Environment International 97 (2016) 195–203

Contents lists available at ScienceDirect

Environment International

journal homepage: www.elsevier.com/locate/envint

Full length article

Biomonitoring Human Exposure to Household Air Pollution and Association with Self-reported Health Symptoms – A Stove Intervention Study in Peru

Zheng Li, PhD, MPH, MS [a,b,*], Adwoa Commodore [c], Stella Hartinger [d,e,f,g], Michael Lewin [b], Andreas Sjödin [a], Erin Pittman [a], Debra Trinidad [a], Kendra Hubbard [a], Claudio F. Lanata [d], Ana I. Gil [d], Daniel Mäusezahl [e,f], Luke P. Naeher [g,h]

[a] *Centers for Disease Control and Prevention, National Center for Environmental Health, Atlanta, USA*
[b] *Agency for Toxic Substances and Disease Registry, Division of Toxicology and Human Health Sciences, Atlanta, USA*
[c] *Medical University of South Carolina, Charleston, USA*
[d] *Instituto de Investigación Nutricional, Lima, Perú*
[e] *Swiss Tropical and Public Health Institute, Basel, Switzerland*
[f] *University of Basel, Basel, Switzerland*
[g] *Universidad Peruana Cayetano Heredia, Lima, Perú*
[h] *University of Georgia, Athens, USA*

ARTICLE INFO

Article history:
Received 6 June 2016
Received in revised form 12 August 2016
Accepted 13 September 2016
Available online 24 September 2016

Keywords:
woodsmoke
household air pollution
stove intervention
polycyclic aromatic hydrocarbon
biomonitoring
1-hydroxypyrene

ABSTRACT

Background: Household air pollution (HAP) from indoor biomass stoves contains harmful pollutants, such as polycyclic aromatic hydrocarbons (PAHs), and is a leading risk factor for global disease burden. We used biomonitoring to assess HAP exposure and association with self-reported symptoms in 334 non-smoking Peruvian women to evaluate the efficacy of a stove intervention program.

Methods: We conducted a cross-sectional study within the framework of a community randomized control trial. Using urinary PAH metabolites (OH-PAHs) as the exposure biomarkers, we investigated whether the intervention group ($n = 155$, with new chimney-equipped stoves) were less exposed to HAP compared to the control group ($n = 179$, with mostly open-fire stoves). We also estimated associations between the exposure biomarkers, risk factors, and self-reported health symptoms, such as recent eye conditions, respiratory conditions, and headache.

Results: We observed reduced headache and ocular symptoms in the intervention group than the control group. Urinary 2-naphthol, a suggested biomarker for inhalation PAH exposure, was significantly lower in the intervention group (GM with 95% CI: 13.4 [12.3, 14.6] μg/g creatinine) compared to control group (16.5 [15.0, 18.0] μg/g creatinine). Stove type and/or 2-naphthol was associated with a number of self-reported symptoms, such as red eye (adjusted OR with 95% CI: 3.80 [1.32, 10.9]) in the past 48 h.

Conclusions: Even with the improved stoves, the biomarker concentrations in this study far exceeded those of the general populations and were higher than a no-observed-genotoxic-effect-level, indicating high exposure and a potential for increased cancer risk in the population.

Published by Elsevier Ltd.

1. Introduction

Nearly 40% of the global population uses biomass fuel, such as wood, charcoal, and crop residues, as their primary energy source for cooking and heating (Rehfuess et al., 2014). Household air pollution (HAP) from indoor biomass stoves contains harmful pollutants, such as fine particulate matter ($PM_{2.5}$), carbon monoxide (CO), and polycyclic aromatic hydrocarbons (PAHs). HAP has been linked to a variety of adverse health outcomes (Naeher et al., 2007; Zhang and Smith, 2007), such as chronic obstructive pulmonary disease (Kurmi et al., 2010), eye diseases (West et al., 2013), adverse birth outcomes (Amegah et al., 2014; Pope et al., 2010), lung cancer (Bruce et al., 2015) and other cancers (Josyula et al., 2015). In the latest Global Burden of Disease, Injury, and Risk Factor Study 2013, HAP was ranked as the 7th leading risk factor globally (Forouzanfar et al., 2015).

Biomass fuel is most commonly used in developing countries, especially in rural areas with limited resources. For example, while 34% of

---

Abbreviations: PAH, polycyclic aromatic hydrocarbon; OH-PAH, hydroxylated polycyclic aromatic hydrocarbon metabolite; CO, carbon monoxide; $PM_{2.5}$, fine particulate matter with aerodynamic diameters <2.5 μm; HAP, household air pollution; c-RCT, community randomized control trial.

[*] Corresponding author at: 4770 Buford Highway, F-57, Atlanta, GA 30341.
E-mail address: ZJLi@cdc.gov (Z. Li).

http://dx.doi.org/10.1016/j.envint.2016.09.011
0160-4120/Published by Elsevier Ltd.

the total population and 13% of the urban population in Peru use solid fuel, over 95% of the rural population rely on solid fuel for cooking and heating (WHO, 2013). Moreover, open-fire pits or inefficient stoves are often used in poorly ventilated conditions, contributing to high levels of harmful incomplete combustion products inside the house and kitchen (Desai et al., 2004; Naeher et al., 2007). Stove improvement programs have been implemented in numerous countries as reviewed elsewhere (Lewis and Pattanayak, 2012; Rehfuess et al., 2014).

As stove improvement programs are being implemented to reduce HAP and associated health burdens globally, there is an urgent need for direct, accurate, and robust exposure assessment tools to evaluate and guide such programs, and provide information to delineate the exposure-response relationship with specific health outcomes (Rylance et al., 2013). However, among studies investigating association between HAP exposure and health outcomes, few had direct exposure measurements and many relied on proxies to characterize exposure, such as stove type and fuel type (Rylance et al., 2013). Moreover, among studies with exposure assessment, it is common to measure smoke components, such as $PM_{2.5}$ and CO, in kitchen or personal air (Clark et al., 2009; Rosa et al., 2014; Ruiz-Vera et al., 2015). While air pollutant levels can reflect stove emissions, they cannot account for other factors that can significantly impact the effectiveness of the intervention programs, such as personal behavior. Biomonitoring is an effective tool that can assess overall exposure and account for various factors, such as personal behaviors related to stove usage and individual physiological differences.

We conducted a cross-sectional study within the framework of a community randomized control trial (c-RCT) in Peru (Hartinger et al., 2011) to assess HAP exposure through air monitoring and biomonitoring, and, to evaluate the efficacy of a stove intervention program. While the HAP exposure assessment based on air monitoring has been reported previously (Commodore et al., 2013; Hartinger et al., 2013), we report here the biomonitoring results on 10 hydroxylated PAH metabolites (OH-PAHs) in morning urine samples and self-reported health symptoms from 334 non-smoking women. Our objectives are, 1) to investigate whether participants in the intervention group (with new chimney-equipped stoves) were less exposed to HAP than those in the control group (with mostly open-fire stoves) using the urinary OH-PAHs as exposure biomarkers; 2) to study whether the intervention group had less self-reported health symptoms (ocular and respiratory symptoms, headache) than the control group; and 3) to study the associations between the HAP exposure biomarkers, risk factors, and self-reported health symptoms.

2. Material and methods

2.1. Study design

This study was conducted within the framework of a c-RCT involving 51 communities that used wood for cooking and heating in Peru, hereafter referred to as the parent study (Hartinger et al., 2011). The parent study aimed to evaluate reduction of childhood illness through reducing HAP and improving drinking water and kitchen hygiene conditions. The households in the intervention arm received an intervention package that included a new stove, a kitchen sink, and a solar disinfection home-based water treatment. The new stoves were built from red burnt bricks, plastered with a mixture of mud, straw and donkey manure; the stoves consisted of three pot-holes for cooking, a closed combustion chamber, a metal chimney with a regulatory valve, a hood, and metal rods for support (Hartinger et al., 2012). In the control arm, households used their existing stoves, most of which were traditional open-fire stoves. To reduce potential dropout and non-blinding bias in the control arm, households also received a psychomotor stimulation package focusing on early child development, a package that was unrelated to the environmental factors targeted in the study. The new stoves were installed in intervention households between September 2008 and January 2009. No exposure assessment was conducted before the installation of the intervention package in the parent study.

Starting February 2009, 503 households (250 and 253 in the intervention and control arms, respectively) entered the follow-up evaluation phase of the parent study (Hartinger et al., 2011). From June to August 2009, we conducted this cross-sectional study evaluating exposure to HAP (Commodore et al., 2013). Female members of the households (one per household) were eligible for this study if they met the following criteria: 1) were the mother or primary caregiver of the children enrolled in the parent study, 2) used an indoor wood stove, and, 3) agreed to participate in this study and agreed to comply with the project instructions during the 48-h sampling period. Eligible and enrolled participants provided a first-morning urine sample, a 48-h personal CO measurement, and filled out a questionnaire on demographics, smoking status, daily activities, household and community characteristics, and health symptoms, including headache, respiratory and eye-related symptoms. Although field workers visited all households in the parent study, subjects' availability and willingness for participation, and time and budget constraints limited the total sample size of this study.

After the HAP exposure measurement, we classified post-hoc the intervention group into two sub-groups—“no-repair” sub-group with stoves in good running conditions at the time of the assessment, and, “need-repair” sub-group with stoves that needed repairs, e.g., re-plastering, filling small cracks, and chimney valve replacement. The control group was stratified into three sub-groups based on the type of wood-burning stoves: 1) traditional three-stone open-fire stoves and non-vented stoves (“traditional”), 2) chimney-stoves built by a non-governmental organization (“built-by-NGO”), and, 3) chimney-stoves built by the household members (“self-improved”). A flow diagram for this cross-sectional study is given in Supplemental Material, Fig. S1.

2.2. CO measurements, urine sample collection and analytical method

Time-integrated 48-h personal CO measurements were taken from the participants as described elsewhere (Commodore et al., 2013). In brief, the CO measurements were collected using passive CO diffusion tube, i.e., Dräger Diffusion Tube for Carbon Monoxide (Dräger Safety Inc., USA). The sampler uses principles of diffusion and colorimetry where CO passively diffuses into the tube and causes the reduction of sodium palladosulfite to palladium metal, which results in a grayish stain corresponding to a cumulative dose of CO. During the 48-h sampling period, the participants wore the passive CO diffusion samplers in the breathing zone. Field workers recorded the time of tube breakage and capping, which marked the beginning and ending of the CO sampling period, respectively. Upon return to the field station, tubes were read independently by two of the authors (AAC and SMH) and an arithmetic mean was taken. Additional information on the personal CO measurement is given in Supplemental Materials.

At the end of the 48-h personal CO sampling period, the participants collected a morning urine void between 5:00 am and 7:00 am in a prelabeled sterile polyethylene container and placed the container in an insulated bag with ice packs. Field workers retrieved the urine samples from the participants, recorded the date and volume of the void, and delivered them to the study base, whereupon the samples were transferred into polypropylene tubes and stored at −20 °C until the end of the field work. Samples were then shipped frozen on dry ice to the University of Georgia and the Centers for Disease Control and Prevention (CDC) and stored at −70 °C until analysis. The study protocol was approved by the Human Research Protection Office at the CDC, the Human Subjects Division at University of Georgia, the Ethical Review Board of the Instituto de Investigacion Nutricional and the Universidad Peruana Cayetano Heredia in Lima. Written informed consent was obtained from all participants prior to enrollment in the study.

We analyzed the urine samples for 10 OH-PAHs, i.e. 1-, 2-naphthol, 2-, 3-, 9-hydroxyfluorene, 1-, 2-, 3-, 4-hydroxyphenanthrene and 1-hydroxypyrene. The detailed laboratory method was described