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Association of Carbon Monoxide exposure with blood pressure among pregnant women in rural Ghana: Evidence from GRAPHS

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ABSTRACT

Background and objective: The Ghana Randomized Air Pollution and Health Study (GRAPHS) is a community-level randomized-controlled trial of cookstove interventions for pregnant women and their newborns in rural Ghana. Given that household air pollution from biomass burning may be implicated in adverse cardiovascular outcomes, we sought to determine whether exposure to carbon monoxide (CO) from woodsmoke was associated with blood pressure (BP) among 817 adult women.
Methods: Multivariate linear regression models were used to evaluate the association between CO exposure, determined with 72 hour personal monitoring at study enrollment, and BP, also measured at study enrollment. At the time of these assessments, women were in the first or second trimester of pregnancy.
Results: A significant positive association was found between CO exposure and diastolic blood pressure (DBP): on average, each 1 ppm increase in exposure to CO was associated with 0.43 mmHg higher DBP [0.01, 0.86]. A non-significant positive trend was also observed for systolic blood pressure (SBP).
Conclusion: This study is one of very few to have examined the relationship between household air pollution and blood pressure among pregnant women, who are at particular risk for hypertensive complications. The results of this cross-sectional study suggest that household air pollution from wood-burning fires is associated with higher blood pressure, particularly DBP, in pregnant women at early to mid-gestation. The clinical implications of the observed association toward the eventual development of chronic hypertension and/or hypertensive complications of pregnancy remain uncertain, as few of the women were overtly hypertensive at this point in their pregnancies.

Introduction

Worldwide, close to 3 billion households rely on biomass fuels for cooking and heating (Bonjour et al., 2013). Household Air Pollution (HAP) is created by the combustion of these fuels in open fires, and has been associated with many adverse health outcomes. In 2010, HAP was ranked the fourth contributing risk factor to the burden of disease worldwide (Lim et al., 2012). For the country of Ghana specifically, HAP is the number one risk factor, contributing to the highest national burden of disease including cardiovascular disease (CVD) (Institute for Health Metrics and Evaluation, 2013). Despite the huge estimated CVD burden associated with HAP, only one study to date has directly investigated the association between HAP and cardiovascular morbidity (Lee et al., 2012a). Given the long latencies in CVD, such studies are very challenging. Most research has consequently focused on risk factors for CVD.

Blood Pressure (BP) is a known risk factor for CVD (Lewington et al., 2002), and has been shown to respond to changes in air pollution, particularly with respect to particulate matter less than 2.5 microns in aerodynamic diameter ($PM_{2.5}$) (Brook et al., 2010). Mechanisms that may underlie the response of BP to exposure to particulate matter include autonomic imbalance and

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oxidative stress (Brook et al., 2009). Several controlled experiments in humans have demonstrated almost immediate increases in BP in response to short-term increases in $PM_{2.5}$ (Cosselman et al., 2012; Langrish et al., 2009; Urch et al., 2005), although other studies have not found this association (Brook et al., 2002). A review of epidemiologic studies, largely conducted in economically advanced countries, indicates that a 10 $\mu g/m^3$ increase in ambient $PM_{2.5}$ is associated with BP elevations of approximately 1–8 mmHg (Brook and Rajagopalan, 2009). Meanwhile, exposures to $PM_{2.5}$ can be much higher in the developing world (Clark et al., 2013); in the geographic region of this study, personal air sampling has previously recorded 24 hour exposure levels averaging 128.5 $\mu g/m^3$ among women who are the primary cooks for their households (Van Vliet et al., 2013).

HAP from biomass burning contains a complex mixture of volatile and particulate pollution (McCracken et al., 2012), including $PM_{2.5}$ and carbon monoxide (CO). Due to its relative ease of monitoring, CO monitoring has been used as an indicator of woodsmoke exposure in previous cookstove intervention studies, including the RESPIRE trial in Guatemala (Smith et al., 2011); however, the use of CO as a proxy for $PM_{2.5}$ exposure has been brought into question by several studies that have found poor correlations between the two pollutants in biomass settings (Dionisio et al., 2012; Klasen et al., 2015). Other studies have found stronger correlations between PM and CO, both in cooking areas and using personal measures (Dionisio et al., 2008; McCracken et al., 2013; Pollard et al., 2014). CO may itself be related to cardiovascular disease, with studies demonstrating associations between short-term increases in ambient CO and CVD hospital admissions in Taiwan (Yang et al., 2004) and the United States (Bell et al., 2009), and with CVD emergency department visits in Canada (Stieb et al., 2009), in statistical analyses that controlled for levels of co-pollutants such as PM and NO_2. The adverse health effects of chronic, low-level exposure to CO appear to reflect mechanisms other than the hypoxia that is implicated in acute CO poisoning—including endothelial inflammation and immune activation (World Health Organization (WHO), 2010). Few studies have so far been conducted to assess the relationship between CO and blood pressure, and those among pregnant women have yielded conflicting results. A large study of pregnant women in the United States found that 0 to 4-day-lagged ambient exposures to CO, but not PM, were associated with higher blood pressure at delivery among women who were normotensive or diagnosed with chronic hypertension (Männistö et al., 2014). Conversely, a cohort study of healthy pregnant women in Pennsylvania found that chronic exposure to PM, but not CO, was associated with higher BP in late pregnancy (Lee et al., 2012b).

The epidemiologic basis for our understanding of the association between HAP and BP currently rests on eight studies conducted in five locations: Guatemala (McCracken et al., 2007), India (Dutta et al., 2011), Nicaragua (Clark et al., 2011), China (Baumgartner et al., 2011), and Nepal (Neupane et al., 2015). Notably, all eight analyses have reported a positive association between HAP and BP, although the studies differ in the methods used to categorize HAP exposure (McCracken et al., 2012). While personal exposure monitoring is widely considered to be preferable to static monitoring techniques in terms of capturing health-relevant exposures to air pollutants (Clark et al., 2013; Steinle et al., 2013), few of these studies have employed personal monitoring. Those that have done so have been limited by sample sizes that were fairly small. These studies, meanwhile, have largely taken place among populations of non-pregnant adults, but pregnancy presents a period of particular concern for elevations in blood pressure. Hypertension complicates an estimated 5–10% of pregnancies worldwide (Duley, 2009; Lindheimer et al., 2010) and contributes substantially to global maternal mortality, accounting for an estimated 18% of all maternal deaths (Abalos et al., 2014). Hypertensive disorders during pregnancy also contribute to other adverse outcomes in both mother and child (Barker, 1995; Männistö et al., 2013). To our knowledge, only two studies (Agrawal and Yamamoto, 2015; Wylie et al., 2015) have previously investigated the relationship between biomass smoke exposure and hypertension in pregnancy, and neither has used personal monitoring to determine exposure to HAP.

The fact that HAP is a potentially modifiable environmental risk factor for both BP and CVD (Brook et al., 2011b) makes the case for the public health importance of scientific studies to clarify the relationship between HAP and cardiovascular risk factors, and to evaluate the potential impact of interventions to reduce HAP. Here, we report the results of a cross-sectional analysis of the association between CO exposure and blood pressure among 807 pregnant women in a predominantly rural setting of Ghana.

Methods

Data sources

Participants were studied upon initial enrollment into the study, "Ghana Randomized Air Pollution and Health Study (GRAPHS)". In brief, GRAPHS is a community-level clustered randomized controlled trial of a cookstove intervention in a predominantly rural area of Ghana (Jack et al., 2015) (NCT01335490). Inclusion criteria for enrollment include being in the first or second trimester of pregnancy, living in one of 35 communities in the Kintampo Health Research Center (KHRC) catchment area, being the primary cook of the household, and being a non-smoker. Exclusion criteria include carrying multiple fetuses or a gestational age greater than 28 weeks (determined via ultrasound) (Boamah et al., 2014). The predominant type of cookstove used by households in this area of Ghana is a three-stone fire, fed by firewood. GRAPHS is a collaboration between Columbia University and KHRC, and the location of the study is the Kintampo North Municipality and Kintampo South District of the Brong Ahafo Region, located in the middle belt of Ghana. In the study area, hypertension is one of the leading causes of adult visits to health facilities (Ghana Health Service, 2011).

Ethical approvals

Ethical approvals for GRAPHS were obtained from the Institutional Review Boards of Columbia University Medical Center, Massachusetts General Hospital/Partners Healthcare, the Ghana Health Service Ethical Review Committee, and the Kintampo Health Research Centre Institutional Ethics Committee.

Study participants

Enrollment and data collection for GRAPHS began in September 2013. Potential participants in this analysis included women who had been enrolled in GRAPHS and for whom both a baseline BP and an initial CO measurement session had been conducted by September 2014 ($n = 1183$).

Exposure monitoring

Personal CO measurements were collected for 72 hour periods immediately after the GRAPHS women were enrolled into the study, prior to delivery of improved cookstoves. Each woman was outfitted with a Lascar (Erie, PA) EL-CO-USB Carbon Monoxide (CO) data logger set to record CO measurements every 10 s. The Lascar EL-CO-USB device reports concentrations between 0 and 1000 parts per million (ppm) CO and has a manufacturer-reported precision of ±6%. The monitor was worn in the woman's breathing zone (attached to clothing) during the day, and women were instructed