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A feasibility study of the association of exposure to biomass smoke with vascular function, inflammation, and cellular aging

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ABSTRACT

Background: Biomass smoke at higher concentrations is associated with respiratory symptoms and, after years of exposure, increased risk of respiratory disorders in adults, but its effects on cardiovascular diseases are not well characterized, particularly compared with other pollution sources like tobacco smoke or traffic.

Methods: We conducted a cross-sectional study and enrolled 25 women living in rural Sichuan, China. We measured integrated 24-h personal exposure to fine particulate matter ($PM_{2.5}$) and black carbon, and measured $PM_{2.5}$ and black carbon in their kitchens. We assessed participants' brachial and central blood pressure and arterial stiffness using pulse wave analysis, and analyzed dried blood spot and buccal cell samples for C-reactive protein and relative telomere length. We also evaluated the difference in these physiological and biomarker measures between individuals with high (≥ median) versus low (< median) $PM_{2.5}$ exposure using multivariate regression.

Results: Geometric mean 24-h $PM_{2.5}$ and black carbon exposures were 61 μg/m^3 (95% CI: 48, 78) and 3.2 μg/m^3 (95% CI: 2.3, 4.5), respectively. Average kitchen $PM_{2.5}$ and black carbon concentrations were only moderately correlated with personal exposures ($PM_{2.5}$: r=0.41; black carbon: r=0.63), although they had similar means. Women in the high and low exposure groups were similar in age, obesity, socioeconomic status, salt intake, and physical activity. Women in the high $PM_{2.5}$ exposure group had higher mean brachial systolic blood pressure (SBP; difference=4.6 mmHg, 95% CI −7.8, 16.9), central SBP (difference=3.1 mmHg, 95% CI: −8.4, 14.5), central pulse pressure (difference=4.1 mmHg; 95% CI: −4.2, 12.4), and augmentation index (difference=2.8%, 95% CI: −1.6, 7.2). High exposed women had 43% shorter telomere length (95% CI: −113, 28) than that of women in the low exposure group. There were no differences in pulse wave velocity or C-reactive protein between the two exposure groups. None of the results was statistically significant.

Conclusions: Our results suggest that it is feasible to measure markers of vascular function and biomarkers of inflammation and oxidative stress in field studies of biomass smoke. Although many of the associations were in the expected direction, larger studies would be needed to establish the effects.

1. Introduction

Almost half the world's population and over 40% of Chinese homes cook with traditional biomass stoves that emit high concentrations of particulate matter (PM) and gases (Bonjour et al., 2013), which we refer to here as household air pollution (HAP). HAP is estimated to be the fourth leading contributor to the global

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burden of disease, responsible for 3.5 million yearly premature deaths (Lim et al., 2012), and is a contributor for global and regional climate change (Bond et al., 2013).

Exposure to HAP is associated with an increased risk of respiratory diseases in children and adults (Dherani et al., 2008; International Agency for Research on Cancer, 2006; Kurmi et al., 2010). Limited evidence suggests that HAP exposure may also affect the vascular system in ways that increase cardiovascular disease risk (Tolunay and Chockalingam, 2012). Our previous studies in rural China documented a dose–response relationship between personal exposure to fine PM ($PM_{2.5}$; <2.5 μm in aerodynamic diameter) and BC with blood pressure in women cooking with biomass (Baumgartner et al., 2014; Baumgartner et al., 2011a), and cookstove intervention studies in Latin America found lowered blood pressure (Alexander et al., 2014; Clark et al., 2013a; McCracken et al., 2007) and reduced ST-segment depression (McCracken et al., 2011) in women with reduced HAP exposure. Recent cross-sectional studies found greater prevalence of carotid atherosclerotic plaque (Painschab et al., 2013), heart disease, and stroke (Lee et al., 2012) among biomass users compared with users of cleaner-burning gaseous fuels, though neither study controlled for socioeconomic status which is associated with both fuel use and health. An experimental study found that short-term exposure to high woodsmoke concentrations was associated with acute arterial stiffness in healthy Swedish adults (Unosson et al., 2013).

Overall, however, very little is known about the effects of HAP on the cardiovascular system compared with other major PM sources like tobacco smoke, traffic, and industry (Clark et al., 2013b). Exposure to environmental tobacco smoke has been associated with acute arterial stiffness and increased risk of myocardial infarction, stroke and, cardiovascular mortality (Barnoya and Glantz, 2005; U.S. Department of Health and Human Services, 2006). Longer-term exposure to outdoor PM over many years is associated with an increased risk of heart disease and cardiovascular mortality (Pope and Dockery, 2006; Pope et al., 2004a; Dockery et al., 1993; Krewski et al., 2004), while shorter-term exposure (days to weeks) can trigger unstable angina and myocardial infarction (Laden et al., 2000; Peters et al., 2001; Pope et al., 2006; Qian et al., 2008). The mechanisms by which PM exposure affects arterial stiffness and cardiovascular diseases are not entirely understood, but oxidative stress and systemic inflammation appear to be involved (Brook et al., 2010). These mechanisms have been implicated in increased blood pressure (Bautista et al., 2005) and arterial stiffness (Vlachopoulos et al., 2005), as well as shortened telomere length (Demissie et al., 2006; Grahame and Schlesinger, 2012). Notably, exposure to outdoor PM and motor vehicle traffic has been associated with increased presence of blood inflammatory markers like C-reactive protein (Brook et al., 2010) and telomere attrition (Zhang et al., 2013).

We conducted a small, comprehensive pilot study of exposure to multiple air pollutants and their relationship with physiological outcomes and biomarker measures in Chinese women cooking with biomass fuel to assess the feasibility of larger field studies on HAP and its related environmental and human health impacts.

2. Materials and methods

2.1. Study location and population

Our study site, Shiyi Village, is located in Sichuan Province on the eastern edge of the Tibetan Plateau at ~1000 m elevation (31°48′31.27″N; 104°27′30.03″E). The climate is relatively mild in this mountainous region with an average temperature of 15.6 °C; 24.6 °C in July; and 5.4 °C in January.

Data collection took place in September of 2012. We recruited never-smoking women who were not pregnant and primarily used biomass fuel for cooking. Verbal informed consent was obtained from all participants.

The study was approved by the Institutional Review Board at the University of Minnesota, USA and the Sichuan Health Bureau.

2.2. Housing and household energy practices

Participants lived in single or two story homes, many of which were recently built as part of a reconstruction effort following the 2008 earthquake. Poorer families have homes with wooden frames and partial earth exterior whereas better-off families typically have homes constructed of brick and cement. Most homes have connected rooms, but the kitchen is in a separate building from the living quarters in a small number of homes. Kitchens typically have at least one set of windows and a door venting outside or into the living area.

Though wood was the primary fuel of our study homes, most also used secondary fuels for cooking (Table 1). Wood is burned for cooking 2–3 times each day in traditional brick chimney stoves with a ceramic outer layer that are built into the kitchen and designed for cooking on large, round-bottom pots (i.e., woks). Local masons construct the brick chimney stoves, which are very durable and can be used for a decade or longer. Though the stove's chimney vents most smoke outside of the kitchen, pollutants are released into the kitchen and other rooms of the house during lighting, re-fueling and from smoke that escapes from the combustion chamber openings during cooking events. In addition, the smoke vented out of the kitchen through the chimneys contributes to community pollution levels and can re-enter homes through windows and other openings into the home.

Though we conducted our study during the non-heating season, questionnaire results indicated that space heating is common for 3–11 months of the year. A small number of families reported using portable electric heaters, but most reported using wood-charcoal, which is burned in free-standing, metal fire pits that can be easily transported between rooms. Women reported using the wood-charcoal for several hours in the morning and evening, though a few homes reporting heating throughout the day and evening. They also reported burning wood in their cookstoves for extended periods during colder days as a secondary space heating stove. More details on housing and energy use practices at our field site are provided in the Supplementary information text.

2.3. Personal $PM_{2.5}$ and black carbon exposure

We measured average 24-h personal exposure to fine particulate matter <2.5 μm in aerodynamic diameter ($PM_{2.5}$) using Personal Exposure Monitors (PEMs) (Harvard School of Public Health, Boston, MA) with a d_{50} of 2.5 μm at 1.8 lpm (±10%) and a greased impaction surface (Demokritou et al., 2001). The PEMs held 37 mm PTFE filters (SKC Inc., USA, 2.0 μm pore size) and were connected to small pumps (Apex Pro, Casella CEL, UK). Participants wore the monitor in a small waistpack that they were instructed to wear at all times, but could place within 1 m while sitting or sleeping and within 2 m when wearing it was

Table 1
Household energy use practices in Sichuan.

Characteristic	Number (%) $n=25$
Cooking fuels (ever use)	
Wood	25 (100%)
Crop residues	9 (36%)
Coal	0 (0%)
Electricity	19 (76%)
Liquefied petroleum gas	5 (20%)
Biogas	4 (16%)
Primary cooking fuel	
Wood	25 (100%)
Crop residues	0 (0%)
Secondary cooking fuel	
Wood	0 (0%)
Crop residues	3 (12%)
Coal	0 (0%)
Electricity	18 (72%)
Liquefied petroleum gas	2 (8%)
Biogas	1 (4%)
No secondary fuel	1 (4%)
Heating fuels (ever use)	
Wood	18 (72%)
Coal	0 (0%)
Wood charcoal	18 (72%)
Electricity	9 (36%)
Primary heating fuel	
Wood	2 (8%)
Coal	0 (0%)
Wood charcoal	16 (64%)
Electricity	7 (18%)
No heating fuel	0 (0%)
Months using space heating (mean ± SD; range)	5 ± 2; 3–11
Heating hours per day in winter (mean ± SD; range)	3 ± 6; 0–22