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Childhood asthma and indoor woodsmoke from cooking in Guatemala

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We estimated the prevalence and severity of asthma, and the association with cooking on open wood fires, as preparation for a large-scale randomized field trial on effects of indoor air pollution and child health. This is one of the first systematic studies of asthma and indoor wood-smoke pollution and to our knowledge the first asthma study in a purely indigeneous population in Latin America. The mothers of 1058 children aged 4–6 years were interviewed, using the standardized ISAAC (International Study of Asthma and Allergies in Childhood) procedures and questionnaire. The study population is a Mam-speaking (Maya), indigenous group living at relatively high altitude (2000 m) in Western Guatemalan Highlands. We found that asthma prevalence is low among indigenous children in Gautemala, compared to other populations in Latin America. Only 3.3% of the children reported wheezing symptoms in the last 12 months, and 72% wheezing symptoms ever. The majority of the current wheezers had at least one of the criteria for severe asthma. The prevalence of all the symptoms of asthma was higher in children from households that used open fires compared to improved stoves with chimneys. In a logistic regression model, use of open fire for cooking was a significant risk factor for a number of asthma symptoms, with odds ratios varying from 2.0 to 3.5. Among the different cooking technologies (1—improved stove with chimney, 2—mixture of gas and open fire, 3—open fire) trends of higher prevalence with more pollution was found for some of the symptoms. Hence use of open fire for cooking, may be an important risk factor for asthma symptoms and severity.
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Introduction

Evaluation of asthma and allergic disease in Latin America has been largely ignored by the international scientific community, perhaps due to a lack of resources and the relative importance of infectious diseases. No published data on asthma from Guatemala could be found. The largest systematic evaluation of asthma in Latin America is the recent ISAAC study (International Study of Asthma and Allergies in Childhood), which conducted surveys in nine different countries including one country in Central America (Costa Rica). ISAAC concluded with higher prevalence rates of asthma than could be expected in Latin America, and suggested less impact of classical hypothesized factors found to be important for asthma in other countries (e.g. poverty and living in rural, nonpolluted areas) (Mallol et al., 2000). None of these studies looked at non-Spanish-speaking indigenous communities.

There is increasing suggestive evidence for a link between exposure to particle air pollution and asthma. It is well confirmed that exposure to passive tobacco smoke in childhood increases the risk of asthma and allergic disease (Bjorksten, 1999), and a growing database of immunotoxicological studies indicate that diesel exhaust particles has the potential to cause asthma (McConnell et al., 1999; Hajat et al., 1999). Approximately half the world's population and up to 90% of rural households in developing countries still rely on unprocessed biomass fuels in the form of wood, dung and crop residues. These are typically burnt indoors in open fires or poorly functioning stoves, often causing extreme pollution. Levels of respirable particles may reach levels 1–2 orders of magnitude higher than accepted pollution standards in developed countries during meal preparation (McCracken and Smith, 1998). Young children are often carried on their mothers' backs while cooking is in progress and therefore spend many hours breathing smoke (Smith K.R., 1993). Despite the large population exposed (World Health Report, 2002), and the fact that asthma is now the most common chronic disease among children worldwide (Asher et al.,

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1998), only a handful of studies have explored the potential association. The few studies that address the topic have yielded mixed findings, but some of these studies were underpowered or did not adjust for any confounding factors (Bruce et al., 2000). There is an increasing number of studies pointing at effects of smoke on other lung diseases, mainly acute respiratory infections (ARI) (Ezzati and Kammen, 2001; Smith, 2000) and chronic obstructive pulmonary disease (COPD) (Albalak et al., 1999; Pandey, 1984). Unfortunately, due to a lack of resources most of the existing studies on the health effects of biomass smoke are small observational studies, sometimes with methodological difficulties (Bruce et al., 2000). For asthma and allergies, the lack of attention to developing countries in general, and indoor smoke pollution specifically is quite striking considering the large body of research that has been performed in developed countries. The research efforts in industrialized countries have mapped out the contour of a complicated web of causes for asthma and allergies, but much is still unknown. Arguably, the epidemiology of asthma is still in some respects similar to that of cancer epidemiology in the 1960s, when the international patterns of cancer incidences were studied (Asher et al., 1998). Those studies revealed striking international differences that gave rise to many new hypotheses, tested in further epidemiological studies that identified previously unknown risk factors. Whole populations may be exposed to risk factors for disease and the patterns may be apparent only when comparisons are made between, rather than within, populations. This underlines the importance of carrying out standardized asthma studies in countries like Guatemala, and of including "new" risk factors like biomass smoke.

Methods

Study Population

The study was carried out in La Victoria, Monrovia and Varsovia, three adjacent rural communities in the Western Highlands of Guatemala. The area is mountainous, lying at an altitude of 2000–2300 m. The majority of the people in the area belong to the Mam-speaking Native American (Mayan) population. The households are largely dependent on wood fuel with an occasional supplement of crop residues. Engle et al. (1997) found that in a Kiche-speaking neighboring village, women spend on average 5 h per day with the fire lit. As a result, women and children receive substantial exposure on a daily basis. The majority of the families in the area are subsistence farmers, earning some cash supplement from selling their agricultural products at the local markets. Infant mortality rates are estimated to be approximately 55/1000 live births, and ARI are the leading cause of death (Albalak et al., 2001). Typical homes are made of simple adobe walls (bricks made of dried dirt), dirt floors and tile or metal roofs.

Cooking Technologies

Over the past 20 years, a locally produced cookstove called a *plancha* has been developed in this and other districts of Guatemala. The body of the *plancha* is made of cement blocks and bricks. The iron surface has three to four potholes filled with several concentric rings that can be moved for the placement of pots of different sizes. The *plancha* uses wood and sometimes crop residues for fuel, but also has a flue made of metal or cement pipe sections, which allows for removal of most of the smoke from the kitchen. A few households invested their own funds in small gas stoves that are used together with the traditional open fires, producing an intermediate range of smoke pollution (Albalak et al., 2001). The rest of the households in this study relied entirely on the traditional "open fires", that is nothing more than an uncovered fire on the floor in the kitchen. The Mam use three stones of equal size in the fire to place their pots and pans. Women accustomed to cooking on open fires managed to quickly adapt their cooking skills to the *plancha* (Albalak et al., 2001).

The Survey

Data were collected during November 1998, after the rainy season. In 1058 homes with children 4–6 years of age, the standardized ISAAC questionnaire with selected additional questions was administered. We chose to include 4–6 year olds because this age group does not attend school, and is likely to spend more time with their interviewed mothers; thus is it is more likely that the mother knows their symptoms.

The ISAAC core questions have been used in a number of countries and allow for international comparison (Asher et al., 1998). For the translation to the native Mam language, standard ISAAC guidelines were followed. A Mam-speaking physician performed the translations in consultation with local focus groups. The translated version was pilot-tested and adjusted after discussions with other health workers and an anthropologist. The interviewers were native speakers, and received training according to the ISAAC standard requirements. Since this was a door-to-door and not a school-based approach, it was not feasible to use the ISAAC video questionnaire, which might have reduced translation related bias even further (Fuso et al., 2000). The field supervisor accompanied the interviewers unannounced in approximately 5% of the households, and there was overlap of interviewers in approximately 10% of the household to minimize interviewer bias. The houses were re-visited if nobody was home. The response rate was close to 100%.

Key Information from Other Preparatory Studies

Other studies preparing for the intervention trial were also performed in the area. These studies included a detailed family survey including socio-economic factors, testing of the

plancha as a possible intervention device, detailed exposure monitoring and anthropological studies (Saenz de Tajeda, 1998; Naeher et al., 1996; Grajeda et al., 1994; Engle, 1993; Smith K.R., 1993). To avoid unnecessary burden on our participants, the new questionnaire was kept short, and did not include questions well covered in other preparatory studies from the same area, unless believed to differ between the stove groups.

Smoking Smoking habits were evaluated thoroughly in the planning of the intervention trial, and it seems clear that smoking is not culturally accepted among women in this indigenous group. According to anthropological information, the mothers might use tobacco occasionally as a medicine against certain health problems. Our baseline data from the study villages found that less than 2% of the women admitted to ever having smoked, and the fathers who did smoke did not do so at home (Albalak et al., 2001). A survey in a neighboring Mam-speaking area (Grajeda et al., 1994) did not identify a single mother who admitted to be a smoker. The smoking habits were one of the key reasons for selecting this area for the intervention trial, as we avoided a key confounding variable in our evaluation of biomass smoke on disease.

Distribution of "Planchas" and Socio-economic Status In this area, the "*planchas*" were distributed at minimal costs by a governmental organization (Fundo de Invercion, Social, FIS) to any home that signed their name on a public list. The mode of distribution of the improved wood stoves is thought to have reduced the socio-economic differences between the exposure groups, since the stove was equally available to poor and rich households. Another pilot study confirmed this assumption, by showing that the socio-economic status proxied by floor type, wall material and roof material was essentially the same in each of the three stove groups. The level of maternal education was also similar, with approximately 90% with none and the rest 1–3 years. Despite some differences in the kitchen volume between the groups that might influence exposure (Albalak et al., 2001), the study households included seemed well suited for an unbiased evaluation of health effects from indoor air pollution.

Data Analysis

First analysis included χ^2 tests to evaluate unadjusted differences between stove groups on categorical outcome variables. Logistic regression models were fitted for each of the asthma symptoms to obtain evaluation of stove effects adjusted for the following potentially confounding factors: family history of atopic disease, sex of the child, number of siblings, age and interviewer. Socio-economic variables were not included, as they were found to be similar between the stove groups in an other pilot study (Albalak et al., 2001). Variables for cooking technology, sex and age were retained in all the final models. Other variables were retained if considered independent risk factors ($P<0.10$). The nonparametric test for trend across ordered groups by Cuzick (1985) was used to assess changes in symptom prevalence in relation to the different cooking technologies (1 = improved stove with chimney, 2 = mixture of gas and open fire, 3 = open fire). Previous studies in the area found that particle levels trended in this direction, with 24-h means of PM3.5 in the kitchen area of 330, 1200 and 1930 $\mu g/m^3$ by stove type (Albalak et al., 2001).

Results

The data show that 51.5% of the households cooked on improved stoves, 38.1% on open fires and 10.4% on both open fires and gas stoves. There were 52% girls in the sample, and an approximately equal distribution of children of 4, 5 and 6 years of age. 31 (3.0%) of the mothers reported earlier wheezing symptoms. There were no significant differences between the stove groups for any of the demographic variables mentioned above. Table 1 shows the prevalence rates of asthma symptoms and a comparison of the prevalences in the open fire vs. the improved stove group. The prevalence is higher in the open fire group for all the asthma symptoms. Figure 1 illustrates that the overall prevalence of current wheeze is low compared to other Latin American centers, but comparable to some other developing countries (the data in Figure 1 are based on the written, not the video questionnaire). Table 2 shows unadjusted and adjusted risks for various asthma symptoms related to open fire vs. *plancha*. The odds ratios are relatively high, from 1.6 to 3.5, and tend to be higher after adjustment, indicating that some of the adjusting factors are biasing the smoke-disease relation towards the null. Open fire was not significantly related to waking up at night due to symptoms, number of wheezing episodes, or dry cough at night apart from having a cold. For all symptoms except night cough, there is a tendency for increased risk in the open fire group. Similar analysis comparing the group using both gas and open fire with the improved stove gives significantly increased risk only for exercise-induced symptoms. Test for trend (non-parametric) was significant for wheezing symptoms ever ($P<0.05$), current wheeze ($P=0.06$) and exercise-induced symptoms in the last 12 months ($P=0.01$). A family history of wheezing was highly significant in the logistic model for all asthma symptoms, with odds ratios ranging from 9 to 55 pooled across all the stove groups. Sex, age and number of siblings were not significantly related to any of the symptom categories. Because of the strong effect of family history of wheeze, a separate analysis after dropping the 31 positive households was carried out. Using the same logistic

Table 1. Prevalence and severity of asthmatic symptoms (includes a comparison of prevalence between the plancha and the open fire group) Guatemala 1998.

	Prevalence estimates		
Written questionnaire	Total (%)	Improved stove (%)	Open fire (%)
Wheeze "ever"	7.2 (5.6–8.8) $n=77$	6.0 (4.1–7.8)	9.5 (6.6–12.4)*
Wheeze in last 12 months	3.3 (2.2–4.3) $n=36$	2.4 (1.2–3.5)	4.8 (2.7–7.0)*
Diagnosed asthma	2.6 (1.6–3.6) $n=28$	2.0 (0.9–3.2)	3.8 (1.9–5.8)
Exercise-induced wheeze last year	3.7 (2.5–4.8) $n=40$	2.7 (1.4–4.0)	5.4 (3.1–7.6)*
Nocturnal cough last year	17.0 (1.5–1.9) $n=178$	16.4 (13.5–19.3)	17.4 (13.6–21.2)
Number of wheezing episodes last year			
1–3	1.0 ($n=10$)		
4–12	0.4 ($n=4$)		
More than 12	2.2 (1.3–3.1) $n=23$	1.9 (0.8–2.9)	2.5 (0.9–4.1)
Sleep disturbance due to wheeze last year			
Less than once/week	0.8 ($n=8$)		
More than once/week	2.2 (1.3–3.1) $n=23$	1.9 (0.8–2.9)	2.3 (0.8–3.8)
Speech limit to 1–2 words	2.0 (1.2–2.9) $n=22$	1.4 (0.5–2.3)	3.1 (1.3–4.8)
All severity criteria[a]	1.7 (0.9–2.5) $n=18$	1.3 (0.4–2.1)	2.3 (0.8–3.8)

[a]Combination of speech limitation last year, sleep disturbance >1/week or >4 wheezing episodes last year).
*$P<0.05$ (one-sample t-test).

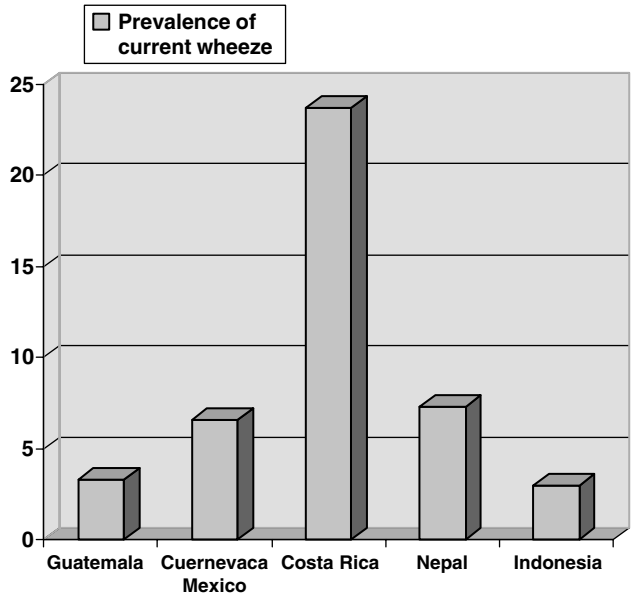

Figure 1. Prevalence of current wheeze in this study compared to selected ISAAC centers in Latin American countries and around the world (Mallol, 2001; ISAAC Steering Committee, 1998; Schei et al., 2004). The Guatemala study was done in a purely rural community, while the other studies were mainly urban/peri-urban.

regression models, the same symptoms came up as significantly affected by stove group, with the exception of current wheeze that became borderline significant ($P=0.08$).

Discussion

A recent publication of asthma symptoms among 6–7 year olds from 17 centers in nine Latin American countries showed a large variation in the prevalence of current wheeze (wheezing in the last 12 months), ranging from 8.6% to 32.1% (Mallol et al., 2000). To our knowledge, no centers worked with a purely Native American population. It is remarkable that in our study only 3.4% of the 4–6 year olds had wheezing symptoms in the last 12 months, less than half the prevalence of the center with the lowest prevalence (Cuernavaca, Mexico) in the main Latin American survey. The authors of the main Latin American ISAAC study reported high prevalence also in the poorest areas, and concluded that factors considered protective against asthma in other regions of the world, like parasitic infestations and a high level of respiratory infections, did not seem to have the same effect in Latin America. The Mam-speaking natives of Guatemala are believed to be among the most exposed populations to parasites and respiratory infections, and our findings are not in agreement with the conclusions from the Latin American group but support the findings from other parts of the world (ISAAC Steering Group, 1998) that a lifestyle associated with a high prevalence of infections is related to lower asthma prevalence.

Most countries in Latin America are currently considered transitional economies, where life-styles change rapidly. Guatemala is among the poorest counties in the region, and our rural, indigenous study population might represent the most traditional population ever evaluated for asthma in

Table 2. Adjusted and unadjusted odds ratios of asthma symptoms in relation to use of open fires for cooking (logistic regression models including sex, age, family history of wheeze, number of siblings, interviewer).

Outcome	Univariate OR (95% CI)	*P* value	Adjusted OR (95% CI)	Adjusted *P* value
Wheeze "ever"	1.6 (1.03–2.63)	<0.05	2.0 (1.1–3.7)	<0.05
Wheeze in last 12 months	2.1 (1.06–4.19)	<0.05	3.4 (1.3–8.5)	<0.05
Diagnosed asthma	1.9 (0.89–4.04)	<0.10	1.8 (0.76–4.19)	ns
Exercise-induced wheeze last year	2.0 (1.07–3.93)	<0.05	3.5 (1.4–8.6)	<0.05
Nocturnal cough last year	1.0 (0.77–1.50)	ns	1.0	ns
Speech limit to 1–2 words	2.2 (0.92–5.26)	<0.10	3.4 (1.1–11.3)	<0.05
1–3 wheezing episodes last year	3.3 (0.81–13.15)	<0.10	2.0 (0.54–9.77)	ns
>12 wheezing episodes last year	1.36 (0.58–3.17)	ns	2.7 (0.83–10.80)	ns
Woke up more than once/week last year	1.21 (0.51–2.91)	ns	1.8 (0.52–5.44)	ns

Latin America. If so, the low prevalence in our study could be expected, and fits well with the much debated "hygiene hypothesis" (Strachan, 1989). The hygiene hypothesis states that rich microbial exposure during a critical time window *in utero* or early infancy gives a beneficial T-cell differentiation and protects against later atopy. Recent studies have tried to modify this thinking by including the potentially protective effect of moderate exposure to parasites (Scrivener et al., 2001). Another study of indigenous children from Guatemala found that 10–15% of children <18 months were infested with parasites (Arana, personal communication).

We can speculate about other potential reasons for the low prevalence found in our study; they could be due to genetic/racial factors; to food habits; little use of medicine like antibiotics (potentially changing the intestinal flora); altitude or even emotional/cultural issues. A recent study found a protective effect on asthma severity in young children from families with balanced and supportive interactions and a good social network (Gustafsson et al., 2002). We might expect better family involvement and social networks in the traditional Maya-Indian societies, compared to urban slums and peri-uran areas where asthma prevalence seems to increase rapidly, a topic for further, multidisciplinary, research. Our study population lives at a moderately high altitude (approx. 2000 m), which fits well with the Cuernavaca population (Mexico), which had the lowest prevalence and the highest altitude (1500–2000 m) in the main Latin America ISAAC survey. This might suggest a positive effect of higher altitude, possibly related to a cooler climate with lower humidity. Findings from high altitude in the French Alps and Himalaya support this hypothesis (Charpin et al., 1988; Schei et al., 1999), as they found lower levels of common allergens, like dust mites, and a lower prevalence of allergic sensitization.

Our study is the first from Latin America relying on a non-Spanish translation of the ISAAC questionnaire. All our interviews were performed in the local Mam language. The very high prevalence rates found in Spanish-speaking Latin American communities, also compared to findings from other developing countries around the world (ISAAC Steering Group, 1998), makes it tempting to speculate that the Spanish term for wheezing may yield more false positive cases than other language translations. We worked with a professional anthropologist, physicians and focus groups on the translation issue, and changed the original English version of ISAAC into both Spanish and Mam. We learned from this and later work that in Guatemala, the common Spanish term for wheezing, "*silbido*", tended to catch nonasthmatic conditions including phlegm in the throat. We emphasize, however, that there may be significant local variations in the understanding of Spanish terms within Latin America. Our study population was somewhat younger (4–6 years) compared to the main study (6–7 years). The fact that younger children usually have more wheezing makes the low prevalence found in our study even more striking.

Biomass-Smoke Exposure We only included a crude exposure assessment in this survey (type of stove for cooking), but have relatively detailed quantitative information from three different exposure assessment studies in the area (Albalak et al 2001; McCracken et al., 1999; Smith, 1993) of expected pollution levels in the different stove groups. One study took place some time after installation of the *planchas*, thus mimicking the real-life situation better than any evaluation of newly constructed stoves. That study reported 24-h means of PM3.5 in the kitchen area of 330 (SD $\pm$ 220), 1200 (SD $\pm$ 1080) and 1930 (SD $\pm$ 1280) $\mu g/m^3$ by stove type (Albalak et al., 2001). We see that the pollution-reducing effect of the improved stove is large, but the mean level of PM3.5 in the improved stove group is still at least twice the level accepted by the US EPA (Environmental Protection Agency) for one 24-h period of PM10 exposure every year: 50 $\mu g/m^3$ (USEPA, 1997). Thus, for all the different exposure groups, we are looking at the higher end of the potential dose–response curve, compared to most industrialized world settings.

The group that used both open fire and gas stove had an intermediate average pollution level, but this difference from

the open fires was not statistically significant in the study by Albalak et al. (2001). It is somewhat surprising that the introduction of gas stoves does not reduce the pollution levels more. The households clearly prefered to use their open fire for cooking tasks that could have been done with the gas stove. The main reason reported was a need for space heating, and that it took too long to cook certain items on the gas stove. In addition, many of the older women did not feel comfortable with the technology (Albalak et al., 2001). It seems likely that more powerful gas stoves and better training of the users would result in lower pollution levels.

There is a large overlap in pollution levels between stove groups. Such overlap is commonly found in these types of studies, and may have a number of possible explanations, for example variation in amount of daily cooking, ventilation and technique for maintaining the fire. Thus, it seems likely that we have introduced substantial nondifferential misclassification by using this crude exposure measure, and that we could expect to find even larger odds ratios for differences between exposure categories, and narrower confidence intervals if we included pollution monitoring in each household or, even better, personal exposure measurements for each child surveyed. Whether sophisticated pollution monitoring is really useful, however, will depend largely on aspects of the medical condition we are studying. If we believe asthma is partially caused over time by indoor air pollution, the historical air pollution exposure will be more important to estimate than details of the current exposure. If, however, we believe the role of air pollution mainly is to create short-time exacerbation of existing disease, a detailed evaluation of current exposure might be critical to establish an association. As will be argued below, there is reason to believe that indoor air pollution has a causal effect on asthma incidence as well as effect on severity and exacerbations of existing asthma; thus, information of both current and historical exposure would be useful. In this population, the historical exposure is probably more similar between the groups than the current exposure, since the governmental stove implementation started a few years ago (most or all children born into homes with open fires). Thus, there is reason to believe that the positive effects of less polluting cooking technologies that we observed in this study would have been even larger for children who were born into homes with "*planchas*".

Most epidemiological studies evaluating the effects of indoor air pollution rely only on cooking technology or fuel type as dependent variables, sometimes including questions on time periods exposed to different stove types. An important recent exception is a study from Kenya by Ezzati and Kammen (2001) using relatively sophisticated pollution monitoring and health outcome measures. This study was the first to describe a dose–response curve for indoor air pollution and acute lower respiratory infections (ALRI), all based on a relatively limited sample size ($n = 55$ households). The best way to determine the role of historical and current exposures to air pollution for asthma would be a randomized controlled trial where children were born into groups with different exposure levels (e.g. homes with open fires or improved wood stoves). Such a trial, would have given the opportunity to compare differences in asthma incidence between the groups; and with detailed pollution monitoring to look at the acute effects of fluctuations in pollution levels within each group. By introducing improved stoves in the open fire group at the end of the trial, one could evaluate if the prevalence of asthma symptoms in the two groups became equal when the current exposures were equal (but the historic exposure different). With a sufficiently large sample size, the randomization process would eliminate most of the potential confounding. With a detailed evaluation of immune status/atopic status and clinical symptoms over time, a randomized trial might also help us to understand better the mechanism behind potential causal effects of air pollution on asthmatic disease. Such a trial is currently starting up in rural Guatemala, and has the potential to change our views on air pollution and asthma (Smith, 2003).

We found a consistent trend, with higher prevalence of general symptoms and symptoms indicating severity of disease among children from homes cooking on open fires, with adjusted odds ratios indicating a doubling or more of the risk of symptoms. Few other studies have reported similar findings. A study from Nepal of people aged 11–17 years (Melsom et al., 2001) found an adjusted odds ratio of 2.3 (1.2–4.8) for asthma among those cooking on open fires compared to wood stoves with a flue, gas, or kerosene stoves. In a large study from Nepal (N73000) adjusted odds ratios of up to six were found for some of the asthma symptoms when comparing households using only gas for cooking to only open fires (Schei et al., 2004). A case–control study of schoolchildren in Nairobi found increased exposure to wood smoke in asthmatics (Mohammed et al., 1995). Two other studies from Turkey and Jordan found similar results, but did not adjust for confounding (Gharaibeh 1996; Guneser et al., 1994). Several studies have reported no association; some of these studies had small numbers of asthmatic children (Ellegard, 1996; Noorhassim et al., 1995). Several studies, including early papers by von Mutius and others comparing East and West Germany (Nowak et al., 1996; Von Mutius et al., 1992) and the main ISAAC papers (Mallol et al., 2000; ISAAC, Steering Committee, 1998), have reported lower asthma prevalence in areas with higher outdoor air pollution, indicating a counterintuitive protective effect of particle exposure, that is probably due to confounding. These papers, mainly of ecologic design, have influenced the scientific communities' ways of thinking about air pollution in such a way that this exposure is often not considered an important risk factor for asthma. This is a paradox when we look at our findings, studies of passive tobacco smoke and diesel exhaust (Pandya et al., 2002; Cook et al., 1999), and the relatively

strong evidence that outdoor air pollution triggers asthma attacks in asthmatic individuals (Ostro et al., 1994; Lebowitz et al., 1985). In addition to the overall controversies of whether smoke pollution has any measurable negative effects on asthma symptoms in a population, there is also the key question of whether the smoke may actually cause asthma, or if the smoke merely induces exacerbations in children who already have the disease. Better knowledge of both these potential effects of smoke is important for public health and scientific reasons. A growing number of toxicological studies indicate that a causal effect of smoke pollution on asthma and atopy is biologically plausible. Biomass smoke is a complex, unstable mixture containing a number of substances that may be involved in such an effect, including particles, carbon monoxide, nitrous oxides, formaldehyde and polycyclic organic matter (DeKoning et al., 1985). Respirable particles [particles $<10\,\mu$m (PM10)] seem especially important (McConnell et al., 1999; Hajat et al., 1999; Peterson and Saxon, 1996). The majority of laboratory studies providing suggestive evidence for a causal link between respirable particles and asthma are based on diesel exhaust exposure. Despite important toxicological differences between diesel exhaust and wood smoke, there are key similarities; both types of smoke are complex mixtures of particulate matter with approximately the same size distribution. Diesel particles have been found to stimulate IgE production, eosinophilic degranulation and augmentation of cytokine and chemokine production — all effects related to a permanent atopic/asthmatic predisposition, arguing for a causal effect (Casilas et al., 1999; Sagai et al., 1993). Diesel exhaust particles is also indicated as an adjuvant with environmental allergens, inducing and/or increasing atopic individuals' allergic reactions (Takano et al., 1997; Ishizaki et al., 1987), an important effect that remains to be studied for biomass smoke. There may be a link between the ''hygiene hypothesis'' (Strachan, 1989) and particle pollution, as diesel exhaust particles appear to enhance the differentiation of CD4+ T lymphocytes into the IgE producing Th2 phenotype associated with atopy (Pandya et al., 2002). This supports the hypothesis of a potential long-term effect of exposure to extreme (Indoor Air Pollution) in infancy for the development of atopic disorder, including asthma. An altered Th-2 response could explain the findings of increased asthma prevalence and severity with increasing levels of indoor air pollution in this study. If we look at the tobacco database, the negative effects on asthma from early life and *in utero* passive tobacco exposure seem relatively well established (Bjorksten, 1999). These findings also support the theory of a causal effect on asthma from early exposure to respirable particles through T-cell differentiation, as indicated in DEP studies (Pandya et al., 2002). In summary, we have toxicological indications for a causal effect of respirable particles on asthma and also evidence for acute toxic effects that may exacerbate existing asthmatic disease.

Despite important differences between pollution mixes like indoor rural and outdoor urban air pollution, the similarities may be more important than the differences. Outdoor air pollution as well as indoor air pollution may very well be independent risk factors for asthma, but other, even stronger risk factors related to modernization may overcome the effects of air pollution in many industrialized societies, explaining the counterintuitive findings in ecologic studies as mentioned above. A homogenous population with large differences in household exposure levels, like in Guatemala, is ideal for evaluation of true health effects from exposure, independent of modernization factors.

We know that indoor biomass smoke affects more than half the children in the world, mainly in developing countries. Many developing countries have prevalence rates of asthma close to 10% (ISAAC Steering Committee, 1998). This is a high number of children, representing a large and not sufficiently recognized public health problem. Simple interventions with improved cooking technologies might be as beneficial to these children as more logistically challenging and costly medical interventions. More research is needed in this field.

Conclusions

Asthma prevalence is low among indigenous children in Guatemala, compared to other populations in Latin America. Our study indicates that the use of open fires for cooking may be an important risk factor for asthma symptoms and severity, which needs to be studied further.

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