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Household biomass fuel use, blood pressure and carotid intima media thickness; a cross sectional study of rural dwelling women in Southern Nigeria☆,☆☆

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ABSTRACT

Background: Rising prevalence of cardiovascular disease requires in-depth understanding of predisposing factors. Studies show an association between air pollution and CVD but this association is not well documented in southern Nigeria where the use of biomass fuels (BMF) for domestic purposes is prevalent.

Purpose: This study aimed to explore the association between household BMF use and blood pressure (BP) and carotid intima media thickness (CIMT) among rural-dwelling women.

Methods: A cross-sectional study of 389 women aged 18 years and older. Questionnaires were used to obtain data on predominant fuel used and a brief medical history. Wood, charcoal and agricultural waste were classified as BMF while kerosene, bottled gas and electricity were classified as non-BMF. Blood pressure and CIMT were measured using standard protocols. Regression analysis was used to assess the relationship between fuel type and BP, CIMT, pre-hypertension and hypertension after adjusting for confounders.

Results: There was a significant difference in the mean (standard deviation) systolic BP (135.3, 26.7 mmHg vs 123.8, 22.6 mmHg; $p < 0.01$), diastolic BP (83.7, 18.5 mmHg vs 80.1, 13.8 mmHg; $p = 0.043$) and CIMT (0.63, 0.16 mm vs 0.56, 0.14 mm; $p = 0.004$) among BMF users compared to non-BMF users. In regression analysis, the use of BMF was significantly associated with 2.7 mmHg higher systolic BP ($p = 0.040$), 0.04 mm higher CIMT ($p = 0.048$) in addition to increased odds of pre-hypertension (OR 1.67 95% CI 1.56, 4.99, $P = 0.035$) but not hypertension (OR 1.23 95% CI 0.73, 2.07, $P = 0.440$).

Conclusion: In this population, there was a significant association between BMF use and increased SBP, CIMT and pre-hypertension. This requires further exploration with a large-scale longitudinal study design because there are policy implications for countries like Nigeria where a large proportion of the population still rely on BMF for domestic energy.

1. Introduction

Air pollution is the world's largest single environmental health risk. About 80% of total air pollution exposure occurs indoors, rather than outdoors, in low and middle-income countries (LMIC) (Bruce et al., 2000).

Cardiovascular disease (CVD) is a leading cause of death globally. The burden is higher in LMIC where over 80% of CVD deaths occur (Yusuf et al., 2011). Air pollution from the use of solid fuels in households has been linked mainly to diseases of the respiratory tract including respiratory tract infections, chronic obstructive airway disease and even lung cancer (Ezzati and Kammen, 2001; Lin et al., 2008; Lissowska et al., 2017). However, it is also an increasingly recognised modifiable risk factor for CVD, with evidence of adverse consequences to the cardiovascular system (Chockalingam et al., 2012; Mittleman et al., 2010). Air pollutants implicated in health problems include particulate matter (PM), carbon monoxide, nitrogen dioxide (NO2), and Sulphur dioxide (SO2). Particles that are

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10 μm in diameter or smaller, especially those below 2.5 μm (PM2.5) are released from several sources including the incomplete combustion of solid fuels. They are hazardous because they can achieve entry into the lungs and contribute to cardio-pulmonary disease through mechanisms that include oxidative stress-induced endothelial dysfunction, cascade of cytokines and inflammatory mediators and pro-coagulation (Naeher et al., 2007). The mass concentration of PM2.5 is a commonly used metric for assessing exposure to combustion products. The World Health Organization's ambient air quality guideline for annual average PM2.5 set an upper limit of 10 $\mu g/m^3$ and 24-hour mean levels of 25 $\mu g/m^3$ to protect human health. Daily average personal PM2.5 exposures among people from households using solid fuels are often in the thousands of $\mu g/m^3$ and these daily exposures generally continue throughout life (Bruce et al., 2000).

In Nigeria, a major source of household air pollution is the incomplete combustion of biomass fuels (BMF) for domestic purposes like cooking and heating. Energy consumption in Nigeria is a paradox. The country is a major exporter of crude oil and natural gas yet most of its population depends on biomass sources for their energy needs (Suleiman and Idris, 2016). The use of firewood, agricultural waste, animal dung and charcoal for domestic use is widespread, particularly in the rural areas and approximately half of the Nigerian population reside in rural areas (Rehfuess et al., 2006; IEA, 2015). Biomass fuels are a renewable source of energy. However, their use can be problematic because incomplete combustion in inefficient stoves leads to the release of harmful air pollutants including particulate matter and greenhouse gases. These are not only harmful to human health, but also contribute to global warming and climate change. In addition, the time spent gathering firewood by mostly women and children keep them away from school and other income generating activities, thus contributing to the burden of inequalities faced by this demographic (Gujba et al., 2015).

The second most common fuel used for domestic purposes in rural areas is kerosene. Kerosene use is known to have adverse effects on health especially with regards to impairment of lung function. In addition, it poses a risk of explosion/burns and accidental poisoning (WHO, 2014). Combustion of liquid kerosene is also associated with the release of harmful air pollutants, but this is much less than with biomass fuels (Pokhrel et al., 2015a). The WHO recommends that kerosene users transition from kerosene to clean fuels like liquified petroleum gas. In resource poor communities, this may be difficult to do without considerable government support as the ability to purchase kerosene in small quantities to meet daily needs, makes it a more attainable option than LPG especially when added to the problem of unstable electricity supply (World Bank Group, 2018). Many times, the only available alternative to biomass fuels is kerosene.

Studies have shown links between inefficient combustion of biomass and blood pressure as well as subclinical atherosclerosis but none of these has involved rural women in rural parts of Nigeria. Thus, this study aimed to examine the association between the exposure to biomass smoke and blood pressure as well as increased carotid intima thickness among rural women in Southern Nigeria. Furthermore, we sought to quantify the concentration of indoor PM2.5, in a subset of the selected households to assess the magnitude of difference in the concentration of this pollutant by fuel use type.

2. Methods

2.1. Study setting

Nigeria is the most densely populated country in Africa with a population of 140,431,790 people at the last official census (Commission, 2009). Rivers State is one of the 36 States and is in the south-south geopolitical zone of Nigeria and currently has 23 local governments, occupying an area of 1,077 km.sq. with a population of 5,198,716 people (Commission, 2009). The main economic activities are fishing, agriculture and crude oil exploration. It is a region beset with environmental challenges ranging from air pollution from natural gas flaring activities to massive water and land pollution from crude oil exploration activities. Added to this are the fact that much of the state is underdeveloped, with high levels of energy poverty (83.1%) causing a significant proportion of the population to use mostly, firewood, sawdust and other crude forms of fuel for cooking purposes (Edoumiekumo et al., 2013).

2.2. Study design

This was a cross-sectional study conducted in three rural communities in Rivers state.

2.3. Sampling

A multi-stage sampling framework was employed to identify rural locations in Rivers state. There are 23 Local Government Areas (LGA) in Rivers state and one (Abua/Odual) was selected. It is a predominantly farming community with ample access to biomass (predominantly wood) for fuel use. The population is estimated at 282,410 (National Population Commission, 2009). Allowing a 95% confidence level and 5% error margin, the estimated sample size required was 384 individuals. There are 9 communities in the LGA and simple random sampling was done to select three (Omelema, Emilaghan and Ogbema). From each of these communities we aimed to sample at least 128 households. We selected the first household by simple random sampling and then subsequently sampled every third household and collected data from one eligible participant from each household until the sample size was achieved. Where selected households did not have eligible participants, we selected the next eligible one.

2.4. Ethical statement

Ethical approval for the study was obtained from the ethics committee of the University of Port Harcourt and the Primary Health Care Management Board of Rivers State. The study was carried out in keeping with the Helsinki Principles for human research. Participants either signed or thumb-printed a consent form. The purpose of the study was explained and relayed in the local language for those who did not understand English. The participants were reassured that the data collected was confidential and anonymised. The participants were informed of their freedom to refuse or withdraw participation at any time with no negative consequences.

2.5. Study population and procedures

In each selected household in the chosen communities, females aged $\geq$18 years who were full-time residents and were the principal cooks in the households were invited to participate in the study. Those that gave informed consent were recruited.

Six trained research assistants collected information on socio-demographic variables, behavioural patterns and a brief medical history using a modified version of the WHO STEPS (core and expanded) instruments. A participant's alcohol intake was deemed significant when it exceeded 14 units a week.

A biomass exposure questionnaire was built on the Open Data Kit software on GPS-enabled android phones and used to obtain information on the predominant type of fuel used for domestic purposes, the proximity of the kitchen/cooking area to the main living area, mode of ventilation in the kitchen, type of stove or fireplace, frequency and timing of cooking. Those who used predominantly firewood, charcoal or agricultural waste classified as biomass users while those who used electricity, bottled gas or kerosene were classified as non-biomass users.

Physical measurements taken included weight, height, and blood pressure. Weight was measured with a Seca mechanical weighing scale to the nearest 0.5 kg with the subject wearing only light clothing, and height was measured using a flexible tape measure held against a straight wall. The participant was asked to stand with their feet together without shoes or head gear, back and heel against the wall and the reading was taken to the nearest 0.5 cm. Body mass index was calculated as body weight in kilograms divided by the square of the height in meters and classified according to the WHO criteria as normal weight (18.5–24.9 kg/m^2), overweight (25–29.9 kg/m^2) or obese (more than 30.0 kg/m^2).

Blood pressure was measured with validated (Omboni et al., 2007) automatic Omron M5 BP monitors (Omron Corp, Tokyo, Japan) with an appropriate cuff size on the patients' right arm in the seated position with feet on the floor after a five-minute rest. The average of two blood pressure measurements taken 5 min apart was used. Normal blood pressure was defined as SBP below 120 mmHg and/or DBP below 80 mmHg. Prehypertension was defined as SBP of 120–139 mmHg and/or DBP of 80–89 mmHg while hypertension was defined as SBP of 140 mmHg and above and/or DBP of 90 mmHg or above (Chobanian et al., 2003).

At the end of each interview, the data collector uploaded the completed questionnaires on the Open Data Kit software to the server domiciled in the WHO state office. To minimize measurement bias, the data collectors who took physical measurements and blood pressure were blinded to the study objectives.

After the questionnaires were administered, the participants were asked to present to the Primary Health Centre the next morning following an overnight fast. At the health centre, five milliliters of venous blood was drawn from the antecubital vein using standard sterile procedures and stored for transportation to a central laboratory for analysis of lipid profile, blood glucose and serum creatinine.

Carotid intima media thickness (CIMT) was measured in real time by carotid ultrasound imaging with a 9 MHz GE 9L-RS Linear Array Probe and a portable GE Vivid i2 machine using the machine's automated software for IMT measurement. Focus and gain settings were adjusted to optimize images of the far wall of the carotid arteries. The IMT was measured over a 10 mm segment of the far wall of both common carotid arteries during peak R wave, 1 cm proximal to the carotid bulb. The mean CIMT was determined by the internal software of the machine as the average of the automated measurements. Each reported CIMT represents the average of both right and left common carotid artery measurements (Simova, 2015). All the scans were performed by one person experienced in carotid ultrasonography and the reproducibility of the scans was assessed by repeating 10% of the scans randomly and the intra-observer variability was 99%. Carotid intima-media thickness was expressed as a continuous variable.

In a subset of the households (33 using BMF and 29 not using BMF), indoor PM2.5 measurements were collected at six time intervals during the day to reflect cook times and non-cooking times using a Metone Aerocet 531 automatic instrument (Metone Instruments Inc., USA). It was held 1.0–1.5 meters off the ground and 0.5–1.0 meter away from the stove/fireplace. Repeated mass measurements of PM2.5 was taken at 2-minute intervals for the duration of sampling.

2.6. Statistical analysis

There were 431 women who met the study criteria and were interviewed but only 389 with complete data as some did not show up at the clinic to have further assessment for various reasons (Fig. 1). The analysis was done on the 389 women with complete data. This was performed with Statistical Package for the Social Sciences for Mac, version 21.0 (SPSS Inc., Chicago, IL, USA). Continuous variables were expressed as mean (standard deviation) and categorical data as proportions and percentages. The outcome variables of interest were systolic and diastolic blood pressure, prehypertension, hypertension and carotid intima media thickness. These variables were compared between biomass and non-biomass users using statistical tests of significance. Association between the type of fuel used and blood pressure and CIMT was assessed with linear regression with the latter as dependent variables. Logistic regression analysis was used to determine the odds of a study participant being classified as having pre-hypertension or hypertension by fuel use category. The analyses were adjusted for confounding variables. Further sensitivity analyses were performed by re-defining fuel use category (considering kerosene as a BMF and as a separate category i.e. three categories of fuel: BMF, non-BMF, and kerosene) to examine how the observed effect of BMF on prehypertension changes. P values less than 0.05 were considered statistically significant.

3. Results

3.1. Demographic characteristics

The study participants consisted of 389 women. The mean age of the study population was 38.7 ± 14.1 years. The average number of years spent as the principal cook in the household was 16.5 ± 15.9 years. The prevalence of predominant BMF use was 249 (64.0%), of which 1 (0.3%) used charcoal, 144 (37%) used wood logs and 104 (26.7%) used wood twigs/branches. Prevalence of kerosene use was 102 (26.2%), electric burners 7 (1.1%) and bottled gas 31 (7.9%). The predominant occupation was farming 187 (48%), followed by trading 98 (25.2%), 52 (13.4%) were students/unemployed and 52 (13.4%) were skilled workers.

Study participants who used kerosene, electricity and bottled gas for fuel were grouped together and analysed as non-BMF users.

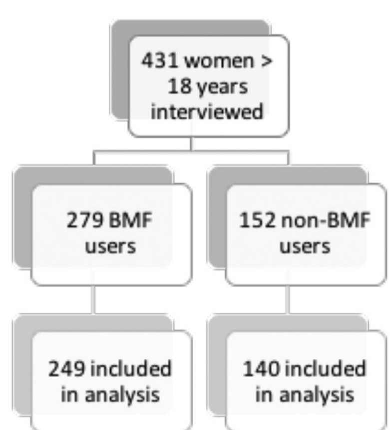

Fig. 1. Study population.

3.2. General characteristics of the participants stratified by type of fuel used

The users of BMF were significantly older. Majority of the study participants had secondary level of education with no significant difference in educational attainment among the two groups. There was an overall low prevalence of cigarette smoking and although the prevalence of significant alcohol intake was higher among non-BMF users, these differences were not statistically significant. The BMF users had significantly lower body weight with more of them classified as underweight compared to the non-BMF users (8.8% vs 3.6% respectively $p = 0.031$). Furthermore, they had higher mean total cholesterol, triglycerides and HDL cholesterol but differences in lipid profile were not statistically significant (Table 1).

3.3. PM2.5

Sixty-two of the households were sampled. In all of them, the mean ± SEM PM2.5 during cooking was higher compared to non-cooking times as expected (BMF: 196.3 ± 24.5 vs 12.3 ± 5.7 μg/m^3; non-BMF: 79.5 ± 13.3 vs 4.6 ± 0.6 μg/m^3). In all assessed households, the average PM2.5 concentrations during non-cooking times was below the WHO guidelines for 24-h mean levels of PM 2.5 which is less than or equal to 25 μg/m^3. When comparing BMF using households to non-BMF using households, the mean ± SEM PM2.5 was significantly higher during cooking compared to non-cooking times (196.3 ± 24.5 μg/m^3 vs 79.5 ± 13.3 μg/m^3, $p < 0.001$) (Fig. 2). The levels of PM2.5 was highest with BMF, then kerosene and least in LPG/electricity using households (Table S1 supplementary material).

3.4. Systolic and diastolic blood pressure and CIMT by biomass fuel use

The mean (SD) systolic blood pressure among BMF users was 135.3 (26.7) mmHg compared to non-BMF users 123.8 (22.6)

Table 1
Differences between the two groups of participants.

Participants characteristic	Biomass fuel user	Non-biomass fuel user	P-value
Sample size	249	140	–
Socio-demographics			
Age (years), mean (SD)	41.5 (14.8)	33.9 (10.9)	<0.001
Educational level n (%)			
• None	21 (8.4)	12 (8.6)	0.388
• Primary	38 (15.7)	13 (9.3)	
• Secondary	143 (57.4)	84 (60.0)	
• Tertiary	47 (18.9)	31 (22.1)	
Occupation n (%)			
• Farming	120 (48.2)	67 (47.9)	0.455
• Trading	58 (23.3)	40 (28.6)	
• Student/unemployed	36 (14.5)	16 (11.4)	
• Skilled worker	35 (14.0)	17 (12.1)	
Time spent cooking/day (minutes) mean (SD)	73.5 (36.8)	68.9 (32.9)	0.225
Poorly ventilated kitchen	179 (71.9)	81 (57.9)	0.007
Anthropometry			
Weight (kg), mean (SD)	61.4 (16.6)	65.1 (13.0)	0.028
Height (cm), mean (SD)	157.9 (7.1)	159.3 (6.8)	0.060
BMI (kg/m^2), mean (SD)	24.7 (6.1)	25.7 (5.0)	0.146
BMI category, n (%):			
• Under weight	22 (8.8)	5 (3.6)	0.031
• Normal	130 (52.2)	61 (43.6)	
• Over weight	61 (24.5)	46 (32.9)	
• Obese	36 (14.5)	28 (20.0)	
Blood pressure			
Systolic BP, mean (SD)	135.3 (26.7)	123.8 (22.6)	<0.001
Diastolic BP, mean (SD)	83.7 (18.5)	80.1 (13.8)	0.043
Pre-hypertension n (%)	92 (36.9)	42 (30)	<0.001
Hypertension n (%)	96 (38.6)	33 (23.6)	0.003
Carotid intima media thickness			
CIMT, mean (SD)	0.63 (0.16)	0.56 (0.14)	0.004
Other variables that may modify CIMT and blood pressure			
Cigarette smoker n (%)	5 (2.0)	1 (0.7)	0.670
Exposed to passive smoke in household n (%)	23 (9.2)	8 (5.7)	0.136
Consumes alcohol n (%)	102 (40.9)	65 (46.4)	0.355
Alcohol intake >14 units/week n (%)	38 (15.3)	27 (19.3)	0.315
History of hypertension, n (%)	30 (12.0)	25 (17.9)	0.115
History of diabetes, n (%)	11 (4.4)	7 (5.0)	0.793
Fasting blood glucose mmol/l, mean (SD)	5.2 (1.9)	4.9 (1.4)	0.320
Total cholesterol, mmol/l mean (SD)	4.51 (0.85)	4.47 (0.85)	0.779
High TC, n (%)	32 (29.1)	13 (26.0)	0.687
HDL-c mmol/l mean (SD)	0.77 (0.22)	0.75 (0.20)	0.518
Low HDL-c, n (%)	99 (90.0)	46 (92.0)	0.687
TG, mmol/l mean (SD)	1.30 (0.53)	1.21 (0.46)	0.278
High TG, n (%)	24 (21.8)	7 (14.0)	0.246
LDL-c mmol/l	3.12 (0.80)	3.14 (0.87)	0.930
High LDL-c, n (%)	69 (62.7)	31 (62.0)	0.930

Unless otherwise stated, values are expressed as n (%) with significant Chi-square values at $p < 0.05$.
Legend: BMI- body mass index, HDL-high density lipoprotein cholesterol, LDL-low density lipoprotein cholesterol, TC- total cholesterol, TG-triglycerides, SD- Standard deviation.

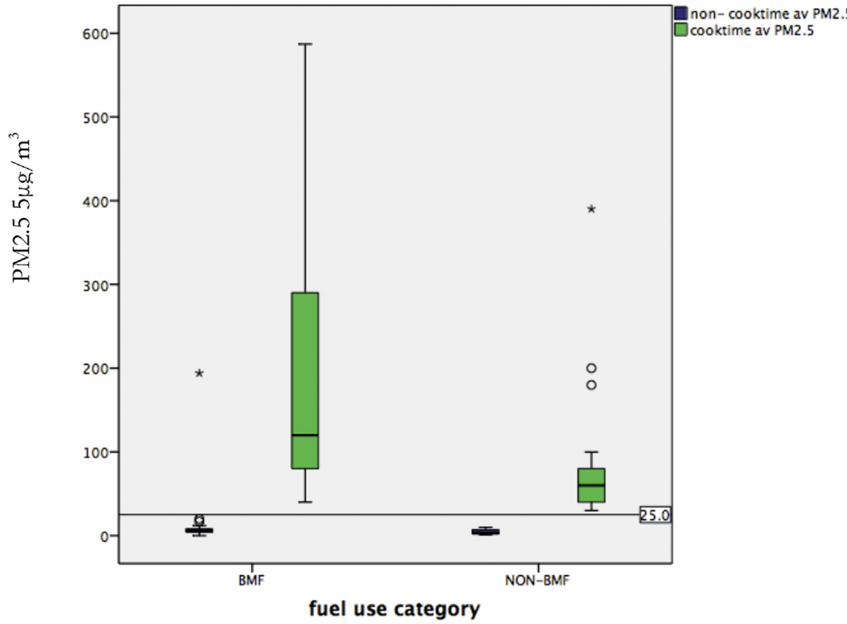

Fig. 2. PM2.5 in a subset of BMF and non-BMF using households.

mmHg. The mean (SD) diastolic blood pressure among BMF users was 83.7 (18.5) compared to 80.1 (13.8) mmHg among non-BMF users. These differences were statistically significant. The mean (SD) CIMT was significantly higher in the BMF group 0.63 (0.16) mm compared to 0.56 (0.14) mm in the non BMF group (Table 1). There was a significant positive correlation between CIMT and age ($r = 0.291$, $p < 0.001$), SBP ($r = 0.237$, $p = 0.001$) and DBP ($r = 0.186$, $p = 0.010$).

In regression analysis, after adjusting for other variables, non-BMF use was associated with a 2.7 mmHg points lower SBP compared to BMF users. Use of non-BMF was associated with lower DBP but this was not significant after adjusting for confounding variables. Furthermore, non-BMF use was independently associated with 0.04 mm lower CIMT and this was statistically significant ($p = 0.048$) (Table 2).

3.5. Prevalence of prehypertension and hypertension by biomass fuel use

A total of 134 women had pre-hypertension giving a study prevalence of 34.4%. Prevalence of pre-hypertension was 36.9% among BMF users compared to 30.0% among non-BMF users. This difference was statistically significant ($p < 0.001$). Overall, 129 women had hypertension giving a study prevalence of 33.2%. Prevalence of hypertension was 38.6% among BMF users compared to 23.6% among non-BMF users ($p = 0.003$) (Table 1). When stratified by age group, pre-hypertension was significantly more prevalent in women aged 18–44 years among BMF users compared to non-users (Table S3).

In logistic regression analysis, BMF users were significantly more likely to have pre-hypertension compared to non-BMF users after adjusting for other variables (OR 1.67 95% CI 1.56, 4.99, $P = 0.035$) (Table 3). However, although the odds of having hypertension associated with using BMF was 1.2 times higher than a non-BMF user, this was not an independent effect (OR 1.23 95% CI 0.73, 2.07, $p = 0.440$).

Further sensitivity analyses (Supplementary Tables S5–S7) were done by considering kerosene with BMF as one category and comparing that to LPG/Electricity. Use of BMF was associated with prehypertension (OR 1.62 95% 0.84, 3.14 CI, $P = 0.152$), hypertension (OR 2.12, 95% CI 0.95, 4.75; $P = 0.067$) and increased CIMT (B 0.06, 95% CI -0.017, 0.135; $P = 0.125$) but the associations were not statistically significant. The associations were also analysed by considering kerosene as a separate category i.e. three categories of fuel: BMF, kerosene and LPG/electricity. With this, BMF was non-significantly associated with prehypertension (OR 1.22 95% 0.61,

Table 2
Association between fuel use type and SBP, DBP, CIMT using multiple regression.

Variable	B	95% CI	p
Fuel use (non-BMF)			
SBP			
Non-adjusted	−11.7	−16.92, −6.47	<0.001
Adjusted	−2.7	−4.80, −0.55	0.040
DBP			
Non-adjusted	−4.3	−7.77, −0.76	0.017
Adjusted	−1.2	−4.56, 2.24	0.499
CIMT			
Non-adjusted	−0.059	−0.11, −0.01	0.014
Adjusted	−0.041	−0.09, −0.01	0.048

The multiple linear regression model was adjusted for age, weight, education, occupation, kitchen ventilation, hours per day spent cooking, alcohol consumption (significant versus non-significant), fasting blood glucose, total cholesterol, triglycerides, HDL and LDL cholesterol. SBP and DBP were added to the model for CIMT (see Table S2 for full table).

Table 3
Association between fuel use and pre-hypertension and hypertension using logistic regression.

Study participants	OR	95% CI	p
Fuel use			
Pre-hypertension			
Non-adjusted	2.03	1.28, 3.24	0.003
Adjusted	1.67	1.56, 4.99	0.035
Hypertension			
Non-adjusted	1.59	1.46, 1.77	0.001
Adjusted	1.23	0.73, 2.07	0.440

Fuel use refers to BMF versus non-BMF with the latter as the reference. The logistic regression model was adjusted for age, weight, education, occupation, kitchen ventilation, hours per day spent cooking, alcohol consumption (significant versus non-significant), fasting blood glucose, total cholesterol, triglycerides, HDL and LDL cholesterol. See full regression model is in Table S4. OR-odds ratio.

2.44 CI, P = 0.574). The association with hypertension (OR 2.35 95% 1.04, 5.34 CI, P = 0.041) and CIMT (B 0.068, 95% CI 0.022, 0.115; P = 0.004) though statistically significant, lost significance after adjusting for confounding variables including age (Tables S6 and S7).

4. Discussion

In this population of rural women in Southern Nigeria, the levels of PM2.5 during cooking was significantly higher in BMF using households compared to non-users. In addition, the use of BMF was associated with higher systolic and diastolic blood pressures and increased odds of having pre-hypertension. The relationship between biomass fuel use and hypertension was however, not independent of confounding variables. Furthermore, women who use biomass fuels had small but significantly higher CIMT measurements compared to women who use cleaner fuels. To our knowledge this is the first study in this part of the world to examine such associations.

The association between BMF use and blood pressure we found in this study is in keeping with studies from other parts of the world. A study in India showed that women who used biomass fuel for cooking were exposed to three times the concentration of indoor PM when compared to women who used liquefied petroleum gas (LPG). Furthermore, they had a higher prevalence of hypertension and higher levels of inflammatory markers (Dutta et al., 2011). In this study, the mean concentration of cooking time PM2.5 was 2.5 times that of households who used cleaner fuels. Cooking is an essential activity of daily life and the women will be involved in cooking for most of their lives. It can thus be presumed that their cumulative exposure to the products of incomplete combustion of BMF will be considerable. The mean levels of PM 2.5 released during cooking in the households who used non-BMF although lower than BMF using households, was surprisingly high. This could be due to the use of wick kerosene stoves that is not a very efficient fuel burner. This has been demonstrated in other studies (Pokhrel et al., 2015b; Apple et al., 2010). Similarly in another study of 1186 Indian women older than 18 years, the investigators found that hypertension and pre-hypertension were significantly associated with the use of BMF (Dutta and Ray, 2012). In China, a cross-sectional survey of 14,068 adults showed that household use of solid fuels was associated with a significantly higher prevalence of hypertension, diabetes mellitus and coronary heart disease (Lee et al., 2012). Pena et al. in their study of 1004 individuals in Peru, found that biomass fuel users had an increase in the relative risk of having prehypertension (OR 5.0; 95% CI, 2.6–9.9) and hypertension (OR 3.5; 95% CI, 1.7–7.0). Furthermore, their study showed that SBP and DBP was higher by 7 mmHg and 5.9 mmHg among biomass fuel users compared to non-users (Peña et al., 2015). The present study found smaller increases in the SBP and DBP of study participants and this may be accounted for by the differences in population characteristics, cooking practices and the smaller sample size. The increase in the odds of having pre-hypertension in our study though small, was significant. Pre-hypertension is an important cardiovascular risk factor. This was demonstrated in a meta-analysis of 18 cohort studies that included 468,561 individuals (Huang et al., 2013). Pre-hypertension increased the risk of CVD (RR = 1.55; 95% CI = 1.41 to 1.71); CHD (RR = 1.50; 95% CI = 1.30 to 1.74); and stroke (RR = 1.71; 95% CI = 1.55 to 1.89). This risk was present even in the “low-range” of pre-hypertension (BP 120 to 129/80 to 84 mm Hg) compared to optimal BP (RR = 1.46, 95% CI = 1.32 to 1.62). The effect of lowering indoor air pollution by using a more efficient wood stove was demonstrated with a randomised controlled trial in Guatemala. They found that this intervention lowered SBP by 3.7 mm Hg (95% CI, −8.1 to 0.6) and DBP by 3.0 mm Hg (95% CI, −5.7 to −0.4) (McCracken et al., 2007).

It has been hypothesised that during combustion of solid fuels, the release of PM and other pollutants including black carbon, allows the entry of small sized particles into the body through the respiratory system which increases oxidative stress and triggers an inflammatory cascade. This includes the release of pro-coagulatory fibrinogen and endothelin (Naeher et al., 2007). The nitric oxide pathway is also altered and this directly impacts on blood pressure. Inflammation in the vessel wall is the pathologic basis for atherosclerosis and increased CIMT is a marker of atherosclerosis. In this study, the use of BMF was associated with a 0.05 mm higher CIMT measurement. Epidemiological studies have shown significant associations between PM2.5 and both acute and chronic CVD (Miller et al., 2007; Mittleman et al., 2010). A study in Peru, evaluated the association between biomass fuel use and CIMT in 266 adults aged 35 years and above (Painschab et al., 2013) They showed that BMF users had higher SBP, higher mean CIMT (mean difference = 0.03 mm, 95% CI 0.01 to 0.06; p = 0.02) and the prevalence of carotid plaques was higher compared to non-BMF users (OR = 2.6, 95% CI 1.1 to 6.0; p = 0.03). Another study conducted on healthy adults who had lifetime exposure to biomass smoke compared to the control group with no exposure, demonstrated no difference in their mean CIMT (Buturak et al., 2011). However, the exposed group had a significantly reduced flow associated dilatation and endothelium independent vasodilatation suggesting that long term exposure to biomass smoke was a factor in the development of endothelial dysfunction which is an early event in atherosclerosis.

Kerosene is a chemical mixture produced from crude oil distillation. Some studies suggest a link between air pollution from kerosene combustion and cardiovascular disease. An animal study showed that exposure to high levels of kerosene exhaust compared to saline aerosols induced aortic plaques in guinea pigs (Noa and Illnait, 1987). Another study showed that among healthy individuals, forearm blood flow was acutely reduced following exposure to diesel exhaust (similar to kerosene as a product of crude oil distillation) and this reduction was in spite of concurrent administration of vasodilators (Mills et al., 2005). Other putative mechanisms for its atherogenic effects include reduction in tissue plasminogen activator with a resultant impairment of endogenous fibrinolysis (Mills et al., 2005). As such, kerosene is not a "clean fuel" but its use is associated with less emission of harmful particulate matter when compared to BMF (Pokhrel et al., 2015a). We tried to examine if the associations would change if kerosene was grouped with BMF and found that although there was increased odds of pre-hypertension, hypertension and increased CIMT, these were not statistically significant. This may have been due to the very small size of the comparator group (LPG/Electricity). Further analyzing kerosene as a separate category from BMF and LPG/Electricity, kerosene was associated with lower odds of hypertension and pre-hypertension and lower CIMT when compared to BMF but again these were not statistically significant. This differed from the findings from a randomised intervention field trial that was conducted in Nigeria (Alexander et al., 2017). The investigators randomised 324 pregnant women to either use ethanol cookstoves or continue their usual practice of cooking with firewood or kerosene. The use of the cleaner fuel resulted in a 2.8 mmHg reduction in diastolic blood pressure and 4.5% reduction in the prevalence of hypertension. In sub-group analysis, they found that switching from kerosene to ethanol improved blood pressure but this did not happen when firewood users switched to ethanol. This may suggest that kerosene is more harmful with regards to blood pressure compared to firewood but the study was not powered to examine this difference and thus the association may have been confounded by other unmeasured variables. Nevertheless it is important that household energy sources shift from solid fuels and kerosene to cleaner fuels because even when more efficient cookstoves are used to burn solid fuels and kerosene, they are still associated with unacceptably high levels of household air pollutants (Miele and Checkley, 2017).

In this era of transdisciplinary research, it is imperative to look beyond just the health consequences of biomass fuel use. This is because widespread use of BMF has environmental and economic implications as well. The relative 'free availability' of firewood (which formed majority of the biomass fuel used by the study participants), contributes to deforestation. This is especially true when these fuels are not harvested in a sustainable manner and their advantage of being a renewable source of energy is lost. Furthermore, the distances travelled to harvest these fuels especially by women and children are often considerable. This takes away time that could have been spent in school or more gainful employment.

This study demonstrates a link between BMF use and markers of cardiovascular risk. More research is needed by cardiovascular and public health physicians to examine these relationships in greater detail as well as to influence energy policy in the country through the design of projects that will determine the effect of changing fuel use practices and improved cook stoves in a culturally acceptable manner.

5. Conclusion

In this population of rural women in southern Nigeria, the use of biomass fuel increased household levels of PM2.5, and was independently associated with higher systolic blood pressure, CIMT and higher odds of pre-hypertension. Larger scale studies are needed to further examine these relationships and assess the cardiovascular impact of improved cook-stove and cleaner fuels interventions.

6. Limitations

This study did not capture all representative exposure variables for the study population as time-trend changes in exposure were not accounted for due to its cross-sectional design. Short term variation in PM2.5 exposure as assessed in this study does not allow for accurate determination of its association with a chronic condition such as hypertension and the consequences of atherosclerosis. Some other confounding variables like physical activity levels, were also not taken into account. Furthermore, this study cannot determine what particular components of air pollution from fuel combustion had an effect on the outcome variables.

Contributors

S.O and O.J designed the study protocol, S.O conducted the research with the help of trained assistants and did the data analysis all under the close supervision of J.F and O.J The manuscript was drafted by S.O and J.F.

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Conflicts of interest

None declared by any of the authors.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.envpol.2018.06.102.

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