan). Gas stove use was not statistically associated with asthma in this study (OR = 1.50, CI 0.90–2.49). However, it was strongly correlated with poor ventilation (88% of gas users) and good ventilation was strongly associated with electric stove use (98% of electric users). Thus, information about ventilation did not provide additional information in the analysis of this study.

Some studies have considered gender differences in the effects of gas stove use. In a nationally representative sample (NHANES III) of asthmatic children (8–16 years), Chapman and colleagues [24] compared the effects of gas stove use on lung function in boys and girls. Girls in homes where a gas stove was used for cooking had consistently lower lung function compared to homes with electric stoves. This association was limited to girls who did not use prescription medication for asthma.

The ISAAC questionnaire administered in Munster, Germany (n = 6,996) [10] also noted effects of gas cooking among girls, but not among boys. Gas cooking was positively associated with current wheeze (OR = 1.52, CI 0.93–2.47), but not with asthma (OR = 0.77, CI 0.17–3.46).

Some authors [10,19] have suggested that the increased risks for girls in these studies may be because girls are more likely than boys to help their mothers with cooking. However, a Swedish study also reported risks of gas stove exposure specifically in girls, although children in this study were less than 4 years old [25]; at this young age, it is unlikely that girls would be in the kitchen with their mothers more than boys. Children hospitalized for “wheezing bronchitis” (n = 197) were compared to age matched controls (n = 350) selected from population registers in the catchment area of the hospital. Among girls, exposure to a gas stove in the home was associated with wheezy bronchitis (RR = 2.4, CI 1.0–5.9).

Nitrogen dioxide exposure

NO₂ is a major pollutant produced by combustion. Some studies have assessed associations between asthma and indoor combustion by directly measuring NO₂ concentrations in homes.

The study by Belanger and colleagues [21] (described above) found that exposure to measured NO₂ concentrations confirmed associations found with gas stoves. Children exposed to > 20 ppb of NO₂ in the home had increased days of wheeze (OR = 1.33, 1.05–1.68) and chest tightness (OR = 1.51, CI 1.18–1.91), but only among children in multi-family housing. NO₂ concentrations in single family homes (mean [SD] = 10.2 [12.3] ppb) were much lower than in multi-family homes (22.9 [17.0] ppb). In addition, single-family homes were larger (82% had six or more rooms), and personal exposure of children may have been much less than the measured concentration.

Two studies [22,26] specifically looked at exposure to gas stoves and NO₂ among low-income children in the United States. In the case control study conducted by Diette and colleagues [22] to investigate factors associated with asthma development, all children lived in the inner city and high percentages were from low-income families (88% Medicaid) and African American (91%). Measured concentrations of NO₂ confirmed results described in the previous section suggesting no association between gas stove exposure and asthma development. For NO₂, the medians [interquartile ranges] were 21.6[14–34] ppb and 20.9[14–31] ppb in homes of asthmatic children and controls, respectively. Fine particles ≤ 2.5 micrometers in diameter (PM_{2.5}) was also measured in the homes; no differences in median concentrations were found in the homes of asthmatics and nonasthmatics (median 28.7 [18–51] ug/m³ and 28.5 [17–50], respectively). Although concentrations did not vary between cases and controls, concentrations of NO₂ and PM_{2.5} were high in both groups.

Exposure to indoor combustion was also examined using data from the National Cooperative Inner City Asthma Study [26]. This study examined environmental factors contributing to increased asthma severity among asthmatic children. Results were reported by measured NO₂ concentrations because more than 87% of participants used a gas stove. Children were often exposed to high NO₂ concentrations (median = 29.8 ppb), with 15.6% of children exposed in their homes to levels greater than 53ppb, the US EPA standard for outdoor air quality [27]. Gas stoves were the largest contributor to NO₂ concentrations (median = 31.7 ppb and 15.9 ppb for gas stove homes and electric stove homes, respectively). To analyze health outcomes, exposure above the 75 percentile of NO₂ was compared to lower exposure and stratified by atopic status. Nonatopic children exposed to more than the 75 percentile of NO₂ were at increased risk for more than 4 days of symptoms in a two-week period (OR = 1.75, CI 1.10–2.78) and decreased peak flow (<80% expected) in the winter months (OR = 1.46, 1.07–1.97).

An advantage of these two studies is that all participants were from low-income families, so differences between gas stove users and non-users, or children exposed to different NO₂ concentrations, cannot be attributed simply to poverty or substandard housing. A disadvantage of the studies is that so many children were exposed to gas stoves and very high levels of NO₂ that the comparison group has nearly as much exposure as the “exposed” group.

In Australia [28], exposure to NO₂ was measured both at school and at home for 174 asthmatic children. Relative risks were calculated per 10 ppb NO₂. Exposure at school was associated with difficulty breathing during the day (RR = 1.09, CI 1.03–1.15), and at night (RR = 1.11, CI 1.05–1.18); chest tightness at night (RR = 1.12, CI 1.07–1.17); and difficulty breathing after exercise (RR = 1.04, CI 1.01–1.09). Exposure at home was associated with difficulty breathing at night (RR = 1.03, CI 1.01–1.05) and asthma attacks at night (RR = 1.04, CI 1.00–1.07). Home exposure was also associated with decreased lung function (FEV₁ = –0.39% predicted per 10 ppb NO₂, CI –0.76 to –0.02).

In Japan [29], 842 school children participated in a study that measured NO₂ concentrations in their homes and followed the children over three years to assess asthma, bronchitis and wheeze. The use of unvented heaters in the home was associated with higher NO₂ concentrations, mean = 34.4 ppb versus mean = 18.4 ppb for homes with vented heaters. However, use of unvented heaters alone was not associated with any of the health outcomes. Exposure to a 10 ppb increase in NO₂ was associated with asthma (OR = 1.63, CI 1.06–2.54), bronchitis (OR = 1.42 CI 1.06–1.90) and wheeze (OR = 1.90 CI 1.30–2.83) among girls. Exposure to NO₂ was not associated with any health outcome among boys.

Discussion

This article did not find any studies that addressed the question of an association between indoor combustion and asthma incidence. To examine this question would require a cohort followed from birth. However, several studies considered increased asthma prevalence in association with combustion sources. Eight studies reported positive associations for asthma prevalence among children [9,11,12,14–16,25,29]; two studies reported negative findings [22,23]. Among adults, there was one positive [5] and one negative [6] association. A larger number of studies investigated increased symptoms, usually wheeze, or decreased lung function. Nine studies reported increased symptoms among children [1,3,9,12,16,17,20,21,28] and an additional four studies reported increased symptoms only in girls [10,24,25,29]. Two studies failed to find any association of asthma symptoms in children with combustion sources [8,23]. Among adults, indoor combustion was not associated with increased symptoms in three studies [6,7] and positively associated in one study, only with women [19].

Children appeared to be more susceptible to exposure to indoor combustion than adults; however, it is difficult to assess differences in susceptibility by age. Most studies specifically recruited children and only a limited number of studies of adult exposure was available. In three studies of adults exposed to woodstoves, only one was positive; and in three studies of adults exposed to gas cooking stoves, only one study had positive results, and only among women. Several studies investigating exposure to gas cooking stoves reported exposure associated with asthma in females, but not in males. This association could be explained among adult women, because women do more cooking in most families than men. However, this association was also reported among girls (even girls less than four years old). Differences between boys and girls may be related to exposure, or may indicate gender differences in susceptibility, for example hormonal differences.

In general, exposure from indoor combustion for heating was more consistently associated with risk than exposure from cooking. This may reflect the higher exposure from heating devices that are used for many hours per day, rather than the shorter duration of exposure associated with cooking. Nonflued heating devices were more often associated with asthma prevalence or asthma symptoms than devices with flues. In particular, woodstoves that are always vented produced less risk. Removal of nonflued gas heaters in schools decreased symptoms in asthmatic children, even though some schools replaced these devices with flued

gas heaters. Exposure from nonflued devices probably exceeds the exposure from flued devices, which might explain these findings.

It appears that exposure to coal poses a special risk. All studies that reviewed burning coal in the home indicated increased asthma prevalence, and the three studies designed to measure increases in symptoms (eg, wheeze, phlegm, inhaler use) also noted increased symptoms in asthmatic children. Results were much less consistent for wood, where only one of the four studies indicated a positive association with increased asthma symptoms among adults. Nonflued gas heaters also posed a significant risk, and a randomized trial provides strong evidence that removing these heaters reduced asthma symptoms in children.

Gas stove use is particularly common in central cities; in the United States, inner cities are associated with high rates of poverty and substandard housing. In rural areas, the use of secondary heating devices (kerosene heaters, unvented gas) may be a means to reduce heating costs among low-income families. Thus, it is possible that gas stoves and portable heating devices are markers for poverty and substandard housing, and this confounds any association with asthma. Two studies specifically analyzed children from low-income families living in inner city neighborhoods. Both studies measured exposure to nitrogen dioxide (one also measured PM_{2.5}) and both documented very high exposures (exceeding the US Environmental Protection Agency [EPA] level for outdoor exposure in some cases). However, these studies found limited association with asthma (one found no association; in the other, associations were limited to subgroups). A limitation of these studies is that measured pollutant concentrations indicate there were no truly unexposed controls; even homes without gas stoves had high measured concentrations of NO₂. Many of these homes were multifamily and children were probably exposed to pollutants from devices in the building, if not in their own apartments. An intervention study in the UK indicated a reduction in symptoms for children when sources in the home were removed and housing conditions improved.

Overall, it appears that exposure to indoor combustion sources may increase the risk of asthma or asthma severity, particularly in children. Characteristics of the device (eg, frequency and intensity of use, type and age of appliance) and of the home (eg, size, ventilation) result in considerable variability in exposures, which may account for some of the inconsistent findings between studies.

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