Title
Relationship Between Daily Exposure to Biomass Fuel Smoke and Blood Pressure in High-Altitude Peru

Journal
Hypertension, 65(5)

ISSN
0194-911X

Authors
Burroughs Peña, Melissa
Romero, Karina M
Velazquez, Eric J
et al.

Publication Date
2015-05-01

DOI
10.1161/hypertensionaha.114.04840

Peer reviewed

Original Article

Relationship Between Daily Exposure to Biomass Fuel Smoke and Blood Pressure in High-Altitude Peru

Melissa Burroughs Peña, Karina M. Romero, Eric J. Velazquez, Victor G. Davila-Roman, Robert H. Gilman, Robert A. Wise, J. Jaime Miranda, William Checkley

Abstract—Household air pollution from biomass fuel use affects 3 billion people worldwide; however, few studies have examined the relationship between biomass fuel use and blood pressure. We sought to determine if daily biomass fuel use was associated with elevated blood pressure in high altitude Peru and if this relationship was affected by lung function. We analyzed baseline information from a population-based cohort study of adults aged ≥35 years in Puno, Peru. Daily biomass fuel use was self-reported. We used multivariable regression models to examine the relationship between daily exposure to biomass fuel smoke and blood pressure outcomes. Interactions with sex and quartiles of forced vital capacity were conducted to evaluate for effect modification. Data from 1004 individuals (mean age, 55.3 years; 51.7% women) were included. We found an association between biomass fuel use with both prehypertension (adjusted relative risk ratio, 5.0; 95% confidence interval, 2.6–9.9) and hypertension (adjusted relative risk ratio, 3.5; 95% confidence interval, 1.7–7.0). Biomass fuel users had a higher systolic blood pressure (7.0 mm Hg; 95% confidence interval, 4.4–9.6) and a higher diastolic blood pressure (5.9 mm Hg; 95% confidence interval, 4.2–7.6) when compared with nonusers. We did not find interaction effects between daily biomass fuel use and sex or percent predicted forced vital capacity for either systolic blood pressure or diastolic blood pressure. Biomass fuel use was associated with a higher likelihood of having hypertension and higher blood pressure in Peru. Reducing exposure to household air pollution from biomass fuel use represents an opportunity for cardiovascular prevention. **(*Hypertension*. 2015;65:00-00. DOI: 10.1161/HYPERTENSIONAHA.114.04840.)**

Key Words: air pollution ■ blood pressure ■ global health ■ health status disparities ■ indoor air pollution ■ Latin America ■ rural health

Household air pollution (HAP) has been identified as the third leading risk factor for death worldwide,[1] and it is estimated to affect 3 billion people each year. HAP results from the burning of wood, animal dung, and other organic debris for cooking and heating. The negative health effects disproportionately burden households in resource-poor settings, as cleaner, more efficient fuels, such as liquefied petroleum gas, are more commonly used in households in urban settings and with higher incomes.[2]

The relationship between exposure to HAP and respiratory conditions, including chronic obstructive pulmonary disease, lung cancer, and pneumonia has been well established.[3] However, given the evidence of the association between ambient air pollution exposure and cardiovascular outcomes, including heart failure, myocardial infarction, arrhythmia, and cardiovascular-related mortality, there has been increased interest in examining the cardiovascular effects of HAP exposure.[2,4–7] Conflicting data on the association between HAP exposure and adverse cardiovascular outcomes exist. Observational studies of HAP exposure and cardiovascular disease have shown that biomass fuel use is associated with increased systemic blood pressure and an increased prevalence of hypertension.[8–10] On a cellular and biochemical level, biomass fuel use is associated with a prothrombotic, proinflammatory biological state, with increased platelet aggregation, reactive oxygen species, and anticardiolipin IgG.[11]

Although it is estimated that HAP from biomass fuel use is a considerable risk factor for cardiovascular disease in resource-poor settings worldwide, additional evidence on the specific ways by which HAP increases systemic blood pressure is needed. Moreover, both pulmonary disease and systemic blood pressure are associated with biomass fuel use, yet the interaction between pulmonary function and systemic blood pressure in the setting of biomass fuel use has not been adequately characterized. Although several large cohort studies have described an association between reduced lung function with blood pressure and arterial elasticity, it remains

Received November 4, 2014; first decision November 30, 2014; revision accepted February 13, 2015.

From the Division of Cardiology, Department of Medicine and Duke Clinical Research Institute, Duke University, Durham, NC (M.B.P., E.J.V.); Biomedical Research Unit, A.B. PRISMA, Lima, Peru (K.M.R.); Division of Cardiology, Department of Medicine, Washington University, St. Louis, MO (V.G.D.-R.); Program in Global Disease Epidemiology and Control, Department of International Health, Bloomberg School of Public Health (R.H.G.) and Division of Pulmonary and Critical Care Medicine, School of Medicine (R.A.W., W.C.), Johns Hopkins University, Baltimore, MD; and CRONICAS Center of Excellence in Chronic Diseases (R.H.G., J.J.M., W.C.) and Department of Medicine (J.J.M.), Universidad Peruana Cayetano Heredia, Lima, Peru.

Correspondence to William Checkley, Division of Pulmonary and Critical Care, School of Medicine, Johns Hopkins University, 1800 Orleans St, Suite 9121, Baltimore, MD 21205. E-mail wcheckl1@jhmi.edu

Hypertension is available at http://hyper.ahajournals.org DOI: 10.1161/HYPERTENSIONAHA.114.04840

unclear whether cardiovascular disease from HAP occurs with concomitant reduced lung function.[12–15] We sought to determine the association between daily biomass fuel use with systemic blood pressure, prehypertension, and hypertension in a population-based cohort of adults in Puno, Peru and if lung function, as measured by spirometry, was an effect modifier of the relationship between daily biomass fuel use and systemic blood pressure.

Methods

Study Setting

We conducted a longitudinal cohort study designed to characterize the prevalence and risk factors of chronic disease in 3 geographically distinct settings in Peru.[16] This study used the baseline round of questionnaire and clinical data in Puno, a city in southeastern Peru at 3825 m above sea level where biomass fuels are used almost exclusively in surrounding rural villages. Puno primarily consists of indigenous, Andean people with both Quechua- and Aymara-speaking populations.

Study Design

Individuals aged ≥35 years, full-time residents in the area, who provided informed consent were invited to participate in the study. We identified a sex, age-stratified (35–44, 45–54, 55–64, and ≥65 years), and location-stratified (urban versus rural) sample, and only 1 participant per household was enrolled. The study was approved by the Institutional Review Boards at Universidad Peruana Cayetano Heredia and A.B. PRISMA, in Lima, Peru, and at the Bloomberg School of Public Health, Johns Hopkins University, in Baltimore, MD.

Study Procedures

Participants responded to a questionnaire on sociodemographics, cardiopulmonary risk factors, and history of cardiopulmonary symptoms. Fieldworkers measured weight, height, blood pressure, and spirometry. Spirometry was conducted using the Easy-On-PC spirometer (ndd, Zurich, Switzerland) before and after 200 µg of inhaled salbutamol via a spacer following standard guidelines.[17] Systolic blood pressure (SBP) and diastolic blood pressure (DBP) were measured in triplicate using a digital sphygmomanometer (OMRON HEM-780; Osaka, Japan) that was previously validated for an adult population.[16] We used the right arm for all measurements using an appropriately fitted cuff size. Participants were asked to sit comfortably for 5 minutes before the first measurement was taken, and the set interval of time between measurements was 5 minutes. The right forearm was supported on a table for all measurements. Final SBP and DBP were calculated as the average of the second and third measurements.

Definitions

The following variables were determined by self-report in a structured questionnaire: daily biomass fuel use, hypertension diagnosis, use of antihypertensive medications, and pack-years of tobacco smoking. Daily biomass fuel use was defined as self-reported daily burning of wood or dung for cooking or heating for >6 months at any time during the participant's lifetime. Prehypertension was defined as SBP of 120 to 139 mm Hg or DBP of 80 to 89 mm Hg in the absence of antihypertensive medication use[18]; and, hypertension as SBP of ≥140 mm Hg, DBP of ≥90 mm Hg, or self-reported diagnosis by a physician with concomitant use of antihypertensive medications. Forced vital capacity (FVC) was defined as the total volume of air (in liters) expired during forced expiration. Percent predicted values were determined using the predictions derived from a healthy Mexican-American population.[19]

Physical activity was determined based on leisure time and transport time domains of International Physical Activity Questionnaire as recommended for Latin American populations.[20] Alcohol abuse was measured using the Alcohol Use Disorders Identification Test.[21] Depressive symptoms were defined as a score of ≥23 in the Spanish-validated version of the Center for Epidemiological Studies Depression Scale.[22,23] Education was categorized by schooling years (<6, 7–11, and ≥12 years). Socioeconomic status was defined as wealth index based on household income, assets, and household facilities as previously described.[24]

Biostatistical Methods

Our primary aim was to compare blood pressure outcomes in participants with and without daily exposure to biomass fuel smoke. We used multivariable linear and multinomial logistic regressions to model continuous blood pressure outcomes and categories of hypertension, respectively. In a minimally adjusted model, we controlled for differences in age, sex, and body mass index. In the fully adjusted model, we controlled for age, sex, body mass index, height, tertiles of wealth index, categories of education years, presence or absence of depressive symptoms, pack-years of smoking, alcohol abuse, and low physical activity. Antihypertensive medication use was included in the model for continuous blood pressure outcomes only. We examined for interaction effects between biomass fuel use and either sex or postbronchodilator percent-predicted FVC on blood pressure, and used the likelihood ratio test to evaluate for effect modification. Statistical analyses were conducted in STATA 12 (STATA Corp, College Station, TX) and R (www.r-project.org).

Results

Participant Characteristics

A total of 1004 participants were included in this analysis (Table 1). Participants with daily exposure to biomass fuel smoke were more likely to be women and live in a rural setting, had a lower prevalence of obesity, lower values of lung function, lower prevalence of tobacco smoking use, increased physical activity, fewer years of education, and a lower wealth index than did participants who did not have daily exposure to biomass fuel smoke. Overall, the prevalence of daily tobacco smoking was low in both the groups.

SBP and DBP by Daily Biomass Fuel Use

In unadjusted analysis, SBP and DBP were higher by 3.0 and 2.5 mm Hg between participants with and without daily biomass fuel use, respectively (Table 2). In the minimally adjusted model, SBP and DBP were higher by 6.1 and 4.7 mm Hg between participants with and without daily biomass fuel use, respectively. The fully adjusted model further strengthened this relationship: SBP and DBP were higher by 7.0 and 5.9 mm Hg between participants with and without daily biomass fuel use, respectively. After stratification by sex, the association between daily biomass fuel use with SBP and DBP remained statistically significant in both men and women; however, there was no interaction effect between sex and daily biomass fuel use on either SBP (P=0.10) or DBP (P=0.56).

Prevalence of Prehypertension and Hypertension by Daily Biomass Fuel Use

In unadjusted analysis, daily biomass fuel use was associated with having prehypertension (Table 2). Both the minimally adjusted and the fully adjusted model increased the strength of the association between daily biomass fuel use

Table 1. Participants Characteristics Stratified by Daily Exposure to Biomass Fuel Use Status

Participant Characteristics	Non–Daily User of Biomass Fuel	Daily Users of Biomass Fuels	P Value
Sample size	495	509	…
Sociodemographics			
Age, y, mean (SD)	55.0 (12.3)	55.6 (12.4)	0.46
Men, n (%)	255 (51.5)	230 (45.2)	0.05
Rural site, n (%)	3.4	95.1	<0.001
Lowest wealth tertile, n (%)	109 (22.0)	362 (71.7)	<0.001
<6 y of education, n (%)	61 (12.3)	325 (63.9)	<0.001
Anthropometrics			
BMI, kg/m^2, mean (SD)	27.9 (4.3)	25.2 (3.8)	<0.001
BMI≥30 kg/m^2, n (%)	130 (26.3)	57 (11.2)	<0.001
Waist circumference, cm, mean (SD)	92.9 (10.6)	84.6 (11.4)	<0.001
Height, cm, mean (SD)	157.1 (9.0)	155.3 (7.9)	<0.001
Hypertension outcomes			
Prehypertension, n (%)	33 (7.6)	79 (18.1)	<0.001
Hypertension, n (%)	56 (12.9)	51 (11.7)	0.58
Use of antihypertensive medications, n (%)	39 (7.9)	8 (1.6)	<0.001
Lung function			
Post-bronchodilator FVC in L, mean (SD)	3.75 (1.06)	3.61 (1.02)	0.04
% predicted FVC, mean (SD)	111.0 (15.8)	112.0 (17.3)	0.36
Factors that may modify blood pressure			
Tobacco smoking in pack-years, mean (SD)	0.93 (4.4)	0.30 (2.1)	0.004
Alcohol abuse, n (%)	97 (19.6)	84 (16.5)	0.21
Diabetes mellitus, n (%)	30 (6.3)	17 (3.5)	0.05
Low physical activity, n (%)	395 (80.1)	379 (74.6)	0.04
Depressive symptoms, n (%)	93 (18.6)	168 (33.1)	<0.001

BMI indicates body mass index; and FVC, forced vital capacity.

and having prehypertension. In unadjusted analysis, we did not find a relationship between biomass fuel use and having hypertension (Table 2); however, after minimal adjustment, an association between daily biomass fuel use and having hypertension became apparent. This suggests that age, sex, and body mass index were important confounders of the relationship between biomass fuels and having hypertension. The fully adjusted model further strengthened the relationship between biomass fuel use and having hypertension. Because of the low prevalence of prehypertension and hypertension, we were unable to adequately stratify these analyses by sex.

Effect Modification of Blood Pressure by FVC

In unadjusted analyses, the difference in SBP and DBP between participants with and without daily exposure to biomass fuel seemed to be greater in participants in the 2 highest quartiles of postbronchodilator percent-predicted FVC (Figure). Despite this trend, after multivariable analyses, we did not find interaction effects between daily exposure to biomass fuels smoke and percent predicted FVC for either SBP (P=0.47) or DBP (P=0.57).

Discussion

In a high altitude region of Peru, participants who reported daily use of biomass fuel had higher blood pressures and an increased risk of having prehypertension or hypertension than did those without daily biomass fuel use. Both men and women seemed to be equally affected. The relationship between biomass fuel use and blood pressure was not modified by lung function.

Our study adds to the growing body of literature on the cardiovascular effects of HAP from biomass fuel use, suggesting that although daily biomass fuel use is associated with increased blood pressure in multiple settings, the magnitude of the association varies.[8,9] Baumgartner et al[10] studied $PM_{2.5}$ personal exposure in rural Chinese women and found a 2.2 mm Hg increase in SBP and 0.5 mm Hg increase in DBP for each 1-log-μg/m^3 increase in 24-hour mean $PM_{2.5}$ exposure. Lee et al[8] examined the cardiovascular effects of biomass fuel use in Chinese adults and found that self-reported biomass fuel use was associated with a 1.7 increased odds of hypertension, which is substantially less than the adjusted relative risk ratio of 6 from the analysis of our cohort. In addition, Lee et al[8] reported that women were more likely to have a doubling in the odds hypertension attributed to biomass fuel use than did men. In contrast, the results from our study show that daily exposure to biomass fuel smoke was associated with higher SBP and DBP in both men and women. These results run contrary to the generally held assumption that the health effects of biomass fuel use might only be present in women because of the larger role women often have in cooking. There are no previous large studies of hypertension or any other cardiovascular disease in relation to biomass fuel use in Latin America, other than 2 small improved cookstove interventions in Guatemala and Nicaragua.[25,26]

Differences in the magnitude of association and the effect of sex across the various studies are probably influenced by several factors, including gene by environment interactions, cultural practices, altitude, and other environmental variables. Aspects of the cooking environment, including ventilation of the cooking space and the types of biomass fuels used, influence the intensity of the exposure as well as the relative concentration of noxious gases and particulate matter released during combustion. In addition, our study was conducted in a population living at high altitude, and thus it is unclear to what extent the relationship between biomass fuel use and systemic blood pressure was affected by this environmental exposure. Although individuals who ascend to high altitude from sea level experience an increase in blood pressure, epidemiological studies of the blood pressure effect of chronic exposure to high altitude have had mixed results.[27,28] The combined effect of altitude and exposure to HAP on blood pressure has not been well described and deserves further study, potentially increasing our understanding of blood pressure regulation.

There are several potential mechanisms by which biomass fuel use might affect blood pressure. Biomass fuel combustion

Table 2. Single Variable and Multivariable Analysis of the Association Between Daily Biomass Fuel Use and Blood Pressure Outcomes*

Blood Pressure Variable	Single Variable	*P* Value	Minimally Adjusted Model	*P* Value	Fully Adjusted Model	*P* Value
Increase in SBP, mm Hg (95% CI)						
Overall	3.0 (1.0 to 5.1)	0.004	6.1 (4.2 to 8.0)	<0.001	7.0 (4.4 to 9.6)	<0.001
Men	5.8 (3.3 to 8.4)	<0.001	8.9 (6.3 to 11.4)	<0.001	8.7 (5.4 to 12.1)	<0.001
Women	1.4 (−1.6 to 4.4)	0.37	3.8 (1.0 to 6.6)	0.007	5.4 (1.4 to 9.4)	0.008
Increase in DBP, mm Hg (95% CI)						
Overall	2.5 (1.3 to 3.8)	<0.001	4.7 (3.5 to 6.0)	<0.001	5.9 (4.2 to 7.6)	<0.001
Men	3.4 (1.7 to 5.1)	<0.001	5.5 (3.7 to 7.3)	<0.001	6.0 (3.6 to 8.3)	<0.001
Women	2.1 (0.4 to 3.9)	0.02	4.1 (2.4 to 5.8)	<0.001	5.6 (3.1 to 8.1)	<0.001
Prehypertension, RRR (95% CI)	2.7 (1.7 to 4.2)	<0.001	4.0 (2.4 to 6.5)	<0.001	5.0 (2.6 to 9.9)	<0.001
Hypertension, RRR (95% CI)	1.0 (0.7 to 1.5)	0.91	2.0 (1.2 to 3.3)	0.005	3.5 (1.7 to 7.0)	<0.001

CI indicates confidence interval; DBP, diastolic blood pressure; RRR, relative risk ratio; and SBP, systolic blood pressure.

*Multivariable models were either minimally adjusted (for age, sex, and BMI) or fully adjusted (for age, sex, BMI, height, tertiles of wealth index, categories of education years, presence or absence of depressive symptoms, pack-years of smoking, alcohol abuse, and low physical activity).

releases gases and fine particulate matter. Fine particulate matter exposure in controlled studies has been shown to increase blood pressure, affecting vasomotor tone through nitric oxide pathways.[29–35] Acute exposure to air pollution also exerts autonomic effects, resulting in increased heart rate and decreased heart rate variability.[35,36] Moreover, exposure to fine particulate matter (2.5 µm in size) has been associated with systemic inflammation, increased oxidative stress, and decreased endothelial function, including increased plasma fibrinogen, serum C-reactive protein, and changes in leukocyte adhesion molecule expression.[37–40] One hypothesis is that the presence of fine particulate matter in the lung interstitium causes systemic inflammation that, in turn, increases blood pressure.[41,42]

In looking at the role of lung function as measured by FVC as a potential mediator in the relationship of daily biomass fuel use with SBP and DBP, our study found no effect modification by quartiles of lung function. However, the trend toward increased difference in SBP and DBP between daily biomass fuel users and nonusers in the higher 2 quartiles of FVC suggests that increased lung function might be associated with increased SBP and DBP in setting of HAP exposure from biomass fuel use. The biological mechanism by which HAP from biomass fuel increases blood pressure might involve translocation of ultrafine particulate matter (0.1 µm in size) via the alveolar capillaries, although studies of ultrafine particle translocation via the lungs in healthy human volunteers

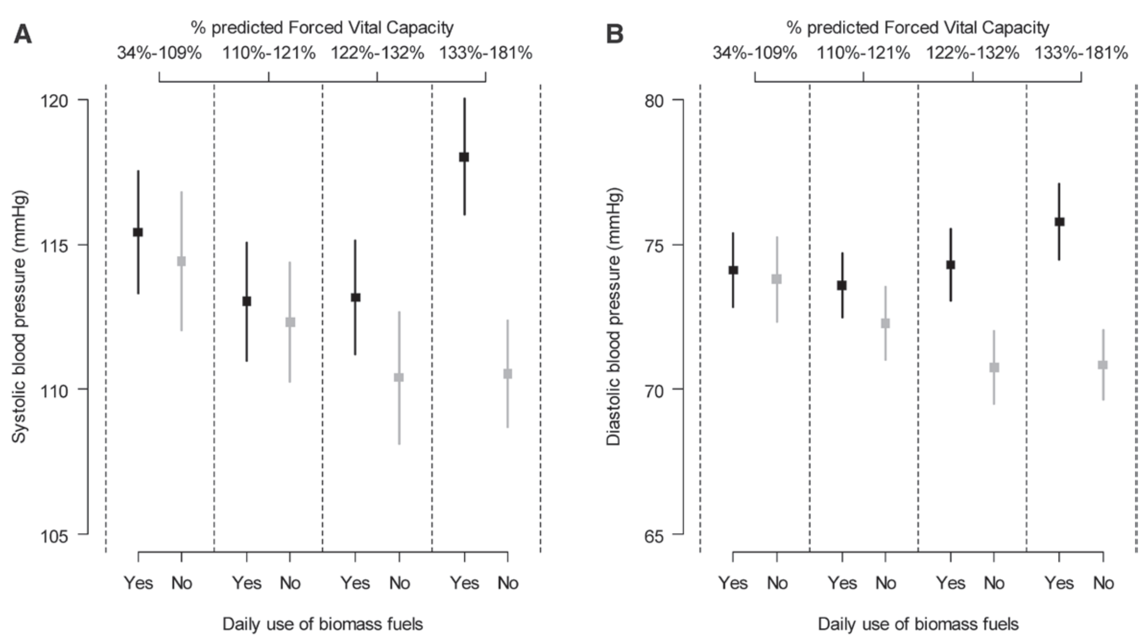

Figure. Differences in systolic blood pressure and diastolic blood pressure in daily biomass fuel users and nonusers stratified by quartiles of percent predicted forced vital capacity. **A**, Unadjusted differences for systolic blood pressure. **B**, Unadjusted differences for diastolic blood pressure.

have had conflicting results.[43,44] Particulate matter other than $PM_{2.5}$ may also account for the association between air pollution exposure and increased in blood pressure. One study in rural China found that exposure to black carbon among women was more greatly associated with increased blood pressure than $PM_{2.5}$ exposure.[45] Additional studies of the interaction between individual components of air pollution, lung function, and systemic blood pressure are needed.

The results of our study support the need for additional research on the effect of HAP from biomass fuel use on cardiovascular disease. Globally, there are initiatives to reduce HAP exposure by replacing traditional cookstoves with cleaner technology that either replaces biomass fuel use with liquefied petroleum gas or electricity, or effectively vents the smoke from biomass fuel combustion out of the home. However, as these initiatives are evaluated, evidence on both the cardiovascular and the pulmonary health benefits of each cookstove initiative is needed to better direct investment. Cultural acceptance and economic sustainability are key components of clean cookstove technology initiatives, however, the precise understanding of potential health benefits is needed to encourage public and private investment and avoid wasting resources on ineffective cookstove technologies. Given the widespread use of biomass fuels globally, reducing exposure to HAP presents a potential opportunity to reduce morbidity and mortality from cardiovascular disease in resource-poor settings.

The primary limitation of this study is that it is observational in design at a single site and thus cannot determine causation. Although we have adjusted for many confounding variables in our analysis, there may be potentially unmeasured confounders. Specifically, biomass fuel use was closely associated with rural residence, which may be associated with unmeasured environmental variables that might affect blood pressure. Moreover, we measured neither individual exposure to HAP nor the gaseous or particulate matter composition of the biomass fuel smoke but rather used self-reported daily biomass fuel use as a proxy for exposure. However, in previous studies in a subgroup of the same cohort, we have determined that 24-hour mean $PM_{2.5}$ exposure in individuals living in rural Puno, where 95% of the population used biomass fuels daily, was substantially greater than in individuals living in urban Puno, where biomass fuel use was low or nonexistent.[46] In addition, unpublished data from our group of ambient $PM_{2.5}$ monitoring in rural Puno suggest that ambient $PM_{2.5}$ levels are low and do not significantly contribute to the air pollution exposure of rural Puno residents (W. Checkley, unpublished data, 2014). Another limitation of our study is that we measured blood pressure in a single examination rather than in multiple visits. We are also unable to account for recent acute environmental exposures that might have transiently affected blood pressure measurement during the day of examination. Given the numerous potentially blood pressure raising exposures found in the urban environment in which most biomass fuel nonusers reside, and the heterogeneity of the biomass fuel smoke exposure captured in our liberal definition of biomass fuel use, our study probably underestimates the true association of biomass fuel smoke exposure and blood pressure in this population. Rural biomass fuel users generally have less access to medical care than urban participants and thus might be less likely to receive a diagnosis of hypertension. The underdiagnosis of hypertension in the rural population may have resulted in further underestimation of the association of biomass fuel use with hypertension.

Perspectives

This study expands on the growing body of literature that examines the cardiovascular risk associated with HAP from biomass fuel use. We have demonstrated an association between biomass fuel use with blood pressure and hypertension prevalence, but additional research is needed to understand the degree to which exposure to HAP affects hard cardiovascular outcomes, including heart failure, myocardial infarction, and cardiovascular-related mortality. In addition, further studies are needed to determine whether improved biomass fuel cookstove technology improves cardiovascular outcomes, or if it is necessary to replace biomass fuels with cleaner fuels, such as liquefied petroleum gas, to effectively reduce cardiovascular risk. This area of future research has broad implications for not only public health policy but also energy policy on a national and regional level. Uncovering the totality of cardiovascular and pulmonary disease associated with HAP from biomass fuel use is necessary to influence policymakers to enact effective public policy to improve the health of the rural poor.

Conclusions

In a high-altitude region of Peru, biomass fuel use was associated with elevated blood pressure and a higher prevalence of hypertension. The association between daily biomass fuel use with SBP and DBP was present and consistent for both men and women. Lung function as measured by FVC was not an effect modifier in the relationship between biomass fuel use with SBP and DBP. Additional studies of the effect of HAP and cookstove interventions on cardiovascular risk and outcomes are needed.

Acknowledgments

We are indebted to study participants. Special thanks to all field teams for their commitment and hard work, especially to L. Cabrera and D. Danz for their leadership in each of the study sites, and M. Varela for data coordination.

Drs Miranda, Gilman, and Checkley conceived, designed, and supervised the overall study. Dr Checkley coordinated and supervised fieldwork activities in Puno. Drs Peña and Checkley developed the idea for this article and wrote the first draft. Drs Peña, Romero, and Checkley led the statistical analysis. All authors participated in writing of article, provided important intellectual content, and gave their final approval of the version submitted for publication.

Sources of Funding

This project has been funded in whole with Federal funds from the US National Heart, Lung, and Blood Institute, National Institutes of Health (NIH), Department of Health and Human Services, under Contract No. HHSN268200900033C. W. Checkley was further supported by a Pathway to Independence Award (R00HL096955) from the US National Heart, Lung, and Blood Institute, NIH. M.B. Peña was supported by NIH Research Training Grant R25TW009337 funded by the Fogarty International Center and the National Institute of Mental Health in addition to the Vanderbilt-Emory-Cornell-Duke Consortium, the Fogarty International Center and the National Heart, Lung, and Blood Institute, NIH.

Disclosures

None.

References

1. Lim SS, Vos T, Flaxman AD, et al. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990-2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet*. 2012;380:2224–2260. doi: 10.1016/S0140-6736(12)61766-8.
2. Rajagopalan S, Brook R. Indoor-outdoor air pollution continuum and CVD burden: an opportunity for improving global health. *Global Heart*. 2012; 7:207–213. doi: 10.1016/j.gheart.2012.06.009.
3. Mortimer K, Gordon SB, Jindal SK, Accinelli RA, Balmes J, Martin WJ II. Household air pollution is a major avoidable risk factor for cardiorespiratory disease. *Chest*. 2012;142:1308–1315. doi: 10.1378/chest.12-1596.
4. Shah AS, Langrish JP, Nair H, McAllister DA, Hunter AL, Donaldson K, Newby DE, Mills NL. Global association of air pollution and heart failure: a systematic review and meta-analysis. *Lancet*. 2013;382:1039–1048. doi: 10.1016/S0140-6736(13)60898-3.
5. Brook RD, Franklin B, Cascio W, Hong Y, Howard G, Lipsett M, Luepker R, Mittleman M, Samet J, Smith SC Jr, Tager I; Expert Panel on Population and Prevention Science of the American Heart Association. Air pollution and cardiovascular disease: a statement for healthcare professionals from the Expert Panel on Population and Prevention Science of the American Heart Association. *Circulation*. 2004;109:2655–2671. doi: 10.1161/01.CIR.0000128587.30041.C8.
6. Brook RD, Rajagopalan S, Pope CA III, Brook JR, Bhatnagar A, Diez-Roux AV, Holguin F, Hong Y, Luepker RV, Mittleman MA, Peters A, Siscovick D, Smith SC Jr, Whitsel L, Kaufman JD; American Heart Association Council on Epidemiology and Prevention, Council on the Kidney in Cardiovascular Disease, and Council on Nutrition, Physical Activity and Metabolism. Particulate matter air pollution and cardiovascular disease: an update to the scientific statement from the American Heart Association. *Circulation*. 2010;121:2331–2378. doi: 10.1161/CIR.0b013e3181dbece1.
7. Milojevic A, Wilkinson P, Armstrong B, Bhaskaran K, Smeeth L, Hajat S. Short-term effects of air pollution on a range of cardiovascular events in England and Wales: case-crossover analysis of the MINAP database, hospital admissions and mortality. *Heart*. 2014;100:1093–1098. doi: 10.1136/heartjnl-2013-304963.
8. Lee MS, Hang JQ, Zhang FY, Dai HL, Su L, Christiani DC. In-home solid fuel use and cardiovascular disease: a cross-sectional analysis of the Shanghai Putuo study. *Environ Health*. 2012;11:18. doi: 10.1186/1476-069X-11-18.
9. Dutta A, Ray MR. Prevalence of hypertension and pre-hypertension in rural women: a report from the villages of West Bengal, a state in the eastern part of India. *Aust J Rural Health*. 2012;20:219–225. doi: 10.1111/j.1440-1584.2012.01287.x.
10. Baumgartner J, Schauer JJ, Ezzati M, Lu L, Cheng C, Patz JA, Bautista LE. Indoor air pollution and blood pressure in adult women living in rural China. *Environ Health Perspect*. 2011;119:1390–1395. doi: 10.1289/ehp.1003371.
11. Dutta A, Ray MR, Banerjee A. Systemic inflammatory changes and increased oxidative stress in rural Indian women cooking with biomass fuels. *Toxicol Appl Pharmacol*. 2012;261:255–262. doi: 10.1016/j.taap.2012.04.004.
12. Jacobs DR Jr, Yatsuya H, Hearst MO, Thyagarajan B, Kalhan R, Rosenberg S, Smith LJ, Barr RG, Duprez DA. Rate of decline of forced vital capacity predicts future arterial hypertension: the Coronary Artery Risk Development in Young Adults Study. *Hypertension*. 2012;59:219–225. doi: 10.1161/HYPERTENSIONAHA.111.184101.
13. Duprez DA, Hearst MO, Lutsey PL, Herrington DM, Ouyang P, Barr RG, Bluemke DA, McAllister D, Carr JJ, Jacobs DR Jr. Associations among lung function, arterial elasticity, and circulating endothelial and inflammation markers: the multiethnic study of atherosclerosis. *Hypertension*. 2013;61:542–548. doi: 10.1161/HYPERTENSIONAHA.111.00272.
14. Margretardottir OB, Thorleifsson SJ, Gudmundsson G, Olafsson I, Benediktsdottir B, Janson C, Buist AS, Gislason T. Hypertension, systemic inflammation and body weight in relation to lung function impairment-an epidemiological study. *COPD*. 2009;6:250–255.
15. Schnabel E, Karrasch S, Schulz H, Gläser S, Meisinger C, Heier M, Peters A, Wichmann HE, Behr J, Huber RM, Heinrich J; Cooperative Health Research in the Region of Augsburg (KORA) Study Group. High blood pressure, antihypertensive medication and lung function in a general adult population. *Respir Res*. 2011;12:50. doi: 10.1186/1465-9921-12-50.
16. Miranda JJ, Bernabe-Ortiz A, Smeeth L, Gilman RH, Checkley W; CRONICAS Cohort Study Group. Addressing geographical variation in the progression of non-communicable diseases in Peru: the CRONICAS cohort study protocol. *BMJ Open*. 2012;2:e000610. doi: 10.1136/bmjopen-2011-000610.
17. Miller MR, Hankinson J, Brusasco V, et al; ATS/ERS Task Force. Standardisation of spirometry. *Eur Respir J*. 2005;26:319–338. doi: 10.1183/09031936.05.00034805.
18. Jones DW, Hall JE. Seventh report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure and evidence from new hypertension trials. *Hypertension*. 2004;43:1–3. doi: 10.1161/01.HYP.0000110061.06674.ca.
19. Hankinson JL, Odencrantz JR, Fedan KB. Spirometric reference values from a sample of the general U.S. population. *Am J Respir Crit Care Med*. 1999;159:179–187. doi: 10.1164/ajrccm.159.1.9712108.
20. Hallal PC, Gomez LF, Parra DC, Lobelo F, Mosquera J, Florindo AA, Reis RS, Pratt M, Sarmiento OL. Lessons learned after 10 years of IPAQ use in Brazil and Colombia. *J Phys Act Health*. 2010;7(suppl 2):S259–S264.
21. Gómez Arnáiz A, Conde Martela A, Alberto Aguiar Bautista J, Manuel Santana Montesdeoca J, Jorrín Moreno A, Betancor León P. Diagnostic usefulness of Alcohol Use Disorders Identification Test (AUDIT) for detecting hazardous alcohol consumption in primary care settings. *Med Clin (Barc)*. 2001;116:121–124.
22. LS R. The CES-D Scale: A Self-Report Depression Scale for Research in the General Population. *Appl Psyc Meas*. 1977;1:385–401.
23. Ruiz-Grosso P, Loret de Mola C, Vega-Dienstmaier JM, Arevalo JM, Chavez K, Vilela A, Lazo M, Huapaya J. Validation of the Spanish Center for Epidemiological Studies Depression and Zung Self-Rating Depression Scales: a comparative validation study. *PLoS One*. 2012;7:e45413. doi: 10.1371/journal.pone.0045413.
24. Howe LD, Galobardes B, Matijasevich A, Gordon D, Johnston D, Onwujekwe O, Patel R, Webb EA, Lawlor DA, Hargreaves JR. Measuring socio-economic position for epidemiological studies in low- and middle-income countries: a methods of measurement in epidemiology paper. *Int J Epidemiol*. 2012;41:871–886. doi: 10.1093/ije/dys037.
25. McCracken JP, Smith KR, Díaz A, Mittleman MA, Schwartz J. Chimney stove intervention to reduce long-term wood smoke exposure lowers blood pressure among Guatemalan women. *Environ Health Perspect*. 2007;115:996–1001. doi: 10.1289/ehp.9888.
26. Clark ML, Bachand AM, Heiderscheidt JM, Yoder SA, Luna B, Volckens J, Koehler KA, Conway S, Reynolds SJ, Peel JL. Impact of a cleaner-burning cookstove intervention on blood pressure in Nicaraguan women. *Indoor Air*. 2013;23:105–114. doi: 10.1111/ina.12003.
27. Parati G, Bilo G, Faini A, Bilo B, Revera M, Giuliano A, Lombardi C, Caldara G, Gregorini F, Styczkiewicz K, Zambon A, Piperno A, Modesti PA, Agostoni P, Mancia G. Changes in 24 h ambulatory blood pressure and effects of angiotensin II receptor blockade during acute and prolonged high-altitude exposure: a randomized clinical trial. *Eur Heart J*. 2014;35:3113–3122. doi: 10.1093/eurheartj/ehu275.
28. Hurtado A, Escudero E, Pando J, Sharma S, Johnson RJ. Cardiovascular and renal effects of chronic exposure to high altitude. *Nephrol Dial Transplant*. 2012;27(suppl 4):iv11–iv16. doi: 10.1093/ndt/gfs427.
29. Zanobetti A, Canner MJ, Stone PH, Schwartz J, Sher D, Eagan-Bengston E, Gates KA, Hartley LH, Suh H, Gold DR. Ambient pollution and blood pressure in cardiac rehabilitation patients. *Circulation*. 2004;110:2184–2189. doi: 10.1161/01.CIR.0000143831.33243.D8.
30. Urch B, Silverman F, Corey P, Brook JR, Lukic KZ, Rajagopalan S, Brook RD. Acute blood pressure responses in healthy adults during controlled air pollution exposures. *Environ Health Perspect*. 2005;113:1052–1055.
31. Törnqvist H, Mills NL, Gonzalez M, Miller MR, Robinson SD, Megson IL, Macnee W, Donaldson K, Söderberg S, Newby DE, Sandström T, Blomberg A. Persistent endothelial dysfunction in humans after diesel exhaust inhalation. *Am J Respir Crit Care Med*. 2007;176:395–400. doi: 10.1164/rccm.200606-872OC.
32. Sun Q, Yue P, Ying Z, Cardounel AJ, Brook RD, Devlin R, Hwang JS, Zweier JL, Chen LC, Rajagopalan S. Air pollution exposure potentiates hypertension through reactive oxygen species-mediated activation of Rho/ROCK. *Arterioscler Thromb Vasc Biol*. 2008;28:1760–1766. doi: 10.1161/ATVBAHA.108.166967.
33. Mills NL, Törnqvist H, Robinson SD, Gonzalez M, Darnley K, MacNee W, Boon NA, Donaldson K, Blomberg A, Sandstrom T, Newby DE. Diesel exhaust inhalation causes vascular dysfunction and impaired

endogenous fibrinolysis. *Circulation*. 2005;112:3930–3936. doi: 10.1161/CIRCULATIONAHA.105.588962.
34. Auchincloss AH, Diez Roux AV, Dvonch JT, Brown PL, Barr RG, Daviglus ML, Goff DC, Kaufman JD, O'Neill MS. Associations between recent exposure to ambient fine particulate matter and blood pressure in the Multi-ethnic Study of Atherosclerosis (MESA). *Environ Health Perspect*. 2008;116:486–491. doi: 10.1289/ehp.10899.
35. Unosson J, Blomberg A, Sandström T, Muala A, Boman C, Nyström R, Westerholm R, Mills NL, Newby DE, Langrish JP, Bosson JA. Exposure to wood smoke increases arterial stiffness and decreases heart rate variability in humans. *Part Fibre Toxicol*. 2013;10:20. doi: 10.1186/1743-8977-10-20.
36. Brook RD, Urch B, Dvonch JT, et al. Insights into the mechanisms and mediators of the effects of air pollution exposure on blood pressure and vascular function in healthy humans. *Hypertension*. 2009;54:659–667. doi: 10.1161/HYPERTENSIONAHA.109.130237.
37. Peters A, Fröhlich M, Döring A, Immervoll T, Wichmann HE, Hutchinson WL, Pepys MB, Koenig W. Particulate air pollution is associated with an acute phase response in men; results from the MONICA-Augsburg Study. *Eur Heart J*. 2001;22:1198–1204. doi: 10.1053/euhj.2000.2483.
38. Pekkanen J, Brunner EJ, Anderson HR, Tiittanen P, Atkinson RW. Daily concentrations of air pollution and plasma fibrinogen in London. *Occup Environ Med*. 2000;57:818–822.
39. Peters A, Döring A, Wichmann HE, Koenig W. Increased plasma viscosity during an air pollution episode: a link to mortality? *Lancet*. 1997;349:1582–1587. doi: 10.1016/S0140-6736(97)01211-7.
40. Frampton MW, Stewart JC, Oberdörster G, Morrow PE, Chalupa D, Pietropaoli AP, Frasier LM, Speers DM, Cox C, Huang LS, Utell MJ. Inhalation of ultrafine particles alters blood leukocyte expression of adhesion molecules in humans. *Environ Health Perspect*. 2006;114:51–58.
41. Mills NL, Donaldson K, Hadoke PW, Boon NA, MacNee W, Cassee FR, Sandström T, Blomberg A, Newby DE. Adverse cardiovascular effects of air pollution. *Nat Clin Pract Cardiovasc Med*. 2009;6:36–44. doi: 10.1038/ncpcardio1399.
42. Seaton A, MacNee W, Donaldson K, Godden D. Particulate air pollution and acute health effects. *Lancet*. 1995;345:176–178.
43. Nemmar A, Hoet PH, Vanquickenborne B, Dinsdale D, Thomeer M, Hoylaerts MF, Vanbilloen H, Mortelmans L, Nemery B. Passage of inhaled particles into the blood circulation in humans. *Circulation*. 2002;105:411–414.
44. Mills NL, Amin N, Robinson SD, Anand A, Davies J, Patel D, de la Fuente JM, Cassee FR, Boon NA, Macnee W, Millar AM, Donaldson K, Newby DE. Do inhaled carbon nanoparticles translocate directly into the circulation in humans? *Am J Respir Crit Care Med*. 2006;173:426–431. doi: 10.1164/rccm.200506-865OC.
45. Baumgartner J, Zhang Y, Schauer JJ, Huang W, Wang Y, Ezzati M. Highway proximity and black carbon from cookstoves as a risk factor for higher blood pressure in rural China. *Proc Natl Acad Sci U S A*. 2014;111:13229–13234. doi: 10.1073/pnas.1317176111.
46. Pollard SL, Williams DL, Breysse PN, Baron PA, Grajeda LM, Gilman RH, Miranda JJ, Checkley W; CRONICAS Cohort Study Group. A cross-sectional study of determinants of indoor environmental exposures in households with and without chronic exposure to biomass fuel smoke. *Environ Health*. 2014;13:21. doi: 10.1186/1476-069X-13-21.

Novelty and Significance

What Is New?

- This study is one of the few studies that investigate the systemic blood pressure outcomes associated with household air pollution exposure from biomass fuel use. Moreover, there are no other published studies that consider lung function as a potential effect modifier in the relationship between biomass fuel use and systemic blood pressure.

What Is Relevant?

- Although it is estimated that exposure to household air pollution is one of the largest contributors to poor health worldwide, there are few studies that closely examine how household air pollution exposure from biomass fuel use might negatively affect cardiovascular disease outcomes. The results of this study have implications for cardiovascular disease prevention, particularly in resource-poor settings.

Summary

In a high-altitude region of Peru, biomass fuel use was associated with higher blood pressure and a higher likelihood of having hypertension.

Hypertension
JOURNAL OF THE AMERICAN HEART ASSOCIATION

Relationship Between Daily Exposure to Biomass Fuel Smoke and Blood Pressure in High-Altitude Peru

Melissa Burroughs Peña, Karina M. Romero, Eric J. Velazquez, Victor G. Davila-Roman, Robert H. Gilman, Robert A. Wise, J. Jaime Miranda and William Checkley

Hypertension. published online March 9, 2015;
Hypertension is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231

Print ISSN: 0194-911X. Online ISSN: 1524-4563