Science of the Total Environment 505 (2015) 56–64

Contents lists available at ScienceDirect

Science of the Total Environment

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

Associations between exposure to polycyclic aromatic hydrocarbons and glucose homeostasis as well as metabolic syndrome in nondiabetic adults

Hui Hu [a], Haidong Kan [b], Gregory D. Kearney [c], Xiaohui Xu [a,*]

[a] Department of Epidemiology, College of Public Health and Health Professional and College of Medicine, University of Florida, Gainesville, FL 32610, United States
[b] Department of Environmental Health, School of Public Health, Fudan University, Shanghai, China
[c] Department of Public Health, Brody School of Medicine, East Carolina University, Greenville, NC, United States

HIGHLIGHTS

- Exposure to PAHs is associated with impaired glucose homeostasis.
- PAHs is also associated with increased prevalence of metabolic syndrome.
- The effects of PAHs observed in this study warrant further investigation.

ARTICLE INFO

Article history:
Received 30 April 2014
Received in revised form 5 September 2014
Accepted 26 September 2014
Available online xxxx

Editor: Lidia Morawska

Keywords:
Polycyclic aromatic hydrocarbons (PAHs)
NHANES
OH-PAHs
Insulin resistance
β-Cell function
Metabolic syndrome

ABSTRACT

Purpose: Polycyclic aromatic hydrocarbons (PAHs) are ubiquitous environmental toxic compounds formed from incomplete combustion of carbon-containing materials, cigarette smoking, and food cooking. The genotoxic effects of PAHs have been widely studied. However, their nongenotoxic effects such as their impacts on glucose and metabolic homeostasis have not been well examined.
Methods: We used the National Health and Nutritional Examination Survey (NHANES) 2001–2008 to investigate the associations between eight monohydroxy urinary metabolites of four PAHs and glucose homeostasis as well as metabolic syndrome in 1,878 nondiabetic participants aged 18 years or older.
Results: In linear regression models, increased level of 2-PHEN was significantly associated with increased insulin resistance (β coefficient 0.05 ± 0.02), and increased concentrations of 3-FLUO (β coefficient −0.02 ± 0.01) were significantly associated with decreased β-cell function (all $p < 0.05$) after controlling for selected covariates. In addition, increased concentrations of 2-FLUO (OR = 1.25, 95% CI: 1.04–1.51), 1-PHEN (OR = 1.36, 95% CI: 1.09–1.70), and 2-PHEN (OR: 1.49, 95% CI: 1.22–1.83) were significantly associated with a higher prevalence of the metabolic syndrome after adjusting for covariates. Consistent results were observed in the subgroup analysis among nonsmokers.
Conclusions: Our findings suggest that environmental exposure to PAHs independent of cigarette smoking is associated with insulin resistance, β-cell dysfunction, and increased prevalence of metabolic syndrome.

1. Introduction

Polycyclic aromatic hydrocarbons (PAHs) are widely spread toxic compounds with fused aromatic rings, mainly generated by incomplete combustion of carbon-containing materials such as coal, fossil fuels, cigarette smoking, and food cooking (IARC, 1983; McGrath et al., 2007). Nonoccupational exposure sources of PAHs include airborne PAHs from air pollution, cigarette smoking, and PAH-containing food such as charred and broiled meat (Bentsen et al., 1998; Vanrooij et al., 1992). PAHs can bioaccumulate through the food chain because of its resistance to degradation (Mumtaz et al., 1996). Most studies studying the adverse health effects of PAHs have focused on increasing risks of chronic diseases such as cardiovascular diseases (CVD) and a variety of cancers (Burstyn et al., 2005; Cai et al., 2012; Gammon et al., 2002,

Abbreviations: PAHs, Polycyclic aromatic hydrocarbons; CVD, Cardiovascular disease; T2DM, Type 2 diabetes mellitus; PM, Particulate matter; MetS, Metabolic syndrome; OH-PAHs, Monohydroxy urinary metabolites of PAHs; HOMA2, Updated Homeostasis Model Assessment; NHANES, National Health and Nutrition Examination Survey; NCEP ATP III, National Cholesterol Education Program Adult Treatment Panel III Guideline; BMI, Body mass index; MEC, Mobile examination center; SBP, Systolic blood pressure; DBP, Diastolic blood pressure; HDL-C, High-density lipoprotein cholesterol; IR, Insulin resistance; 1-NAP, 1-Hydroxynaphthalene; 2-NAP, 2-Hydroxynaphthalene; 2-FLUO, 2-Hydroxyfluorene; 3-FLUO, 3-Hydroxyfluorene; 1-PHEN, 1-Hydroxyphenanthrene; 2-PHEN, 2-Hydroxyphenanthrene; 3-PHEN, 3-Hydroxyphenanthrene; 1-PYR, 1-Hydroxypyrene; PIR, Poverty income ratio; ORs, Odds ratios; CIs, Confidence intervals; AIC, Akaike information criterion; SE, Standard error; PPARs, Peroxisome proliferator activated receptors.

* Corresponding author at: PO Box 100231, Gainesville, FL 32610. Tel.: +352 273 5362 (Office); fax: +352 273 5365.
E-mail address: xhxu@phhp.ufl.edu (X. Xu).

http://dx.doi.org/10.1016/j.scitotenv.2014.09.085
0048-9697/

Table 1
Distribution of selected demographic characteristics and covariates by metabolic syndrome status and glucose homeostasis ($n = 1878$).

Characteristics	Metabolic syndrome					Glucose homeostasis							
	Case ($n = 601$)		Noncase ($n = 1277$)			Glucose		Log insulin		Log HOMA-IR		Log HOMA-B	
	N[a]	Percent (95% CI)[b]	N[a]	Percent (95% CI)[b]	p	Mean ± SE[c]	p	Mean ± SE[c]	p	Mean ± SE[c]	p	Mean ± SE[c]	p
Gender													
Male	299	50.5 (45.8–55.3)	680	50.2 (46.9–53.6)	0.91	98.95 ± 0.44	<0.01	2.19 ± 0.03	0.05	0.02 ± 0.03	0.03	4.38 ± 0.02	0.30
Female	302	49.5 (44.7–54.2)	597	49.8 (46.4–53.1)		95.18 ± 0.40		2.12 ± 0.03		−0.06 ± 0.03		4.41 ± 0.02	
Race													
Non-Hispanic White	358	77.9 (72.6–83.1)	617	71.1 (67.0–75.2)	<0.01	97.32 ± 0.39	0.39	2.12 ± 0.03	<0.01	−0.05 ± 0.03	<0.01	4.37 ± 0.02	<0.01
Non-Hispanic Black	90	7.2 (5.2–9.3)	277	11.0 (8.7–13.3)		94.76 ± 0.47		2.29 ± 0.03		0.11 ± 0.03		4.54 ± 0.02	
Hispanic and others	153	14.9 (10.2–19.7)	383	17.9 (14.6–21.2)		97.38 ± 0.51		2.22 ± 0.04		0.05 ± 0.04		4.43 ± 0.02	
Age													
18–29	56	8.5 (5.8–11.2)	456	28.6 (24.9–32.3)	<0.01	93.00 ± 0.50	<0.01	2.14 ± 0.04	0.89	−0.05 ± 0.03	0.66	4.47 ± 0.03	<0.01
30–39	63	12.7 (8.9–16.4)	244	23.4 (19.6–27.2)		95.07 ± 0.55		2.17 ± 0.04		−0.01 ± 0.04		4.44 ± 0.03	
40–59	235	48.8 (43.7–53.9)	355	35.6 (31.6–39.6)		98.45 ± 0.55		2.18 ± 0.03		0.01 ± 0.03		4.39 ± 0.02	
60+	247	30.0 (26.1–33.9)	222	12.3 (10.1–14.6)		101.30 ± 0.46		2.11 ± 0.03		−0.05 ± 0.03		4.28 ± 0.02	
Education													
<High school	146	15.7 (13.0–18.4)	255	11.0 (9.0–13.0)	<0.01	99.20 ± 0.76	<0.01	2.23 ± 0.03	0.02	0.06 ± 0.03	0.02	4.41 ± 0.02	0.65
High school	134	21.8 (17.3–26.2)	280	19.6 (16.4–22.9)		97.70 ± 0.61		2.18 ± 0.04		0.00 ± 0.04		4.40 ± 0.02	
>High school	321	62.5 (57.6–67.3)	742	69.4 (65.8–72.9)		96.49 ± 0.39		2.13 ± 0.03		−0.04 ± 0.03		4.39 ± 0.02	
Poverty income ratio													
<1.0	113	14.4 (10.1–18.8)	235	12.3 (9.9–14.6)	0.62	97.02 ± 0.73	0.94	2.26 ± 0.05	0.16	0.08 ± 0.05	0.18	4.47 ± 0.03	0.13
1.0–2.0	143	19.0 (15.5–22.4)	327	20.1 (17.2–23.0)		97.23 ± 0.53		2.11 ± 0.03		−0.06 ± 0.03		4.36 ± 0.02	
≥2.0	345	66.6 (62.2–71.1)	715	67.6 (64.0–71.2)		97.04 ± 0.43		2.15 ± 0.03		−0.02 ± 0.03		4.39 ± 0.02	
Smoking													
Current smoker	126	23.6 (19.1–28.0)	355	31.0 (27.5–34.5)	0.03	96.32 ± 0.67	0.96	2.04 ± 0.04	<0.01	−0.13 ± 0.04	<0.01	4.34 ± 0.02	<0.01
Former smoker	185	27.8 (23.0–32.7)	246	20.9 (17.3–24.5)		99.00 ± 0.49		2.18 ± 0.04		0.02 ± 0.04		4.38 ± 0.02	
Nonsmoker	290	48.6 (43.2–54.0)	675	48.1 (44.2–52.0)		96.60 ± 0.43		2.21 ± 0.03		0.04 ± 0.03		4.44 ± 0.02	
Body mass index													
<25.0	51	6.7 (4.2–9.2)	567	45.9 (42.2–49.7)	<0.01	94.01 ± 0.54	<0.01	1.70 ± 0.03	<0.01	−0.47 ± 0.03	<0.01	4.15 ± 0.02	<0.01
25.0–29.9	213	34.0 (29.5–38.6)	466	35.8 (32.2–39.4)		97.78 ± 0.42		2.13 ± 0.02		−0.03 ± 0.03		4.37 ± 0.01	
≥30.0	337	59.2 (53.9–64.5)	244	18.3 (16.0–20.5)		99.55 ± 0.40		2.66 ± 0.02		0.48 ± 0.02		4.69 ± 0.02	
Physical activity													
Low	308	45.8 (40.6–51.0)	495	33.8 (30.6–36.9)	<0.01	98.38 ± 0.45	<0.01	2.23 ± 0.03	<0.01	0.05 ± 0.03	<0.01	4.42 ± 0.02	0.01
Moderate	174	33.4 (27.9–39.0)	367	32.5 (28.6–36.4)		96.56 ± 0.49		2.15 ± 0.04		−0.02 ± 0.04		4.41 ± 0.03	
High	119	20.7 (16.1–25.4)	415	33.8 (29.9–37.7)		96.00 ± 0.57		2.07 ± 0.03		−0.10 ± 0.03		4.36 ± 0.02	
Dietary saturated fatty acid intake													
Low	221	33.1 (27.5–38.7)	405	28.4 (25.3–31.6)	0.29	96.66 ± 0.48	0.08	2.10 ± 0.03	<0.01	−0.07 ± 0.03	<0.01	4.37 ± 0.02	<0.01
Moderate	194	32.0 (28.1–36.0)	432	35.3 (32.6–38.1)		96.71 ± 0.50		2.10 ± 0.04		−0.07 ± 0.04		4.37 ± 0.02	
High	186	34.8 (29.7–40.0)	440	36.2 (33.1–39.4)		97.78 ± 0.48		2.25 ± 0.04		0.08 ± 0.04		4.45 ± 0.02	

[a] Unweight *N*.
[b] Weighted percent with 95% confidence limit.
[c] Weighted mean with standard error.

2004; Grant, 2009; Karami et al., 2011; Rundle et al., 2000; Sagiv et al., 2009; Xia et al., 2013; Xu et al., 2010). Recently, several studies have suggested an association between ambient air pollution with type 2 diabetes (T2DM) and the effects to potentially induce insulin resistance (Andersen et al., 2012; Brook et al., 2008; Coogan et al., 2012; Kramer et al., 2010; Pearson et al., 2010; Raaschou-Nielsen et al., 2013). Because air pollution and cigarette smoking are important sources of PAHs, both have been consistently linked to cardiometabolic diseases such as diabetes (Chang, 2012), the biological plausibility could suggest that PAHs may play an important role in the relationship between cigarette smoking, ambient air pollution, and cardiometabolic diseases. A recent study found that PAHs are associated with prevalence of diabetes among adults in the United States (Alshaarawy et al., 2014); however, the underlying mechanism for this relationship is largely unknown.

Metabolic syndrome (MetS) is a clustering of interrelated metabolic risk factors including obesity, dyslipidemia, abnormal blood glucose, and raised blood pressure (Meigs, 2000). Its importance is increasingly becoming recognized due to its association with elevated risks of developing and aggravation of cardiometabolic disease such as CVD and diabetes (American Heart et al., 2005; Stern et al., 2004). In the U.S., approximately 34% to 40% of adults are diagnosed with MetS, according to different definition criteria (Cheung et al., 2006; Ervin, 2009). Abdominal obesity and insulin resistance are the predominant underlying risk factors for MetS (Carr et al., 2004; Ferrannini et al., 1991; Lemieux et al., 2000; Park et al., 2003; Reaven, 1988), while other associated conditions include physical inactivity and aging (Ford et al., 2002; Gustat et al., 2002). Insulin resistance, a state where there is reduced biological effect for any given concentration of insulin (Kahn, 1978; Matthaei et al., 2000), is also regarded as the essential cause of MetS (Reaven, 2004). On the other hand, pancreatic β-cell failure has been recently acknowledged as the triggering factor for the progression of pre-diabetic states to full-blown diabetes (Muoio and Newgard, 2008) and thus being recommended to be investigated along with insulin resistance when possible (Hectors et al., 2011). Given the dramatically rapid increases in the incidence of cardiometabolic diseases such as obesity and diabetes, genetic modifications in the population and traditional factors such as physical inactivity and excessive energy intake do not fully explain the worldwide explosive increase of these diseases (Baillie-Hamilton, 2002). The nongenotoxic effects of enduring environmental exposure to PAHs in the general population might be another way to understand the potential risks of metabolic syndrome, which may eventually lead to cardiometabolic diseases. PAHs' potential ability to induce insulin resistance and defective