

# Indoor biofuel air pollution and respiratory health: the role of confounding factors among women in highland Guatemala

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**Background** A number of studies have reported associations between indoor biofuel air pollution in developing countries and chronic obstructive lung disease (COLD) in adults and acute lower respiratory infection (ALRI) in children. Most of these studies have used indirect measures of exposure and generally dealt inadequately with confounding. More reliable, quantified information about this presumed effect is an important pre-requisite for prevention, not least because of the technical, economic and cultural barriers to achieving substantial exposure reductions in the world's poorest households, where ambient pollution levels are typically between ten and a hundred times higher than recommended standards. This study was carried out as part of a programme of research designed to inform the development of intervention studies capable of providing quantified estimates of health benefits.

**Methods** The association between respiratory symptoms and the use of open fires and chimney woodstoves ('planchas'), and the distribution of confounding factors, were examined in a cross-sectional study of 340 women aged 15–45 years, living in a poor rural area in the western highlands of Guatemala.

**Results** The prevalence of reported cough and phlegm was significantly higher for three of six symptom measures among women using open fires. Although this finding is consistent with a number of other studies, none has systematically examined the extent to which strong associations with confounding variables in these settings limit the ability of observational studies to define the effect of indoor air pollution adequately. Very strong associations ( $P < 0.0001$ ) were found between the type of fire and a number of household and socioeconomic factors including the arrangement of rooms, floor type, and possession of a radio and television. The spouse's economic activity type was also significantly associated ( $P < 0.05$ ). Thus, while 82% of open fire users had dirt floors and only 18% cement or tile floors, the situation was reversed for plancha users, only 16% of whom had dirt floors.

**Conclusions** Confounding presents a substantial problem for observational studies of indoor air pollution and health, although there is a reasonable case for believing that the observed association is causal. Intervention studies are required for stronger evidence of this association, and more importantly, to determine the size of health benefit achievable through feasible exposure reductions.

**Keywords** Biofuel smoke exposure, respiratory illness, confounding, observational studies, intervention studies

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It is estimated that around 50% of the world's population, and 75% of those living in developing countries, rely on biomass fuels (wood, dung and crop residues) for cooking and heating.<sup>1</sup> These biofuels are usually burnt in open fires or simple stoves which result in very high levels of exposure, particularly for

women and young children.<sup>2-10</sup> A number of studies have reported associations between exposure to this indoor air pollution (IAP) and COLD in adults (especially women) and ALRI in children.<sup>2,5,11-21</sup>

Few of these studies on health effects made direct measurements of exposure, relying instead on proxy measures such as type of fuel used in the home, reported hours near the fire, or carriage on the mother's back. A further weakness has been the inadequacy with which confounding factors have been assessed and adjusted for,<sup>16</sup> although it has been recognized confounding does present a particularly difficult problem for observational studies of this topic.<sup>20</sup> The reason for this is that households adopting cleaner stoves or more advanced fuels often differ very markedly in many other respects, mainly reflecting higher socioeconomic status. Along with reductions in exposure, there may be marked changes in living conditions such as income, house construction, nutritional status, etc., many of which influence respiratory health directly or indirectly. If these factors differ very substantially between users of open fires and those adopting improved stoves or cleaner fuels, then the ability of descriptive studies to measure and adjust for confounding can be severely limited. This is one key advantage of randomized intervention studies, which have been recommended in order to define more precisely the health effects of domestic biomass pollution in developing countries.<sup>13,21</sup> In 1992, the World Health Organization began to examine the feasibility of carrying out controlled intervention studies, designed to assess the effects on key child and adult respiratory health outcomes of a measured reduction in exposure. This has formed part of a review carried out by WHO of potential ALRI prevention strategies, which would complement case management.<sup>22</sup>

This study of respiratory symptoms among women in western Guatemala<sup>23</sup> was carried out as part of the development work for this intervention study. The objectives of the current study were: (1) To describe the prevalence of respiratory symptoms in women of childbearing age. (2) To assess the strength of association between the type of stove and factors which may confound the stove and respiratory health relationship. (3) To examine the association between respiratory symptoms and stove type, allowing (so far as possible) for the effects of confounding.

## Methods

The sample was drawn from 16 of the 20 'housing clusters' (casarios), and part of the central town in the district of Concepcion. The other four casarios were not included as very few households used improved stoves. Concepcion is a poor, rural area in the highlands of Guatemala (altitude range 2500-2800 m), with a population of 10 500: most families burn wood on open fires, with around 10-15% using chimney stoves, and a few using gas. The climate includes a cool rainy season from May to November, and a dry colder season with regular night frost.

Households using 'planchas' (wood burning chimney stoves) were identified, and if agreement to the study was obtained, the nearest household with an open fire was approached. Eligibility criteria were that the woman was the principal cook, a non-smoker and had no serious illness; in practice very few women smoke, and few women were excluded on the latter criterion: it was seen more as a means for women to express their wish not to be involved, and this was rarely due to illness. One woman

known to have TB was excluded. Pregnant women were not excluded.

Respiratory questions were based on the Medical Research Council 1986 questionnaire,<sup>24</sup> which had been back-translated from Spanish. Definitions of symptoms included morning and daytime cough or phlegm in winter, and cough or phlegm in winter for as much as 3 months. The local understanding of winter is the cool wet season between May and September, viewed by local women as the worst time of year for illness. Levels of pollution in these houses using an open fire are high,<sup>25</sup> with typical 24 h mean PM10 levels (particulates <10 microns diameter) of 700-1200 µg/m<sup>3</sup>. Although planchas are capable of markedly reducing indoor air particulates,<sup>25</sup> a high proportion of the planchas were in a functionally inadequate state having been poorly made, installed or maintained.

Odds ratios for the associations between stove type and presence of respiratory symptoms, expressed as either present or absent, have been derived using logistic regression in SAS.

## Results

A total of 181 women using an open fire and 160 using a plancha were studied. The mean age of the women was 28.0 years for the open fire group, and 27.9 years for the plancha group, with a range of 15 to 45 years. Five of the women (1.3%) smoked cigarettes, but the amount smoked was very small. There was no significant difference between the proportion of open fire and plancha households reporting that someone (other than the index woman) smoked while in the home (16.1% and 13.6% respectively,  $P = 0.64$ ).

### Association between respiratory symptoms and stove type

Complete data were available for 173 women using open fires and 148 using planchas. Table 1 shows the prevalence of respiratory symptoms for all women, and by stove type. The prevalence of chronic cough rose with age from 2.0% at 15-24 years to 9.5% at 35-45 years. The prevalence of all respiratory symptoms was lower among women using plancha stoves, significantly so for morning and daytime cough, and for daytime phlegm.

**Table 1** Numbers (%) of women reporting respiratory symptoms, by type of stove

| Symptom                                     | All women<br>n (%) | Stove type    |                  | P-value |
|---------------------------------------------|--------------------|---------------|------------------|---------|
|                                             |                    | Open<br>n (%) | Plancha<br>n (%) |         |
| <b>Cough</b>                                |                    |               |                  |         |
| (a) Mornings, in winter                     | 110 (34.3)         | 70 (40.5)     | 40 (27.0)        | 0.016   |
| (b) Daytime, in winter                      | 57 (17.8)          | 40 (23.1)     | 17 (11.5)        | 0.010   |
| If (a) or (b) was this<br>for 3 months/year | 12 (3.7)           | 9 (5.2)       | 3 (2.0)          | 0.23    |
| <b>Phlegm</b>                               |                    |               |                  |         |
| (a) Mornings, in winter                     | 110 (34.3)         | 66 (38.1)     | 46 (31.1)        | 0.23    |
| (b) Daytime, in winter                      | 53 (16.5)          | 38 (22.0)     | 15 (10.1)        | 0.007   |
| If (a) or (b) was this<br>for 3 months/year | 26 (8.1)           | 18 (10.4)     | 8 (5.4)          | 0.15    |

See text for full definitions of symptoms.

**Table 2** Distribution of household possessions and structure by type of stove. The kitchen design describes whether the kitchen is combined with the sleeping and eating areas, attached (but a different room), or separated

| No. (%) with characteristic | Stove type         |                  | P-value          |
|-----------------------------|--------------------|------------------|------------------|
|                             | Open fire<br>n (%) | Plancha<br>n (%) |                  |
| <b>Radio</b>                | 113 (62)           | 137 (86)         | <0.0001          |
| <b>Television</b>           | 22 (12)            | 49 (31)          | <0.0001          |
| <b>Fridge</b>               | 2 (1)              | 6 (4)            | 0.1 <sup>a</sup> |
| <b>Floor material</b>       |                    |                  | <0.0001          |
| Dirt                        | 149 (82)           | 26 (16)          |                  |
| Poured cement               | 32 (18)            | 119 (75)         |                  |
| Tile/brick                  | 0 (-)              | 13 (8)           |                  |
| <b>Kitchen design</b>       |                    |                  | <0.0001          |
| Combined                    | 44 (24)            | 17 (11)          |                  |
| Attached                    | 39 (22)            | 76 (48)          |                  |
| Separated                   | 96 (54)            | 66 (41)          |                  |

<sup>a</sup> Fisher's exact test.

### Household and socioeconomic characteristics of homes

The household characteristics selected for analysis are those describing the construction materials and layout of the home, and basic consumer goods including radio, television and fridge. Table 2 shows that there were very strong associations between all of these factors and the type of stove ( $P < 0.0001$ ), with the exception of fridges (due to low ownership).

Women were asked about their own and their spouse's economic activity: around three-quarters of the women in both groups were involved in weaving/embroidery, and there were no important differences between the open fire and plancha groups in women's main type of economic activity. A more substantial ( $P = 0.041$ ) difference was found for the spouse's type of economic activity, with the plancha group having more involvement in business and trade.

### Potential for confounding

To confound the association between stove type and respiratory symptoms, these factors must also be risk factors for the health outcomes. In Table 2, floor material, believed to be a particularly important indicator of socioeconomic status, demonstrated an extremely strong association with stove type. The prevalence of all six symptoms among women living in houses with dirt floors was substantially higher than for those women living in houses with cement floors. For statistical analysis the cement and tile floor groups have been combined. Only the differences for morning cough reached statistical significance ( $P = 0.03$ ), although the  $\chi^2$  for two other symptoms were of marginal significance ( $P = 0.06$ ). Other variables such as possession of a radio and television showed similar associations with respiratory symptoms.

### Adjustment for confounding

The lower prevalence of respiratory symptoms among women using plancha stoves, following adjustment for age, is summarized by the odds ratios in Table 3 (column 1). These odds ratios are consistently well below unity, significantly so for three of the symptom categories. Stepwise regression of additional variables

**Table 3** Odds ratios (and 95% confidence intervals) for respiratory symptoms as outcomes, when using a plancha compared to open fire, adjusted for age only, and for age and a selection of indicators of socioeconomic circumstances

| Symptom         | Age-adjustment only |             | Age, radio, spouse activity |             |
|-----------------|---------------------|-------------|-----------------------------|-------------|
|                 | Odds ratio          | (95% CI)    | Odds ratio                  | (95% CI)    |
| Morning cough   | 0.55*               | (0.33–0.88) | 0.61(*)                     | (0.37–1.00) |
| Daytime cough   | 0.43**              | (0.23–0.80) | 0.50*                       | (0.26–0.96) |
| Cough 3 months  | 0.55                | (0.14–2.21) | 0.50                        | (0.11–2.28) |
| Morning phlegm  | 0.73                | (0.46–1.17) | 0.81                        | (0.49–1.34) |
| Daytime phlegm  | 0.40**              | (0.21–0.76) | 0.44*                       | (0.22–0.87) |
| Phlegm 3 months | 0.57                | (0.22–1.46) | 0.72                        | (0.26–1.98) |

(\*)  $P = 0.05$ , \*  $P < 0.05$ , \*\*  $P < 0.01$

showed that floor material (which was the variable most strongly associated with stove type), rendered the model too unstable for analysis.

Adjustment for possession of a radio and the economic activity of the spouse (Table 3, column 2), resulted in small increases in odds ratios for five of the symptoms and a decrease for one, with the same three remaining significant.

## Discussion

There has been no systematic review of the extent to which confounding may have limited the interpretation of observational studies examining the association between indoor air particulates and both adult and childhood respiratory illness. Where information on confounding has been reported however, there is supporting evidence that households with lower exposure demonstrate substantial differences in other important characteristics.

In Kenya and The Gambia, where almost all of the families use open fires, it has been reported that the variation in exposure was greater within houses over time than between houses.<sup>8,9</sup> This implies that in order to study health outcomes effectively, it is necessary to examine communities with substantial between-house differences in exposure, arising from the use of good chimney stoves or cleaner fuels. In addition to the present study, an example of a clear exposure distinction (by fuel type) was reported among slum households in Pondicherry in a study comparing biofuel, kerosene and gas users.<sup>16</sup> Biofuel users had lower income than kerosene and gas users, and there were differences in employment patterns and house construction. Thus, 54% of biofuel users lived in mud and thatch houses, compared to 29% of kerosene users and none of the gas users—the other type of house being of concrete block construction. No further data was reported to assess the importance of these differences in determining health outcomes.

Exposure was also clearly differentiated in a study of respiratory symptoms and woodsmoke exposure among two groups of children attending the same school in the highlands of Papua New Guinea.<sup>6</sup> Village children exposed to the traditional woodfires were compared with children of government employees who lived nearby but in homes constructed of more permanent materials and described as 'free from internal pollution (except cigarette smoke)'. This study found only minor differences in

symptoms and lung function, but illustrates well how in observational studies, individuals with very different exposure experience are likely to differ in other ways (children of subsistence peasant families compared to those of government employees). Further information about the socioeconomic characteristics of these two groups was not reported.

### Dealing with confounding

One approach to this problem would be to carry out a much larger study. This might be able to characterize the differences between exposure groups well enough to adjust for confounding, but this should not be taken for granted. In the Guatemala data, adjustment for confounding by type of floor requires that the effect of fire type be examined while floor type is held constant. However, there were relatively few plancha homes with dirt floors, so that the potential for examining the fire effect within the dirt floor category is very restricted. Also, and probably of greater importance, it appears that plancha users with dirt floors differ from plancha users with cement floors in complex ways that could include the quality, maintenance and usage of the stove, exposure patterns, etc., so that the plancha effect for cement floor houses may be rather different from that in dirt floor houses. One of the main reasons why some people had a plancha without the improvements to the house fabric, was because the stove had been installed without other changes to the house (e.g. by a non-governmental organization project). In this community, people initiating these changes themselves are generally better off, improve the fabric of the house first, and then install the plancha. This emphasises the potential for major differences in social characteristics, and in attitude towards the new stove.

It therefore becomes very difficult to determine whether health differences between open fire and plancha households are due to the fire type or the housing conditions, or underlying factors determining both. A 'plancha effect' that differs between dirt and cement floor households (for example) can in theory be examined and allowed for by testing for an interaction, but statistically this requires more power than the main effect. Thus, while some of these complex differences could be characterized in a large study, there is a limit to how far this can be taken in the analysis, as well as the nagging uncertainty that other factors associated with the household's ability and decision to install a plancha, and which could influence respiratory health, have not been fully understood and included.

### Conclusions

This investigation has highlighted a problem which is likely to be common to observational studies in many settings where substantial differences in levels of exposure exist between subgroups of the population arising from improved stoves or fuels.

In light of this, controlled intervention studies offer a powerful research option, since households using the improved stoves should not then differ (substantially) from those continuing to use open fires. It must be said however, that despite the uncertainty confounding brings to the question of whether biofuel smoke exposure causes COLD and ALRI, the weight of evidence does represent a reasonable case for this being so. This evidence is supplemented by that on urban outdoor particulate pollution<sup>26</sup> and environmental tobacco smoke.<sup>27</sup> The main area of

uncertainty lies with quantifying the dose-response relationship at the levels of exposure commonly experienced in developing countries with open fires and improved stoves.

This issue could be argued to be of little policy relevance if either a moderate reduction in exposure from these very high levels guaranteed useful health gain, or large and sustainable reductions in exposure were easy to achieve, but the former is uncertain and the latter very rarely the case. Thus, levels of particulate exposure in homes with so-called improved stoves (on the comparatively rare occasions where these have been measured) are reported to be lower than for traditional fires, but still in the range 1130 µg/m<sup>3</sup> total suspended particulates (TSP) to 4600 µg/m<sup>3</sup> TSP (personal monitoring during cooking).<sup>11,28</sup>

It is for these reasons that intervention studies involving direct measurement of exposure offer the best means of obtaining the information required to help drive the development and implementation of measures capable of reducing the very substantial global health burden believed to result from biofuel indoor air pollution.<sup>29,30</sup>

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