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Smoke exposure among women in Haiti: The case for improved stoves

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Abstract

Indoor smoke exposure is responsible for two million deaths per year and has been studied globally, but the impacts of exposure have not yet been evaluated in Haiti, the Western hemisphere's poorest nation. This study measures the disproportionate impact of indoor smoke exposure on the women and children of Haiti. We studied 2296 clinic patients in four Haitian villages to determine the extent of carbon monoxide (CO) exposure, using carboxyhemoglobin saturation in the blood as a proxy for overall smoke exposure. We predicted CO levels to be higher in women, who traditionally perform the majority of cooking duties, and in children who accompany their mothers. CO levels averaged 4.9% in women and 3.4% in men. Women of child-bearing age carried a minimum relative risk (RR) for CO exposure of 1.22, relative to all males and younger females. Older females carried no significant difference in risk. Children averaged the lowest CO exposure among all cohorts. These findings demonstrate the burden of indoor smoke exposure that falls disproportionately on women in these regions of Haiti. Global efforts to mitigate indoor exposure have demonstrated the health, economic, environmental and social improvements that are possible by tackling this problem.

Keywords

air pollution; indoor; smoke; women; biomass; stove

Introduction

Approximately half of the world's population and 90% of rural households cook with solid fuels, including woodfuel, charcoal, peat and other grains (Smith, 1987). Many of these families cook indoors or in poorly ventilated shacks, unnecessarily increasing their burden of smoke exposure. The WHO (2012a) states that indoor smoke exposure is responsible for the deaths of two million people per year. This makes it the eighth most important risk factor of the burden of disease worldwide, responsible for 2.7% of this global burden (Desai,

Mehta, & Smith, 2004). In fact, in developing countries with high mortality rate, indoor smoke exposure is responsible for 3.7% of the overall disease burden, making it the most lethal killer after malnutrition, unsafe sex and lack of safe water and sanitation (Bruce, Perez-Padilla, & Albalak, 2000). The recent landmark report on global disease burden, released by Lim et al. (2012), suggests these figures are underestimated, claiming 3.5 million deaths per year from household air pollution alone.

There is strong evidence linking household smoke exposure to acute respiratory infections, pneumonia, chronic obstructive pulmonary disease and lung cancer (Perez-Padilla, Schilmann, & Riojas-Rodriguez, 2010; Po, Fitzgerald, & Carlsten, 2011). Other adverse effects, including asthma, cataracts, tuberculosis, adverse pregnancy outcomes, cardiovascular disease and nasopharyngeal cancers, may also be associated with indoor smoke exposure (Perez-Padilla et al., 2010; Pope et al., 2010).

Women and young children tend to have an increased exposure to this indoor air pollution due to the traditional role that women have in food preparation, reportedly spending between three and seven hours each day cooking. Indeed, 59% of all deaths attributable to indoor air pollution occur in women (WHO, 2012a). Infants and young children are carried on the mother's back or otherwise kept in close proximity, giving them comparable exposure to smoke during their first years of life when developing airways are particularly vulnerable to hazardous pollutants. Beyond the physical health effects listed above, several studies and reviews have documented the adverse neurologic and cognitive effects in children from carbon monoxide (CO) exposure and its resultant hypoxia (Bass et al., 2004; Kim & Coe, 1987).

Efforts across the globe to reduce this indoor exposure and its resulting burden of disease have shown encouraging results, but motivation for change is often driven less by concerns about health than by more immediate community needs such as economic hardship. In areas like Haiti, where fuel must be collected from the local environment, women may spend hours per day obtaining cooking fuel. Deforestation in many parts of the world, often caused by fuel collection, has made this task more difficult. Increasing fuel prices worldwide reduces the economic viability of most alternatives. Currently, the poorest 20% of the population in some areas spend up to 20% of their disposable income on energy, most of it wood fuel (Barnes, Openshaw, Smith, & van der Plas, 1994). The social impact of fuel collection is equally important to address, as the time spent collecting fuel detracts from women's ability to perform the other tasks that make up their daily routine, such as food preparation, instruction and supervision of children, household maintenance and performance of other daily economic activities (Anonymous, 2010; WHO, 2012b). When children must gather fuel, it interferes with their ability to attend school and study. Spending this amount of time on fuel collection interferes with a family's ability to integrate itself within a social network, which has negative consequences for a family's resilience and resistance to stress.

Stove programmes designed to introduce innovative, low-tech cooking technologies have been implemented in various countries over the past decades to address these economic, environmental and social issues (Barnes et al., 1994). Reductions in CO and particulate

matter exposure have been effectively demonstrated from ventilation and technologic improvements. In addition, directly associated health benefits from improved stove units have been measured in the highlands of Guatemala, an area with comparable geographic and cultural features to rural Haiti. A natural experiment by Harris, Weeks, Chen, and Layde (2011) demonstrated a 45% decreased incidence of clinic visits due to lower-respiratory illnesses per year in addition to a 26% decrease in visits due to chronic respiratory illness over the course of only 4 years. Smith et al. (2011) performed a true randomised control trial in the same region, demonstrating possible reductions in childhood mortality but failing to show significant reduction in the incidence of pneumonia from chimney stoves alone. This evidence offers promising potential health benefits and has crucial implications for growth and development in a place like Haiti, a country that has had minimal exposure to these innovative and effective low-tech solutions. Promising global initiatives, such as the Global Alliance for Clean Cookstoves, provide much-needed resources to expand the reach of clean and efficient Cookstoves (Martin, Glass, Balbus, & Collins, 2011).

In this study, we examine the impact of cooking fuel type and kitchen location on the level of smoke exposure for women and children relative to their older, male counterparts, in three regions in Haiti. This is a cross-sectional study of a convenience sample of clinic patients from 2008 to 2010 to determine the extent of smoke exposure in the population. CO exposure is used as a proxy for overall smoke exposure, as it is well correlated with exposure to multiple pollutants in smoke (Naeher, Leaderer, & Smith, 2000; Northcross, Chowdhury, McCracken, Canuz, & Smith, 2010; Reinhardt & Ottmar, 2004). We hypothesise that women and children have higher blood levels of CO than males and adults, respectively, because of their roles in food preparation and cooking. A higher level of CO exposure would thereby indicate increased smoke exposure and an increased risk of smoke-related adverse health outcomes.

Establishing the burden of smoke exposure would provide the opportunity for a randomised, controlled intervention similar to the one used in Guatemala.

Methods

Data collection

Subjects were approached at medical clinics conducted by volunteer providers in three rural locations in the southern peninsula of Haiti surrounding the city of Leogane, as well as at Hopital Ste. Croix, a hospital in the city of Leogane itself. The first of the three rural clinics was in Petit Harpon, a small community that can be reached by an all-wheel-drive vehicle in the dry season, although most patients in the area travel on foot. The Camatin building was near a main road between Leogane and Jacmel and accessible by vehicle, although nearly all patients arrived on foot. The final rural clinic was in L'Azil, a small town that is a three-hour walk from the nearest road. For those enrolled at the hospital in Leogane, most patients arrived at the hospital by motorcycle or taptap (taxi).

Patients presenting voluntarily to clinics for treatment were offered screening for CO exposure. After patients were evaluated by a provider and were waiting to receive their prescriptions from the clinic's pharmacy, they were enrolled in the study. This was done to

avoid the perception that quality of care was contingent on participation in the study. One of three trained interpreter/provider pairs collected a verbal informed consent and collected data.

Upon completion of the CO screening, patients then answered a short oral survey and provided their age. Questions in the survey addressed what fuels are used for cooking, whether the individuals cooked indoors or outdoors, whether they smoked, and how much time had passed since their last exposure to cooking smoke. Trained clinic staff recorded all data.

CO measurement

We use CO as a proxy for smoke exposure. CO, a by-product of incomplete organic combustion, is produced in the amount of 5 g/meal when cooking fuels such as coal or wood are used (Smith, Samet, Romieu, & Bruce, 2000). It is an odourless and colourless gas that enters the body through inhalation. Within the body, it binds to haemoglobin, the molecule that is chiefly responsible for carrying oxygen in the blood stream. CO binds to haemoglobin to form carboxyhemoglobin (COHb) with an affinity that is 200 times that of oxygen. It has a half-life in the body of approximately four hours. Toxic levels of COHb cause headache, malaise, fatigue, cardiac arrhythmias, hallucinations, confusion, unconsciousness and even respiratory arrest and death. Normal COHb saturations are less than 2% for healthy, adult non-smokers and less than 5% for smokers.

CO screening was performed using a Rad 57 CO-oximeter. The CO-oximeter is a non-invasive instrument that, when placed on the finger, uses different wavelengths of infrared light to record levels of oxyhaemoglobin and COHb in the blood stream. The co-oximeter sensor was placed on the finger, and after 60–90 seconds, a measurement of percent CO saturation was obtained and recorded.

All data analyses were done using Stata versions 10.0 and 11.0.

Analysis

We began our interpretation with a univariate analysis of characteristics potentially associated with increased levels of CO, and therefore smoke, exposure. Because we hypothesised that women will have greater smoke exposure due to cooking responsibilities, we also adjusted summary statistics by age and gender.

We then estimated multivariate regression where the outcome was percent of COHb saturation (measured discretely due to equipment used). The explanatory variables in our model included factors salient to our research questions. Gender and age are the primary focus of our study, so we measured the effect of gender and included five separate age categories to discover the disparate effect of smoke exposure on varying age groups. Ages 0–2 represented less mobile infants and toddlers that spend a greater amount of time next to their mothers and are therefore likely exposed more to cooking smoke. Ages 3–8 represented more mobile children with limited household duties, while ages 9–15 represented pre-fertility children who are able to help more with household duties and may

be at school. Ages 16–40 were considered child-bearing age and subjects older than 40 were considered post-childbearing age. Also, we included a series of indicators for the primary type of fuel used in cooking. Wood was used as the reference group, the other groups being charcoal and all other fuels. In addition, we included an indicator for whether the subject cooked outdoors because this could affect smoke exposure. Finally, we included an indicator for smoking status to help control for the effects of tobacco smoke. Therefore data were adjusted for age, gender, type of fuel used, stove location and smoking. All models included clinic random effects due to the possibility that systematic unobserved factors lead to differences in population behaviour with regard to fuels used, cooking, means of transportation to clinic, exposure to other sources of CO, or other health behaviour that may exist between regions in Haiti.

Because the outcome measure was bounded and discrete, regression methods other than ordinary linear regression were more appropriate for analysing these data. We used random effects negative binomial models for each of the estimations, as this distribution best fits data where the mode of the independent variable (CO level, in this case) is 0. The likelihood ratio test of the overdispersion parameter, alpha, indicated that the negative binomial was the appropriate specification.

Results

A total of 2296 patients were screened, interviewed and entered into the database. Table 1 shows the sample characteristics. Patients ranged in age from 2 months to 111 years old, with 1520 (66%) female and 776 (34%) male. Of these, almost all (87.4%) women cooked, in contrast to just under half (42.4%) of men. Smoking prevalence was low, with 2.3% of females and 4.6% of males reported as smokers. COHb saturations ranged from 0% to 38%, averaging 4.9% (median of 4%) in women and 3.4% (median of 2%) in men. Many of the patients with markedly elevated CO levels were symptomatic with headaches and malaise. Wood was the primary fuel source for over half (57.8%) of respondents, while charcoal was used by 37.5%; less than 5% of respondents used a different source of fuel. This fuel was either used on an indoor stove (38%) or an outdoor stove (61.1%).

The marginal effects from the negative binomial estimations using facility random effects are shown in Table 2. Women of child-bearing age were the most prevalent subgroup, so they were used as a reference group. The relative risk (RR) of CO exposure was decreased for all groups, including men of the same age (RR =0.82, 95% CI =0.71–0.95). Interestingly, RR for children fell with age, as girls (RR =0.21, 95% CI =0.13–0.36) and boys (RR =0.19, 95% CI =0.09–0.37) from ages 0–2 had the lowest RR among all subgroups. Using wood compared to other sources did not produce a significant difference in recorded CO saturation, nor did the location of the kitchen or the smoking status of the respondent.

Discussion

This study aimed to demonstrate the increased burden of smoke exposure to women and children in the region surrounding the city of Leogane. Our analysis supported this hypothesis in women, as the RR for CO saturation fell for all age and gender subgroups,

compared to women of child-bearing age. This did not hold for children, who demonstrated a paradoxical decrease compared to their elder counterparts. In sensitivity analysis we included different specifications of age with similar results. Young children had decreased CO levels and therefore reduced smoke in the home, contrary to our hypothesis of increased exposure. Results should have been similar to the expected effect shown in females if young children spent significant time with their mothers – especially infants, traditionally wrapped close to the mother's body. Possible explanations for these contradictory results include: behaviour, as children may not have been present in the kitchen as often as expected; stove placement, where the fire and smoke settled above the young children and exposure was mostly avoided; and an inadequate sample size.

These results support the strategy of the Global Alliance for Clean Cookstoves, a public–private partnership with \$50 million dollars contributed by the US government alone. Along with over 30 additional countries and hundreds of private entities, they support the development of clean stove technology with the direct involvement from local women to design the stove, test and train others in their home communities (Martin et al., 2011).

Cooking methods had no direct impact on CO saturation in this study, as participants with wood-fuelled stoves and indoor kitchens showed no significant differences in CO saturation. While no hypothesis was made regarding these conditions, it was logical to predict that CO levels would have decreased if the stove was moved to an area with no roof and therefore less smoke accumulation. One explanation for a lack of significant correlation could lie in the use of the word 'outside,' as many kitchens were situated in an area separate from the living space but were still enclosed. Ventilation in these 'outside' structures was often limited, consisting of only the space between the wooden planks serving as walls. Few homes appeared to be ventilated with any type of chimney structure that allowed for smoke to dissipate through the roof. Further attempts to explore this relationship will benefit from a more clearly defined and translated use of this concept.

Smoking, a ubiquitous topic in any study that deals with smoke exposure, carried a RR of 1.17, but this difference was not significant (95% CI = 0.94–1.45). Overall the prevalence of smoking was low in Haitian adults at the time of this study, as only 10.7% of males and 8.6% of females in the country were reported smokers (Mackay & Eriksen, 2002). We controlled for this variable in our analysis, thereby eliminating confounding effects.

Limitations

There are several limitations to this study. First, our equipment measured COHb saturation as a discrete variable, limiting the effectiveness of these values. This was a necessary sacrifice to accumulate ample data, however, since its portable nature made data collection across the country in rural areas much more feasible. Previous evidence indicating the potential inaccuracies of the Rad-57 CO-Oximeter at COHb concentrations below 5% should be noted as well (Lam et al., 2011). Blood COHb was related to inhaled exposure with respect to both CO concentration and exposure duration, and significant variation in either parameter could have been a large influence on measured blood levels. For example, a subject exposed to high CO levels over a short period of time may have presented with a

similar COHb reading as a subject exposed to low CO levels over several hours. Real-time monitoring of air CO levels in the home of a given subject and more precisely recording the duration of exposure could have accounted for such variation.

Besides this indoor smoke exposure, environmental sources of CO may have contributed to the measured COHb levels. Environmental tobacco smoke, taptap exhaust, diesel engines and outdoor trash burning all contribute CO to local airspace. The majority of the subjects in this study lived in more remote areas and would likely have had minimal exposure to these other exogenous sources of CO, rendering their influence on our analysis minimal. There were, however, cases of patients who reported no cooking history yet recorded high levels of CO saturation, some symptomatic with headaches and nausea. Several subjects likely travelled to clinic via moto or taptap, leading to significant environmental CO exposure and providing confounding results. Since we did not record method of transportation to the clinic, distance travelled or ask about specific potential exposures, we aimed to control for other possible sources of CO exposure through applying a clinic fixed effects model, grouping locations and their unique environmental exposures together.

Further, despite an identical survey and clinic fixed effects, language translators varied among clinic locations. This had the potential to affect results due to differential phrasing of survey questions. For example, though we initially surveyed subjects to determine time since the last cooking event, significant variability was detected in how translators presented this question to subjects and these data were ultimately not included in our analysis. While we tried to limit variability by using a small number of trained interpreter/provider pairs, allowing for a small amount of variation enabled us to expand our reach across the country and increase our sample size.

A further consideration in interpreting our results is that our evaluation of smoke exposure likely underestimates the full health burden of cooking with biofuels. Indoor combustion of biomass fuels such as wood and charcoal has also been shown to release high levels of endotoxin and other bioaerosols (Semple et al., 2010). Bioaerosols act as inflammogens that induce a state of inflammation in the airway and lungs, predisposing affected individuals to further respiratory illness. Any evaluation of disease burden due to indoor smoke exposure should include these factors.

Conclusion

Smoke exposure in rural areas of developing nations is a significant cause of morbidity and mortality. By measuring an easily obtained proxy for smoke exposure in COHb with a convenience sample, we effectively highlighted a concern in the high-risk subset of Haitian women, providing an impetus for further action. Additional work in this area will more directly relate smoke exposure with disease. While future studies will aim to provide evidence towards a similar exposure burden on children, the implications do not change. Interventions that target cooking will not only directly affect smoke-related disease in women, but also have the potential to indirectly improve social, economic, and environmental factors, and thus overall quality of health and life. Further research to expand the connection can effectively prove a need for funding innovative, cost-effective changes in

cooking across Haiti. This opportunity to provide widespread, multifaceted societal benefits with inexpensive methods must be pursued.

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Table 1

Sample summary statistics.

	Full sample	Females	Males	N
CO level	4.41	4.90	3.35	2296
<i>Age</i>				
0–2	1.86	2.37	0.79	126
3–8	1.79	2.20	1.33	223
9–15	3.09	2.99	3.21	335
16–40	5.16	5.44	4.04	885
41+	5.13	5.64	3.98	727
<i>Primary fuel source</i>				
Wood	77.7%	79.9%	73.7%	
Charcoal	16.2%	16.0%	16.5%	
Other	6.1%	4.1%	9.8%	
<i>Smoke exposure</i>				
Smoker	3.1%	2.3%	4.6%	
Cooks	72.5%	87.4%	42.4%	
<i>Kitchen location</i>				
Outside	34.8%	34.9%	34.7%	
Inside	61.0%	62.6%	57.8%	
Unknown	4.2%	2.5%	7.5%	
Total	2296	1520	776	

Table 2

RR of the impact of CO exposure.

RR of CO exposure (95% CI)	
<i>Females (relative to females age 16–40)</i>	
Age 0–2	0.21 (0.12–0.36)
Age 3–8	0.34 (0.26–0.44)
Age 9–15	0.50 (0.42–0.60)
Age 41+	1.05 (0.95–1.16)
<i>Males (relative to females age 16–40)</i>	
Age 0–2	0.19 (0.09–0.37)
Age 3–8	0.26 (0.20–0.35)
Age 9–15	0.55 (0.45–0.66)
Age 16–40	0.82 (0.71–0.95)
Age 41+	0.81 (0.71–0.93)
Smoker (relative to non-smokers)	1.17 (0.95–1.45)
<i>Fuel source effects (relative to wood)</i>	
Charcoal	1.05 (0.93–1.19)
Other	1.13 (0.86–1.49)
<i>Food cooking location (relative to outside)</i>	
Inside kitchen	0.98 (0.89–1.07)
Unknown	0.92 (0.63–1.32)
<i>N=2222</i>	

Note: Regression completed using negative binomial estimates and facility random effects with bootstrapped standard errors.