USE OF BIOMASS FUEL IS ASSOCIATED WITH INFANT MORTALITY AND CHILD HEALTH IN TREND ANALYSIS

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Abstract. Biomass fuel used for cooking results in widespread exposure to indoor air pollution (IAP), affecting nearly 3 billion people throughout the world. Few studies, however, have tested for an exposure–response relationship between biomass fuel and health outcomes. The aim of this study was to explore the relationship between biomass fuel, infant mortality, and children’s respiratory symptoms. Eighty households in a rural community in Ecuador were selected based on their use of biomass fuel and questioned regarding a history of infant mortality and children’s respiratory symptoms. Carbon monoxide (CO) and particulate matter (PM) were measured in a subset of these homes to confirm the relationship between biomass fuel use and IAP. Results showed a significant trend for higher infant mortality among households that cooked with a greater proportion of biomass fuel ($P = 0.008$). Similar trends were noted for history of cough ($P = 0.02$) and earache ($P < 0.001$) among children living in these households.

INTRODUCTION

Approximately one half the world’s population relies on biomass fuel (wood, charcoal, crop residues, or dung) as a primary source of domestic energy. This practice results in widespread exposure to indoor air pollution (IAP), predominantly in developing countries where other sources of energy are becoming increasingly inaccessible and unaffordable.

Biomass smoke is a complex mixture of pollutants including various gases and respirable particles. Several of these chemicals are known hazards to human health, including carbon monoxide (CO), nitrogen dioxide, benzene, formaldehyde, poly-cyclic organic compounds, and particulate matter (PM). Of these, CO and PM may pose the greatest risk to infant mortality. CO reduces oxygen delivery to vital tissues and has been associated with low birth weight. Small PM can penetrate deep into the lungs, compromising host defense mechanisms and increasing risk for respiratory infections.

It is estimated that IAP in developing countries accounts for 2.2–2.8 million deaths annually. One million of these deaths are thought to be caused by acute lower respiratory infections among infants and children. These estimates of mortality rates are generally derived by extrapolating exposure–response data from ambient air pollution to the higher indoor concentrations found with biomass use. Few studies, however, have examined the specific relationship between biomass smoke within homes and infant mortality. In addition, although several studies have examined the association between biomass smoke and respiratory disease, they have not conducted analyses to determine if increased biomass fuel use is associated with an increased frequency of respiratory signs among household members (trend analysis).

The aim of this study was to examine the relationship between biomass fuel use and adverse health outcomes among children in a rural community in Ecuador. Our primary hypothesis was that households that cooked with a higher proportion of biomass fuel would have a greater history of infant mortality and respiratory symptoms among children. This study was a collaborative effort between Purdue University (West Lafayette, IN) and the Cinterandes Foundation (Cuenca, Ecuador), a non-governmental organization whose mission is to improve health throughout Ecuador.

MATERIALS AND METHODS

Study area. The study was conducted in Santa Ana, a community of 5,000 inhabitants located in the southern Ecuadorian Andes. Santa Ana extends across 46 km² of highland terrain, ranging from 2,300 to 3,200 m in altitude. Climate in the region is cool and dry with an average monthly low of 8°C and a high of 20°C. The study was conducted during the dry season from June to November 2004. The majority of community members are self-employed farmers or artisans, and the average household income is $200 per month. Approximately 13% of adults in the community are illiterate. The primary religion in Santa Ana is Roman Catholicism, and the principal language is Spanish.

There are ~1,000 houses in Santa Ana, typically constructed of adobe or block with tile or zinc sheet roofs. The majority of households use open fires with biomass fuels, including wood and crop residues, for cooking and heating (Figure 1). In addition to biomass fuel, households also rely on liquid propane gas (LPG) to a varying degree. Although all homes studied contained a separate room for cooking, ventilation was poor, with the few windows and doors usually kept closed.

Nearly one third of all doctor’s visits in Santa Ana during 1999 were because of respiratory disease. In children < 1 year old, respiratory disease accounted for 50% of morbidity, with 33.8% of disease caused by upper respiratory infections and 16.2% caused by lower respiratory infections. These are the first and second leading causes of morbidity in children, respectively.

Information on infant mortality is difficult to determine in Santa Ana, because of unreported births and deaths. During 1999, 20 births were reported in the community, of which two infants died.

Study population. Households were selected by random and quota sampling as described previously. Initially, all households in the community were assigned a random number. Households were sequentially visited based on their assigned number. The primary cooking fuel used by the house-
FIGURE 1. A young child sits next to an open cooking fire in his home in Santa Ana, Ecuador. The corresponding author received permission from the child’s parents to use this photograph in the journal.

hold was identified, and quota sampling was used to create four cooking categories containing 20 households each. The four categories were as follows: LPG only, primarily LPG with some biomass fuel, primarily biomass fuel with some LPG, and biomass fuel only.

All of the research procedures were approved by the Committee on the Use of Human Research Subjects at Purdue University. The study was explained to local government, church, and health care workers in Santa Ana, and their oral consent was obtained. Written consent for each child’s participation was obtained in Spanish from an adult in each household, and written assent was obtained from all literate children.

Data and statistical methods. An adult within each study household was asked a series of questions in Spanish by a local health care worker. The questionnaire included information on demographics, socioeconomics (defined by the number of electrical appliances in the home), level of education, smoking within the household, and lifetime history of infant mortality (defined as the death of a child < 1 year of age). In addition, a 30-day history of the presence of cough, fever, sore throat, and earache was obtained for each child < 16 years old living in each household.

To quantify differences of IAP among households in different cooking fuel categories, PM and CO emissions were measured from both LPG stoves and open biomass fires in a convenience sample of five households cooking with LPG only and five households cooking with biomass fuel only. Emissions were measured 1 m above and 1 m away from the stove/fire. CO was monitored continuously over a 24-hour time period using HOBO Carbon Monoxide Loggers (Onset Computer Corp., Pocasset, MA). Respirable PM (< 4 μm) was assessed gravimetrically over a 4-hour period using AirLite personal sample pumps, with three-piece filter cassettes and aluminum cyclones (SKC, Eighty Four, PA). Pumps were calibrated daily for flow rates of 2.5 L/min. Filters were weighed before and after sampling by Clayton Group Services.

A χ² trend test was used to examine the relationship between biomass fuel use and the frequency of infant mortality among households. χ² trend tests were similarly used to assess the relationship between biomass use and the frequency of cough, sore throat, fever, and earache among children.

Multivariate logistic regression was used to further assess trends between cooking fuel use and the frequency of adverse health outcomes, after controlling for potential confounding factors. Potential confounders, included socioeconomic status of the household (relative to the median number of appliances in the home), mother’s education (relative to the median level of education), smoking among household members, number of people living in the household, and the age and sex of each child (for respiratory symptoms only). The association between cooking fuel (ordinal values 1–4) and respiratory symptoms was also adjusted for the random effects of children living in the same household (i.e., household was included in the model as a random variable). Odds ratios (ORs) and 95% confidence intervals (CIs) were calculated for each variable. Statistical analyses were performed using SAS version 9.1 and SPSS version 12.0.

RESULTS

Twenty-three (28.8%) of the 80 households had a lifetime history of infant mortality. Among those households with a history of infant mortality, the mean (SD) number of infants that had died was 1.6 (0.8). Among the 80 households, there was a total of 212 living children < 16 years old, including 115 (54.2%) boys and 97 (45.8%) girls. The mean (SD) age of the

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Comparison of baseline characteristics between different cooking fuel categories using χ² and ANOVA analyses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Socioeconomics (SES)</td>
<td>LPG only</td>
</tr>
<tr>
<td>Lower SES: N (%)</td>
<td>5 (11.1)</td>
</tr>
<tr>
<td>Higher SES: N (%)</td>
<td>15 (42.9)</td>
</tr>
<tr>
<td>Mother’s education</td>
<td></td>
</tr>
<tr>
<td>Lower education: N (%)</td>
<td>6 (10.7)</td>
</tr>
<tr>
<td>Higher education: N (%)</td>
<td>14 (58.3)</td>
</tr>
<tr>
<td>Smoking in the home</td>
<td></td>
</tr>
<tr>
<td>Yes: N (%)</td>
<td>8 (32.0)</td>
</tr>
<tr>
<td>No: N (%)</td>
<td>12 (21.8)</td>
</tr>
<tr>
<td>No. people/household</td>
<td>Mean (SD)</td>
</tr>
</tbody>
</table>

† Higher SES defined by greater than two electrical appliances in the household.
‡ Higher mother’s education defined by at least graduating from primary school.
§ Comparison using ANOVA analysis.
children in the study was 7.8 (4.3) years, and the mean (SD) number of individuals living in each household was 5.1 (2.3). One hundred percent of children experienced at least one adverse health symptom in the previous 30 days. Baseline characteristics were significantly different between households (Table 1). Households that cooked with a higher proportion of biomass fuel had lower socioeconomic status, lower level of mother’s education, and less crowding.

**Figure 2.** Twenty-four-hour continuous CO monitoring from biomass fires (A–E) and LPG (F–J), representing a subset of study households.
CO emissions in homes using biomass fires were significantly higher than in homes using LPG stoves (Figure 2). Mean 24-hour CO concentration produced by biomass fires was 20.6 ppm (SD = 14.8) versus 2.3 ppm (SD = 0.8) for LPG stoves. Average 4-hour PM concentrations from biomass fires ranged from undetectable (< 100 μg/m³) in one household to 9.885 μg/m³ in another. LPG stoves all had undetectable PM concentrations.

In χ² analysis, there was a significant (P = 0.008) trend for a greater percent history of infant mortality with type of biomass fuel used in homes (Figure 3). Similar significant trends were noted for a higher percent of respiratory symptoms including earache (P < 0.001) and cough (P = 0.02) with increasing use of biomass fuels. A nonsignificant trend was observed for a history of fever (P = 0.11) and sore throat (P = 0.14) with increasing use of biomass fuel (Figure 4).

In multivariate analysis, infant mortality was significantly associated with the proportion of biomass fuel used, after controlling for potential confounders (P = 0.02; Table 2). However for respiratory symptoms, only a history of earache was significantly associated with biomass fuel use after controlling for confounders (Table 3).

Stratifying these results by age (data not shown) showed that children 5–10 years old continued to have a significant association (OR = 2.2; P = 0.01) between biomass fuel and earache, whereas children < 5 years old (OR = 2.7; P = 0.02) and 11–16 year olds (OR = 2.1; P = 0.17) had nonsignificant associations between these variables. No other outcome was significantly associated with biomass fuel in stratified analysis.

DISCUSSION

A history of infant mortality was high in this study (28.8% of households). There was a significant trend for a higher rate of infant mortality among households that used a greater portion of biomass fuel. A similar trend was found for a history of earache among children. Association of biomass fuel use with other respiratory symptoms, however, was suggestive for an association but was not statistically significant.

Studies on the effects of biomass smoke typically focus on two pollutants, namely PM and CO. PM < 10 μm (PM₁₀), and especially those < 2.5 μm (PM₂.₅), can penetrate deep into the lung where they cause morphologic and biochemical changes. Acute exposure to PM causes bronchial irritation, inflammation, and reduced mucociliary clearance.⁶ In laboratory animals, PM are immunosuppressive, possibly by inhibiting macrophage responses.⁷⁻⁸ The US EPA standard for 24-hour average PM₁₀ exposure is 150 μg/m³.²¹ In houses that use biomass fuel, the mean 24-hour PM₁₀ levels have been shown to be 300–3,000 μg/m³, but can reach up to 30,000 μg/m³.²² Biomass fuel use by participants in our study produced similar household PM levels.

Inhaled CO has systemic biologic effects by binding with hemoglobin to produce carboxyhemoglobin that reduces oxygen delivery to vital tissues.⁴ As a result, chronic CO exposure is thought to contribute to low birth weight and an increase in perinatal deaths. A study in rural Guatemala showed that babies born to women using biomass fuel for cooking were 63 g lighter than those born to women using gas and electricity (P = 0.049).⁵ The EPA 8-hour CO standard is an average of < 9 ppm.²³ Mean CO concentrations in homes that use biomass fuel are typically in the range of 2–50 ppm, but can be as high as 500 ppm during cooking.²² Similar CO levels were produced by biomass fuel in our study.

A systematic review on ambient air pollution and infant mortality showed conflicting results, with some studies finding little or no increase in infant mortality with increases in ambient pollution.²⁴ However, studies examining the specific causes of infant mortality found a significant association between respiratory-related mortality and ambient PM concentration.²⁵⁻²⁷ These studies typically have been the basis for estimating the effect of air pollution from biomass smoke on global infant mortality and child health. This approach, however, may not adequately assess the unique relationship between infant mortality and indoor concentrations of biomass smoke.¹⁰

Few studies have examined the relationship between infant mortality and IAP from biomass smoke. One hospital-based, case-control study in India considered exposure to cooking smoke as one of many risk factors for perinatal mortality.¹² In that study, exposure to IAP was significantly associated with mortality in univariate analysis but did not retain significance after adjusting for potential confounding factors. A later unpublished analysis was conducted based on a national health survey in India to examine the association between household conditions and mortality in children < 5 years of age.¹³ A significantly increased risk of mortality was found for children living in households that cooked with unclean fuels such as wood, dung, or crop residues, after controlling for potential confounders. Another unpublished study examined the impact of biomass fuel on infant and child mortality across 108 countries.¹⁴ In this study, countries that used a higher percent of biomass fuel use for domestic energy also had a higher percent of infant and child mortality. Our data support the conclusions of previous unpublished studies and is the first to show a significant trend between higher infant mortality and greater use of biomass fuel.
A review of published evidence relating IAP and acute lower respiratory infections in children revealed an increased risk of respiratory infections with biomass use in 10 of 15 studies examined (OR range, 2.2–9.9). The results of this study also found a significantly increased history of cough and earache with greater biomass use. Furthermore, a history of earache among children remained significantly associated with biomass use in our study after controlling for potential confounders. The fact that earache had the strongest association with biomass use may be because of the specificity of ear pain for upper respiratory infection, whereas the other symptoms examined may have a variety of causes. Several studies have shown a positive association between exposure to IAP and middle ear infections, showing similar ORs to those found in our study. One study in rural New York State reported an adjusted OR for otitis media of 1.73 (1.03–2.89) for exposure to wood-burning stoves.

The major limitations of this study include its cross-sectional design, which did not account for past exposure to IAP or recent changes in cooking methods. Although levels of CO and PM were assessed in a subset of households, personal exposures were not measured, and we did not evaluate individual differences in exposure duration or intensity. Because of inadequate health records in the community, several

**Table 2**

Multivariate logistic regression analysis for the association of cooking fuel with infant mortality among 80 households in Santa Ana, Ecuador

<table>
<thead>
<tr>
<th>Variable</th>
<th>OR*</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooking fuel</td>
<td>2.2†</td>
<td>(1.1, 4.1)</td>
</tr>
<tr>
<td>Socioeconomics</td>
<td>1.9</td>
<td>(0.5, 7.0)</td>
</tr>
<tr>
<td>Mother’s education</td>
<td>0.9</td>
<td>(0.3, 3.4)</td>
</tr>
<tr>
<td>Smoking in the home</td>
<td>1.2</td>
<td>(0.4, 3.6)</td>
</tr>
<tr>
<td>No. individuals/household</td>
<td>1.1</td>
<td>(0.8, 1.4)</td>
</tr>
</tbody>
</table>

*Reference groups are cooking with LPG only, higher than median SES, higher than median level of mother’s education, and no smoking in the home.
† P < 0.05.
Multivariate logistic regression analysis for the association of biomass fuel use with respiratory symptoms among 212 children living in Santa Ana, Ecuador

<table>
<thead>
<tr>
<th>Variable</th>
<th>Cough OR*</th>
<th>95% CI</th>
<th>Sore throat OR*</th>
<th>95% CI</th>
<th>Fever OR*</th>
<th>95% CI</th>
<th>Earache OR*</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooking fuel</td>
<td>1.2</td>
<td>(0.9, 1.8)</td>
<td>1.3</td>
<td>(0.9, 1.8)</td>
<td>1.1</td>
<td>(0.8, 1.6)</td>
<td>1.9†</td>
<td>(1.2, 3.0)</td>
</tr>
<tr>
<td>Socioeconomics</td>
<td>0.9</td>
<td>(0.4, 1.7)</td>
<td>0.5</td>
<td>(0.3, 1.1)</td>
<td>1.0</td>
<td>(0.5, 1.9)</td>
<td>0.8</td>
<td>(0.3, 1.8)</td>
</tr>
<tr>
<td>Mother’s education</td>
<td>2.0†</td>
<td>(1.0, 3.9)</td>
<td>2.0</td>
<td>(0.9, 4.1)</td>
<td>2.3†</td>
<td>(1.1, 4.5)</td>
<td>0.9</td>
<td>(0.4, 2.1)</td>
</tr>
<tr>
<td>Smoking in the home</td>
<td>1.2</td>
<td>(0.4, 3.6)</td>
<td>0.5</td>
<td>(0.3, 1.0)</td>
<td>0.8</td>
<td>(0.4, 1.4)</td>
<td>0.7</td>
<td>(0.3, 1.6)</td>
</tr>
<tr>
<td>No. individuals/household</td>
<td>0.9</td>
<td>(0.8, 1.1)</td>
<td>1.0</td>
<td>(0.9, 1.2)</td>
<td>1.0</td>
<td>(0.8, 1.1)</td>
<td>1.0</td>
<td>(0.8, 1.2)</td>
</tr>
<tr>
<td>Age</td>
<td>1.0</td>
<td>(0.9, 1.1)</td>
<td>1.1†</td>
<td>(1.0, 1.2)</td>
<td>1.0</td>
<td>(0.9, 1.0)</td>
<td>1.0</td>
<td>(1.0, 1.2)</td>
</tr>
<tr>
<td>Sex</td>
<td>1.5</td>
<td>(0.9, 2.8)</td>
<td>0.9</td>
<td>(0.1, 1.7)</td>
<td>1.2</td>
<td>(0.7, 2.1)</td>
<td>1.4</td>
<td>(0.7, 2.7)</td>
</tr>
</tbody>
</table>

* Reference groups are cooking LPG only, higher than median SES, higher than median mother’s level of education, no smoking in the home, and men.
† P < 0.05.

Factors related to infant mortality could not be assessed or statistically controlled for (low birth weight, sex of infant, maternal age, parity, and causes of infant death). Furthermore, because the analysis was retrospective, there is potential for recall bias to influence the results. Last, the study was limited by the small sample size in each cooking category as evident by the relatively large confidence intervals of the ORs.

In conclusion, the results of this study contribute to an understanding of the association of IAP with infant mortality and respiratory disease in children. These results suggest an exposure–response relationship between IAP and infant mortality. Further research is warranted to study the causal relationship between IAP and infant mortality using longitudinal methods and medical records to determine the specific causes of death.

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REFERENCES

25. Penna ML, Duchiaide MP, 1991. Air pollution and infant mortal-


