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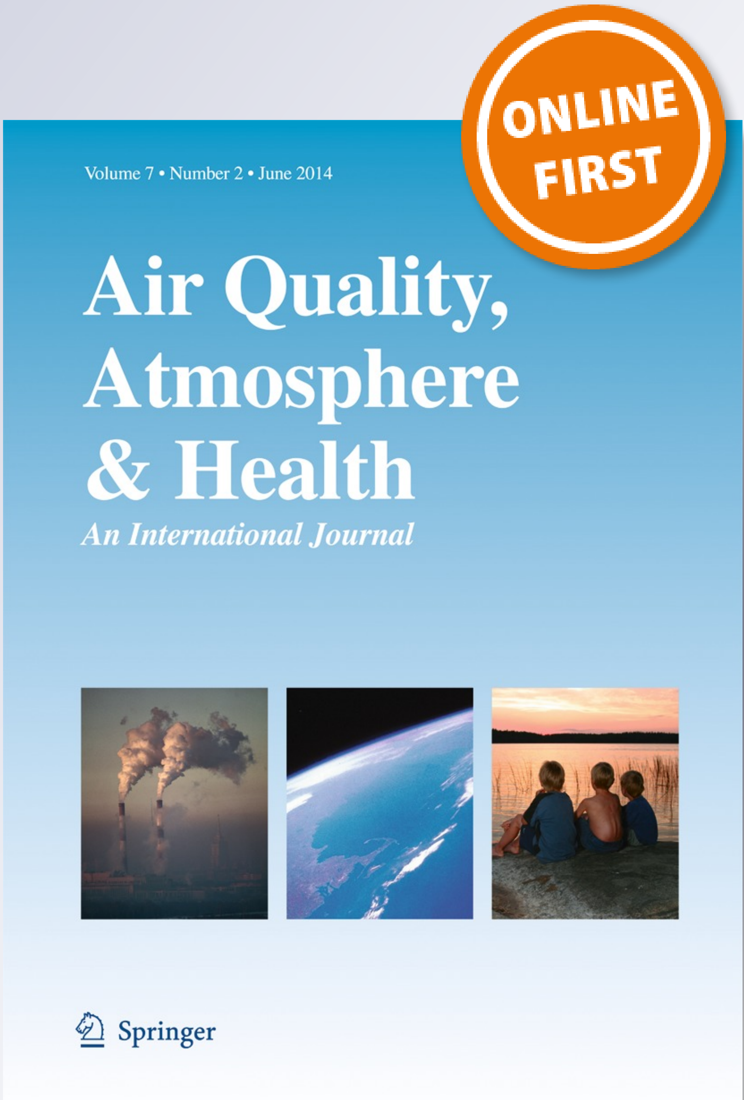

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Systolic blood pressure changes in indigenous Bolivian women associated with an improved cookstove intervention

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Abstract The use of biomass fuels as a primary fuel source is widespread and is linked to significant health effects. High blood pressure is a risk factor for cardiovascular effects including myocardial infarction and stroke. Few studies evaluating the health effects of household air pollution (HAP) have included blood pressure measurements. This study evaluated the effects of changes in cookstove-related particulate matter on blood pressure in 28 women head-of-households pre-intervention and 1 year post-intervention of an improved cookstove in a small, indigenous community in rural Bolivia. Blood pressure and kitchen particulate matter (PM) measurements were taken in August and September 2009 (pre-intervention) and in a 1-year follow-up in September and October of 2010 (post-intervention). Mean systolic blood pressure (SBP) decreased from 114.5±13.0 mm Hg to 109.0±10.4 mm Hg, (p=0.01) after the improved cookstove intervention. Small decreases in diastolic blood pressure (DBP) were also seen, but these changes were not significant (p=0.50). Decreases in SBP were correlated with reductions in 24-h mean kitchen PM levels (r=0.59, p=0.04). Somewhat stronger correlations were found between reductions in cooking PM concentrations and reductions in both SBP (r=0.66, p=0.01) and DBP (r=0.66, p=0.01). This study finds associations between decreases in both 24-h mean and mean cooking PM levels and decreases in SBP following an improved cookstove intervention.

Keywords Blood pressure · Cookstove · Household air pollution · Particulate matter · Systolic · Diastolic

D. Alexander (✉)
Center for Global Health, University of Chicago, 5841 S Maryland Ave, Chicago, IL 60637, USA
e-mail: dalexander1@bsd.uchicago.edu

D. Alexander · T. Larson
Department of Civil and Environmental Engineering, University of Washington, Seattle, WA, USA

S. Bolton
School of Environmental and Forest Sciences, University of Washington, Seattle, WA, USA

S. Vedal
School of Public Health, University of Washington, Seattle, WA, USA

Introduction

Approximately 3 billion people rely on solid fuel combustion for their primary domestic energy needs (Bonjour et al. 2013; UNDP-WHO 2009). In many developing countries, the burning of biomass accounts for almost 50 % of domestic energy production and can reach as high as 95 % in some lower income countries (Ezzati et al. 2000; Ezzati and Kammen 2002). In these countries, biomass fuels are typically burned in open pit fires or inefficient cookstoves without sufficient ventilation and can result in extremely high levels of household air pollution (HAP). HAP from household combustion of biomass fuels in developing countries has been linked to acute respiratory infections (Bates et al. 2013; Ezzati and Kammen 2001; Smith et al. 2000), chronic obstructive pulmonary disease (Bruce et al. 2002; Naeher et al. 2007), asthma, and other health problems (Schei et al. 2004; Smith-Sivertsen et al. 2004). In 2010, annual global mortality due to HAP from solid fuels was estimated at approximately 4 million deaths (Lim et al. 2012).

The importance of blood pressure as a risk factor for cardiovascular disease is well documented (Vasan et al. 2001). Lewington and colleagues (2002) conducted a meta-analysis that included individual data on 1 million adults in 61 prospective studies. In their findings, a 2-mm Hg decline in the population mean systolic blood pressure (SBP) was estimated to result in a 10 % lower stroke mortality and 7 % lower

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mortality from ischemic heart disease or other vascular diseases of middle age (Lewington et al. 2002).

Fine particulate matter and secondhand tobacco smoke are associated with cardiovascular morbidity and mortality (Brook et al. 2003; Dockery et al. 1993; Franchini and Mannucci 2012; Pope et al. 1995) including increased risk of myocardial infarction and stroke (Barnoya and Glantz 2005; Brook et al. 2010; USDHHS 2006). Controlled human exposures have resulted in increases in blood pressure with concentrated ambient particles and diesel exhaust (Brook et al. 2009; Cosselman et al. 2012). In a controlled face mask intervention study, increased blood pressure associated with filterable particulate matter (PM) was reported (Langrish et al. 2009). Several community observational studies have found associations between ambient air pollution and blood pressure (Auchincloss et al. 2008; Baumgartner et al. 2011; Clark et al. 2011; Dvonch et al. 2009; Kannan et al. 2010; Liu et al. 2009; McCracken et al. 2007); however, other studies have not corroborated these findings (Brauer et al. 2001; Ebelt et al. 2005; Harrabi et al. 2006; Jansen et al. 2005).

Thus far, three studies have found that the use of improved biomass cookstoves is associated with lower BP (Baumgartner et al. 2011; Clark et al. 2013; McCracken et al. 2007), with the latter two utilizing a pre-intervention and post-intervention design. In addition, McCracken and colleagues (2007) evaluated the effects of a chimney stove intervention on BP and found changes consistent with their cross-sectional results (McCracken et al. 2007).

In 2009, we began a pre-intervention and post-intervention study to evaluate the within-person health effects of an improved cookstove intervention in rural Bolivia and had an excellent cookstove adoption rate of over 90 %. We hypothesized that reductions in PM levels during cooking would be associated with reductions in BP.

Methods

The study was conducted in Tuquiza, Bolivia, a rural community of 63 families in the northern region of the department of Potosí. The altitude within the village ranges from 3,000–3,350 m, and all inhabitants are subsistence farmers, live in adobe houses with thatched roofs, and are of Quechua descent. Kitchens, which are detached from the house, are of the same type of structure. Women spend 3 to 8 h/day cooking, and their primary fuel source is hardwood trees and shrubs.

An initial general questionnaire was administered to women head-of-households (WHHs) at baseline to obtain information about general health status, diet, household characteristics, and socioeconomic status. This same questionnaire was administered at the 1-year post-intervention follow-up. None of the participants reported previous myocardial infarction, stroke, or had physician-diagnosed diabetes.

Other eligibility requirements for this study included WHHs who cooked exclusively indoors over open pit fires without ventilation, lived in the community permanently, did not smoke, did not take prescription medications, and were in good health. All participants participated in an improved cookstove intervention in September 2009, implemented by the University of Washington chapter of Engineers Without Borders (EWB-UWS). EWB-UWS policy required all recipients of the improved cookstove to have constructed a 3 m× 4 m adobe kitchen which would house the stove. The intervention included an improved adobe wood-burning cookstove called the Yanayo cookstove, a chimney and a metal roof for the kitchen.

For the duration of the study, all women reported exclusively using wood fuel for cooking and heating. No women reported being pregnant during pre-intervention or post-intervention testing. Their exposure to tobacco smoke was insignificant as it is not culturally acceptable for women to smoke, and men only occasionally smoke and then only while working away from the home. Similarly, occupational exposure to dust was deemed insignificant as women only work in the fields during brief planting and harvesting periods. The community of Tuquiza did not have electricity during the evaluation period, and households used small kerosene lamps or candles to light their houses in the evenings. This exposure was deemed relatively small and disregarded in the analysis.

Household exposure measurements and blood pressure measurements were recorded in 28 WHHs during August/ September 2009 prior to the intervention and September/ October 2010, 1 year after the cookstove intervention. All community members who desired the cookstove intervention received one whether they participated in the study or not. Of the 63 families in the community, 47 participated in the intervention. Of these, 30 WHHs enrolled in the study, two of whom died after year one testing. The total number of subjects who participated in the study was 28. In addition to blood pressure measurements, the authors evaluated respiratory health-related quality of life of the participants. Those data can be found in Alexander et al. (2013).

University of California at Berkeley (UCB) particle monitors were placed in a random subset of 15 women's kitchens both pre-intervention and post-intervention for roughly 24-h periods to measure PM concentrations. The UCB monitors, developed by the University of California at Berkeley to measure PM <2.5 μm ($PM_{2.5}$), are based on light scattering principles (Edwards et al. 2006; Litton et al. 2004). The UCB particle monitors were placed on the wall, level with the women's heads during cooking. Because women are of different sizes and use different cooking techniques (i.e., some sit on stools while others sit on the ground), the placement was varied for each individual household. On average, the distance from the floor was 57 cm, and the distance away from the stove was 36 cm. The time of placement and collection were recorded, as were the number of times stoves were used. Hobo brand thermocouples were placed in the chimney of the improved cookstoves to verify cooking times. No exposure measurements were taken within the houses themselves as they are only used for sleeping and are locked during the day. All data presented are based on factory calibration using pine wood smoke and filter-based samples of the light scattering signal with gravimetric mass. Postprocessing of the data involved baseline adjustment to account for within-machine baseline shifts.

An Omron blood pressure monitor (Model HEM-705CP) was used to measure systolic and diastolic blood pressure and heart rate in the supported left arm of the seated subject. The monitor is an automatic inflation digital arm monitor, which does not require calibration. Two repeat measures were taken after 10 min of continued rest. The mean of the two measures was used in the final analysis. Blood pressure of each participant was taken both pre-intervention and 1 year post-intervention. Blood pressure measurements were taken in the morning hours between 5:00 a.m. and 10:30 a.m. Measurements were taken during or directly after cooking, when the fire was still lit and the woman was still in the kitchen near the fire. Those participants that were visited in the early morning hours during pre-intervention were also visited in the early morning post-intervention. The same trend was followed for late morning visits.

Two local bilingual (Quechua and Spanish) field workers were trained to take blood pressure measurements and read and translate the questionnaires. The first author (DA) was also present during all testing.

Normality of measured data was assessed using the Kolmogorov–Smirnov (K–S) test prior to performing parametric tests. Pre-intervention and post-intervention outcomes were compared using paired *t* tests, and Pearson correlation coefficients and simple linear regression analysis were used to assess the relationships between PM concentrations and blood pressure. Covariates were not included in the analyses because of the within-individual study design and the limited power to detect interactions. Exploratory analyses with stratification by age (less than or equal to 50 years vs greater than 50 years, the 50th percentile of the age distribution) and body mass index (BMI) were carried out to assess the possibility of effect modification. Weight classifications were based on international classifications for underweight (<18.5), normal (18.5–25.0), overweight (≥25.0), and obese (≥30.0). The Mann–Whitney test was used to make cross-group comparisons of blood pressure change.

Results

We enrolled 30 women between the ages of 23 and 81. Of these, 28 completed the study. Subject information, kitchen PM concentrations, and baseline blood pressure values are presented in Table 1.

Kitchen PM concentrations

Using the UCB particle matter monitor, 24-h mean kitchen PM levels, mean cooking PM levels, and peak PM levels were measured over approximately 24-h time intervals in 15 randomly selected homes. Kitchen pre-intervention levels ranged from 23 to 750 μg/m^3 (mean, 240 μg/m^3±210) and kitchen post-intervention levels ranged from 8 to 170 μg/m^3 (mean, 48 μg/m^3±41), an 80 % reduction (p=0.005). Pre-intervention cooking PM levels ranged from 87 to 1,650 μg/m^3 (mean, 780±440), while 1-year post-intervention cooking PM levels ranged from 39 to 400 μg/m^3 (mean, 135 μg/m^3±97), an 83 % reduction (p<0.0001). Similarly, pre-intervention peak PM levels ranged from 1,460 to 63,800 μg/m^3 (mean, 21,100 μg/m^3±16,400); whereas, 1-year post-intervention peak PM levels ranged from 550 to 18,700 μg/m^3 (mean, 3,500 μg/m^3±4,600), an 83 % reduction (p=0.001). These data are shown in Figs. 1, 2, and 3.

Blood pressure

Blood pressure measurements were completed on 28 subjects, pre-intervention and post-intervention. Mean pre-intervention SBP was 114.5±13.0 mm Hg (range, 89.8 to 142.0 mm Hg). One-year mean post-intervention was significantly reduced to 109.0±10.4 mm Hg (range, 89.0 to 134.0 mm Hg), a reduction of 4.8 % (p=0.01). Similarly, mean diastolic blood pressure (DBP) was reduced from 71.2 mm Hg±6.3 (range, 62.8 to 89.8 mm Hg) pre-intervention to 70.1 mm Hg±7.8 1-year

Table 1 Baseline characteristics of the study participants (n=28)

Variable	Mean ± SD	Range
Mean age (years)	52±18	23–81
Weight (kg)	52±10	30–70
Height (cm)	147±7	133–160
BMI	23.0±4.0	16.7–30.7
Blood pressure at recruitment		
SBP	114.5±13	89.8–142.0
DPB	71.2±6.3	62.8–89.8
Kitchen PM concentrations at recruitment[a]		
24-h PM (μg/m^3)	240±210	23–622
Cooking PM (μg/m^3)	780±440	87–1,652
Peak PM (μg/m^3)	21,100±16,400	1,457–63,783

BMI body mass index, *SBP* systolic blood pressure, *DBP* diastolic blood pressure, *PM* particulate matter

[a] Includes data from 15 randomly selected homes

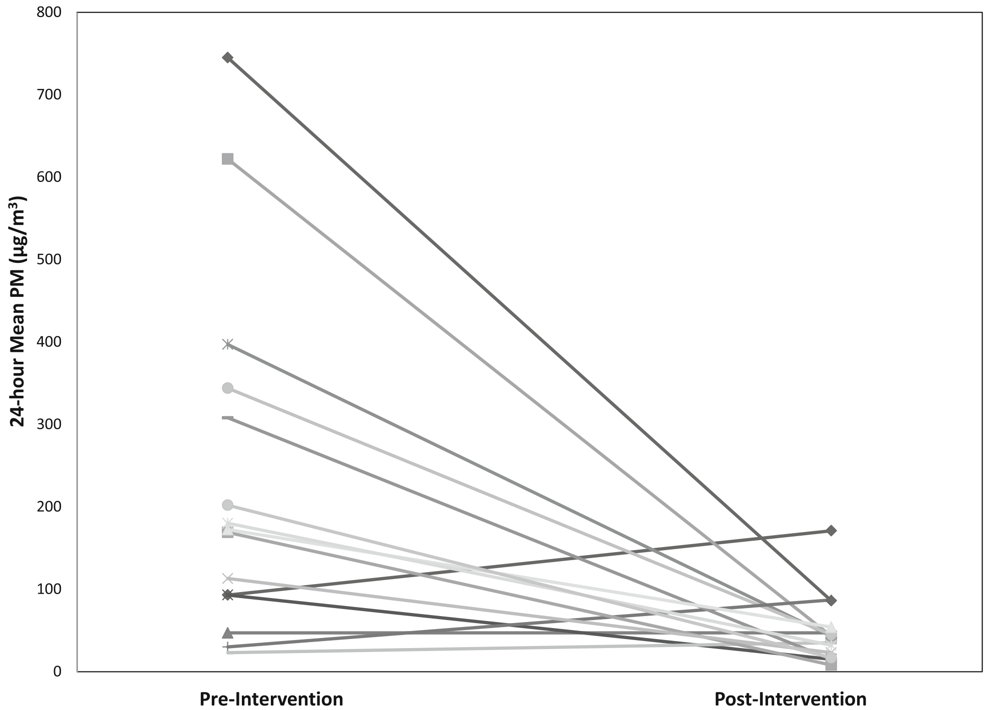


Fig. 1 Pre-intervention and post-intervention mean kitchen particulate matter (PM) concentrations

post-intervention (range, 56 to 88 mg Hg), although the change was not statistically significant (p=0.5).

We then split the subjects into two age groups: 23–50 and >50 years. We saw statistically significant decreases in SBP in women >50 years of age (n=15) 1-year post-intervention, from 115.2 mm Hg±14.6 to 108.2 mm Hg±12.3 (p=0.05). No significant decrease was seen in women <50 years of age (p=0.17, n=13). However, there was no statistically significant difference in change of SBP when comparing the two age categories (p=0.25). Changes in BP in underweight and

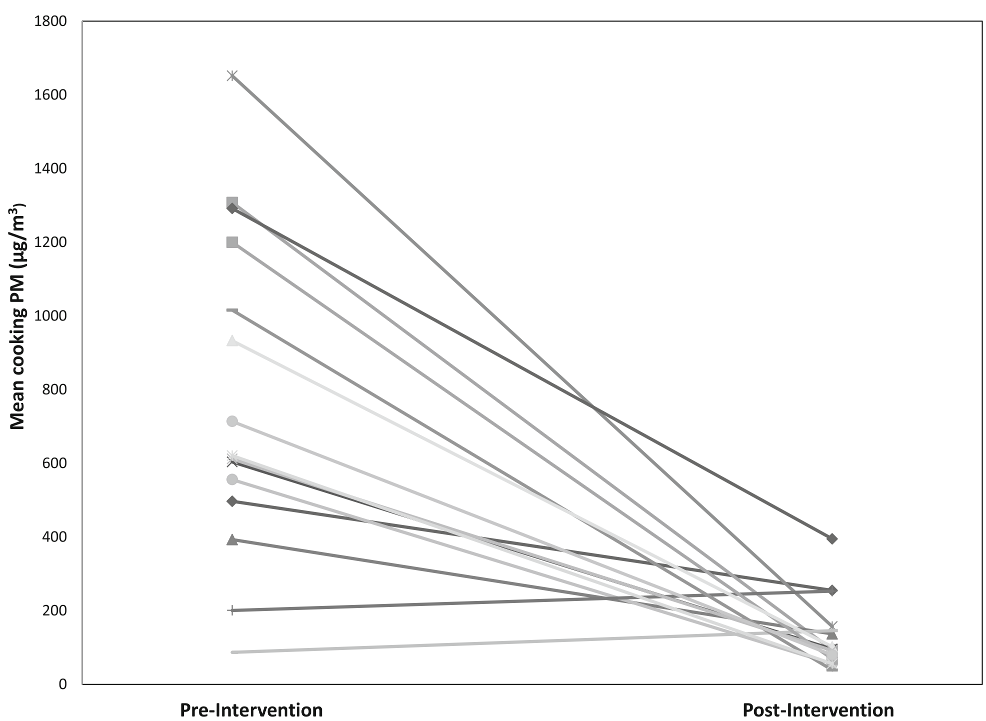
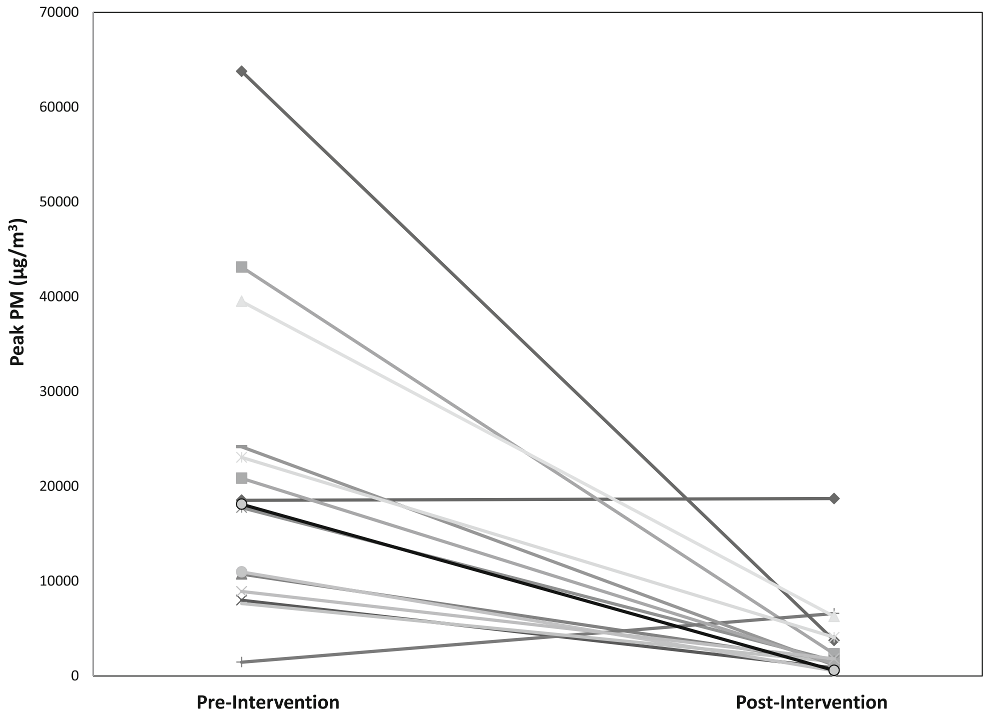


Fig. 2 Pre-intervention and post-intervention mean kitchen particulate matter (PM) concentrations during cooking periods

Fig. 3 Pre-intervention and post-intervention peak kitchen particulate matter (PM) concentrations

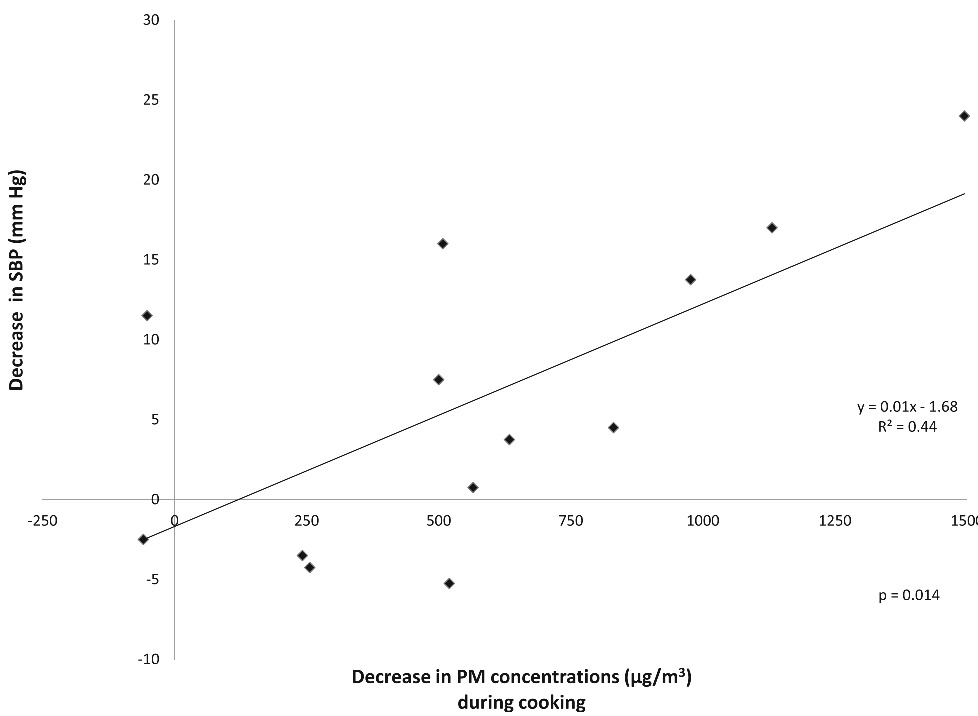


normal weight women compared to overweight and obese women were also examined. In the normal weight classes, SBP decreased by 5.9 mm Hg from 111.8 mm Hg±13.8 to 105.9 mm Hg±7.7 (p=0.09, n=15). In the overweight category, SBP decreased from 117.7 mm Hg±11.8 to 112.6 mm Hg±12.1 (p=0.08, n=13).

PM–blood pressure associations

In the subset of homes with PM concentration measurements, reductions in 24-h mean kitchen PM levels (µg/m^3) were correlated with reductions in SBP (r=0.59, p=0.04, n=13). Somewhat stronger correlations were found between

Fig. 4 Post-intervention to pre-intervention change in particulate matter (PM) concentrations during cooking and changes in systolic blood pressure (SBP)



reductions in cooking PM concentrations (μg/m^3) and reductions in both SBP (r=0.66, p=0.01, n=13, Fig. 4) and DBP (r=0.66, p=0.01, n=13).

Discussion

Our results are consistent with previous epidemiologic studies on indoor biomass smoke and BP (Baumgartner et al. 2011; Clark et al. 2013; McCracken et al. 2007) and add to the body of evidence on the adverse health effects of biomass smoke exposure. Baumgartner and colleagues (2011) studied the effects of biomass burning on blood pressure in adult women in rural China. The authors observed an association between personal $PM_{2.5}$ exposure and postexposure measurements of SBP and DBP (Baumgartner et al. 2011). This relationship was most apparent among women >50 years of age where a log microgram per cubic meter increase in $PM_{2.5}$ exposure was associated with a 4.1 mm Hg higher SBP and a 1.8 mm Hg higher DBP. Similarly, our results suggested that the relationship between decreases in exposure to PM was most apparent among women >50 years. However, because of limited power, this difference by age group was not statistically significant and needs to be interpreted carefully.

The two previous intervention studies of improved cookstoves also found some evidence for reductions in BP. Clark et al. conducted an improved cookstove intervention in 74 female cooks in Nicaragua (Clark et al. 2013). Although significant reductions in blood pressure were not observed among the entire study group, a 5.9-mm Hg reduction [95 % confidence interval (CI): −11.3, −0.4] in SBP was observed among women aged 40 or more years and a 4.6-mm Hg reduction (95 % CI: −10.0, 0.8) was observed among obese women. The authors reported that nearly half of the study group, however, reported continued use of their traditional stove either alone or together with the improved cookstove, which may have hampered their ability to observe the full effect of the intervention. McCracken and colleagues (2007), in the before- and after-improved cookstove intervention arm of the RESPIRE study in 55 women in Guatemala, found a 3.1-mm Hg decrease in SBP and a 1.9-mm Hg decrease in DPB associated with use of improved cookstoves (McCracken et al. 2007).

Besides the intervention design, other important strengths of this study were the high adoption rate of the improved cookstove and the large decreases in exposure concentrations that were achieved. These partially made up for the relatively small sample size and made it possible to detect significant reductions in blood pressure despite relatively limited power.

Several limitations of this study need to be considered. The most significant limitation of this pre-design and postdesign is the lack of a control group followed over the same period of time that did not have a cookstove intervention. Therefore, any temporal trend in BP could not be controlled. Some reassurance that the observed decreases in BP were not due to a temporal trend is provided by the observed correlation between reductions in kitchen PM concentrations and BP. Also, the intervention may have altered other factors that could influence BP. In a previous study on the same population, Alexander and colleagues (2013) reported an increase in activity level 1 year post-intervention of the improved cookstove (Alexander et al. 2013). It is not clear what impact this had on the reductions in BP of the study population. A stipulation of Engineers Without Borders, the organization providing the improved cookstoves, was that all families within a community that wished to participate in the project would receive a cookstove, making it difficult to include a control group. Phased in implementation of the cookstove, however, may have allowed identification of appropriate controls and could be an approach to consider for future intervention studies. Bias could also have been introduced because neither the participants nor the researchers were blinded, although the use of an automatic blood pressure machine makes this unlikely.

Summary and implications

In this pre-intervention and post-intervention study of an improved cookstove intervention in WHH cooks in rural Bolivia, the intervention resulted in substantial reductions in kitchen PM concentrations and parallel decreases in SBP, especially in the older women. Unique to this study were the high cookstove adoption rate and the resulting dramatic decreases in kitchen PM concentrations. This study adds to the body of evidence that cardiovascular disease may be a public health burden of HAP in developing countries and that improved cookstove interventions could have significant cardiovascular health benefits.

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