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Indoor air pollution, cookstove quality, and housing characteristics in two Honduran communities

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ABSTRACT

Elevated indoor air pollution exposures associated with the burning of biomass fuels in developing countries are well established. Improved cookstoves have the potential to substantially reduce these exposures. However, few studies have quantitatively evaluated exposure reductions associated with the introduction of improved stoves, likely due to the cost and time-intensive nature of such evaluations. Several studies have demonstrated the value of estimating indoor air pollution exposures by evaluating personal cooking practices and household parameters in addition to stove type. We assessed carbon monoxide (n=54) and fine particulate matter ($PM_{2.5}$) (n=58) levels among non-smoking Honduran women cooking with traditional or improved wood-burning cookstoves in two communities, one semi-urban and one rural. Exposure concentrations were assessed via 8-h indoor monitoring, as well as 8-h personal $PM_{2.5}$ monitoring. Housing characteristics were determined to indicate ventilation that may affect carbon monoxide and $PM_{2.5}$. Stove quality was assessed using a four-level subjective scale representing the potential for indoor emissions, ranging from poorly functioning traditional stoves to well-functioning improved stoves. Univariately, the stove scale as compared to stove type (traditional versus improved) accounted for a higher percent of the variation in pollutant concentrations; for example, the stove scale predicted 79% of the variation and the stove type predicted 54% of the variation in indoor carbon monoxide concentrations. In multivariable models, the stove scale, age of the stove, and ventilation factors predicted more than 50% of the variation in personal and indoor $PM_{2.5}$ and 85% of the variation in indoor carbon monoxide. Results indicate that using type of stove alone as a proxy for exposure may lead to exposure misclassification and potentially biased exposure and health effects relationships. Utilizing stove quality and housing characteristics that influence ventilation may provide a viable alternative to the more time- and cost-intensive pollutant assessments for larger-scale studies. Designing kitchens with proper ventilation structures could lead to improved indoor environments, especially important in areas where biomass will continue to be the preferred and necessary cooking fuel for some time.

1. Introduction

More than half of the world's population still relies on biomass combustion to meet basic domestic energy needs (Rehfuess et al., 2006). Cooking in many developing countries usually consists of burning solid fuels over an open fire or in a poorly functioning traditional stove (Rehfuess et al., 2006). Improved stoves have been designed to burn fuel more efficiently and have usually incorporated a chimney or flue. These new designs have the potential to substantially reduce pollutant emissions and indoor air pollution exposures (Albalak et al., 2001; Bruce et al., 2004; Ezzati and Kammen, 2002; Khushk et al., 2005; Naeher et al., 2000a, 2000b; Smith, 2002; Zuk et al., 2007); however, evaluations of improved stoves are limited (Saksena and Smith, 2003; Smith, 2002).

Research on the health effects of indoor air pollution from the burning of biomass is limited by a lack of quantitative exposure assessments (Bruce et al., 1998, 2002; Chauhan and Johnston, 2003; Ezzati and Kammen, 2001; Smith, 2002). Many investigators rely on indirect measures of personal exposure, such as stove type or fuel. Because the use of biomass for cooking and heating is so common in rural areas of developing countries, many people are grouped into a single exposure category (Ezzati and Kammen, 2001). In reality, there are large variations in emissions from specific stove types (Ballard-Tremeer and Jawurek, 1996; Naeher et al., 2000a), as well as

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large variations in exposure profiles of individuals residing in the same households (Ezzati et al., 2000; Saksena et al., 1992). These variations are due to different types and qualities of stoves and fuels, housing characteristics (i.e. ventilation), cooking and heating methods, differences in time-activity patterns, and season (Balakrishnan et al., 2002; Smith et al., 2004). Indirect exposure assessments and groupings of people most likely lead to risk estimates that are poorly quantified and subject to bias (Bruce et al., 2002; Ezzati and Kammen, 2001).

Housing and stove conditions may greatly influence concentrations of pollutants (Begum et al., 2009; Bruce et al., 2004, 2002; Dasgupta et al., 2009; Desai et al., 2004; Riojas-Rodriguez et al., 2001; Smith, 2002). Investigators of one study in Mexico reported that the use or non-use of the improved stove, the number of windows in the kitchen, and the amount of firewood used best explained the variation in PM_{10} (particulate matter less than 10 μm in diameter) concentrations measured several meters from the stove; however, these variables accounted for only a quarter of the variation in PM_{10} (adjusted R^2=0.26) (Riojas-Rodriguez et al., 2001). A larger sample size and the use of stoves emitting a wider range of pollutants may result in models accounting for a higher percentage of the variation (Riojas-Rodriguez et al., 2001). Fuel type, kitchen type, and proximity to the stove during cooking were associated with concentrations of respirable particulate matter in India (Balakrishnan et al., 2002). The investigators stressed the need for further assessment of factors such as room/window dimensions, fuel quantity, and ventilation levels to allow for a better evaluation of the most important determinants of indoor air pollution exposures in households (Balakrishnan et al., 2002). Although quantitative exposure assessments are ideal, larger studies will be more feasible if investigators can confidently utilize the more easily collected housing and stove condition variables as exposure surrogates.

We conducted a cross-sectional investigation to quantify indoor air pollution exposures in homes with traditional and improved stoves and to identify factors contributing to elevated indoor air pollution levels among women in Honduras. We evaluated the contribution of domestic factors (cooking practices and housing conditions) to measured indoor and personal air pollution concentrations and developed a four-level subjective stove scale representing potential for indoor emissions in order to assess the variation within stove types.

2. Methods

2.1. Study population

The data collection period was from June to August 2005. Fifty-nine non-smoking women (mean age of 43.2 years) who used cookstoves in enclosed or semi-enclosed kitchens participated from two Honduran communities, 30 from Santa Lucia and 29 from Suyapa. Approximately half of the women cooked using traditional stoves and half using improved stoves. Traditional stoves typically consisted of open fire or poorly designed combustion chambers and some included poorly functioning chimneys. The improved stoves (called *Justa* stoves) incorporated a chimney and an improved combustion chamber. All participants gave informed consent and the study was approved by the Institutional Review Board of Colorado State University (CSU). The relationships between exposure concentrations and health endpoints have been described (Clark et al., 2009).

2.2. Exposure assessment

Exposure monitoring began around 8 am each morning and lasted for approximately 8 h. $PM_{2.5}$ (particulate matter with an aerodynamic diameter of less than or equal to 2.5 μm) was assessed via 8 h indoor and outdoor monitoring and 8 h personal monitoring using PEM samplers (SKC Inc., PA) and 37 mm Teflon polytetraflouroethylene filters (2 μm pore size). Sampling pump (Universal, SKC Inc., PA) flow rates were set to 2 l/min and calibrated in the laboratory with the SKC DryCal DC-Lite (SKC Inc., PA). Filters were pre- and post-weighed using a Mettler MT5 balance (Mettler-Toledo International, Inc.). Time-weighted average $PM_{2.5}$ values were assessed in statistical analyses Carbon monoxide was assessed via 8 h indoor monitoring and 20-min outdoor monitoring using a direct reading instrument (Q-TRAK Plus IAQ Monitor; TSI Inc., MN). Data were logged at 1 min intervals. The Q-TRAK was pre- and post-calibrated using zero air and 35 ppm carbon monoxide gas cylinders (TSI Inc., MN). Average, maximum, and 1-h maximum carbon monoxide values were assessed in statistical analyses $PM_{2.5}$ and carbon monoxide indoor sampling devices were collocated inside the kitchen at a height representative of breathing zones. Personal $PM_{2.5}$ was assessed by attaching the sampler to the participant's clothing nearest her breathing zone and placing the pump in a pack worn around her waist.

Kitchen volume, building materials, size of eave spaces and windows, and temperature were determined via an investigator housing survey to indicate ventilation conditions that may affect carbon monoxide and $PM_{2.5}$ indoor concentrations. Personal cooking practices were assessed via questionnaire. Recall accuracy was high among Guatemalan women asked to recall durations of activities occurring during the previous 24 h (Engel et al., 1997). Field investigators assessed stove quality using a four-level subjective scale representing potential for indoor emissions, based on factors such as chimney and plancha (griddle) condition and maintenance. The scale ranged from poorly functioning traditional stoves to well-functioning improved stoves. We assessed how well the stove scale predicted quantitative air quality measurements.

2.3. Statistical analysis

Data were analyzed using the SAS computer program (SAS 9.1, SAS Institute, Cary, NC). Personal, indoor, and outdoor 8-h average $PM_{2.5}$ and indoor 1-h maximum carbon monoxide means, standard deviations, minimum values, maximum values, and geometric means were calculated for the entire population and by stove type or levels of the stove scale. Spearman correlation coefficients were calculated for air quality measures.

Linear regression models were created to determine a set of variables that best explained the variation in air quality measurements. Analyses of individual contributions of potential predictors were followed by a best subsets selection method to determine the final multivariate model (described below). Stove type (*Justa* versus traditional), stove scale, chimney condition scale, total area of windows (no windows, window area $<700\,in^2$, and window area $>700\,in^2$ [approximate median split based on those with windows]), the number of walls in the kitchen (less than four walls versus four walls), the number of doors in the kitchen (no doors, one door, and more than one door), the volume of the kitchen (cubic feet), the number of walls with eave spaces (no walls, 1–2 walls, and 3–4 walls), the primary material of the walls (blocks/bricks, wood, and iron sheets), the age of the stove (years), the hours the fire burns on a typical day (hours), and the time spent in the room with the fire burning (hours; for personal $PM_{2.5}$ models only), were evaluated as predictors in univariate and potentially, multivariate models predicting air quality measurements. Squared and cubed polynomial terms of the continuous variables were also assessed to determine if they better explained the variation in pollution levels. Correlation coefficients (for continuous variables) and chi-square tests (for categorical variables) were used to assess the potential for collinearity between variables. Stove type, stove scale, and chimney condition were considered to be collinear with each other and therefore were not allowed in the same model. The natural logarithms of the exposure parameters were created for use as the dependent variables in order to satisfy assumptions of linear regression.

The selection criterion (an index computed for each candidate model and used to compare models) (Kleinbaum et al., 1998) consisted of a combination of R^2 and Mallow's Cp that was used to determine the optimal multivariable prediction model. The selection criteria compare the maximum (full) model with all potential predictors to a reduced model with fewer predictors. Considering more than one criterion is often recommended because no single criterion is best (Kleinbaum et al., 1998). Although the use of R^2 is a common selection criterion, a limitation is that the R^2 will always increase with the addition of variables to the model. It is, therefore, useful to combine this criterion with others, such as Mallow's Cp (an estimate of total prediction error). When comparing sets of models, choosing the model with the lowest Cp will result in the model with the smallest mean squared prediction error. Due to the small sample size, if the selection criteria for model selection were similar for multiple models, the most parsimonious model was chosen.

3. Results

Mean kitchen and cooking characteristics for the total population and stratified by stove type are presented in Table 1. On average, improved stoves were in kitchens with larger kitchen volumes and with greater total window areas (Table 1). In addition, as expected, women with traditional stoves had their stoves for a longer period of time (9.7 years) than those with improved stoves (2.3 years) (Table 1).