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Association of polycyclic aromatic hydrocarbons (PAHs) and lead co-exposure with child physical growth and development in an e-waste recycling town

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HIGHLIGHTS

- Higher levels of PAH and lead are found in the blood of children from Guiyu.
- IP is the most abundant congener among the 16 measured PAHs.
- Milk consumption might be a protect factor from PAH accumulation.
- PAH levels were negative associated with child height and chest circumference.
- High PAH levels in children from Guiyu comes from e-waste recycling activities.

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ABSTRACT

Informal e-waste recycling activities results in serious environmental pollution of PAHs. We evaluated the body burden of 16 PAH congeners and potential health risks for children. A total of 167 children from exposed and reference area entered this study. Child blood samples were collected; height, weight, head and chest circumferences were measured. Blood PAH and lead concentrations were determined. The blood median of total PAHs from the exposed group was significantly higher than the reference group (68.53 μg/L vs. 26.92 μg/L, $P < 0.01$). The major sources of Σ16-PAH and Σ7 carcinogenic-PAH were residence adjacent to e-waste workshop, paternal occupation related to e-waste recycling and house as a workshop. Inverse correlations were observed in the age and milk consumption with these two PAH groups, while a positive association was found between BMI and Σ7 carcinogenic-PAH, and between child height and blood lead. When divided into high and low exposure groups by Σ16-PAH, a significant negative association was found between body height and blood PAHs (β and 95%CI: −3.838, −6.469 to −1.206), while for weight and chest circumferences, negative associations were obtained only in the male subgroup before adjustment. After adjustment by sex, age, child milk products consumption per month and blood lead, child height was negatively associated with Σ16-PAH (β and 95%CI: −3.884, −6.736 to −1.033). Same trends were observed for child chest circumference (β and 95%CI: −1.147, −2.229 to −0.065). We suggest a negative association of PAHs and child height and chest circumference, while the correlation is more obvious in boys.

1. Introduction

Guiyu town, located in Guangdong province, south of China, is one of the largest e-waste destinations and recycling areas in the world, and has nearly 30-year history of unregulated e-waste disposal (Huo et al., 2007; Guo et al., 2012). In Guiyu, more than 6000 small-scale family-run workshops (nearly 60–80% of families in the town) and 160,000 workers are engaged in the business of e-waste dismantling and recycling. E-waste recycling in Guiyu is home-based and family-run with highly insufficient occupational hygienic conditions. Due to these informal activities, amount of chemicals including toxic heavy metals and persistent organic pollutants (POPs) such as lead, chromium, cadmium, polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs) and polycyclic aromatic hydrocarbons (PAHs) are released to the

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environment, can pose a threat to the local people, especially to children (Wu et al., 2010, 2012; Chen et al., 2011; Zhang et al., 2011, 2014; Lin et al., 2013; Yang et al., 2013).

Remarkably, many studies have found that soil, water and air in Guiyu are highly polluted by PAHs (Alabi et al., 2012; Zhang et al., 2011). In Guiyu, the sum of 16 PAHs concentrations in total suspended particulates (TSP) and $PM_{2.5}$ were 148 and 102 ng m^{-3}, respectively. The monthly average levels of benzo[a]pyrene (B[a]P) in $PM_{2.5}$ and TSP were 8.85 and 15.4 ng m^{-3} and the highest levels reached 18.9 and 29.9 ng m^{-3}, respectively (Deng et al., 2006). B[a]P, as an indicator of carcinogenic risk, was 2-6 times higher than that in other Asian cities (WHO, 2000). Metabolites of B[a]P are mutagenic and highly carcinogenic, and it is listed as a Group 1 carcinogen by the IARC. Biomonitoring studies have showed that these PAHs contaminants mainly result from e-waste dismantling in Guiyu (Yu et al., 2006; Zhang et al., 2011; Leung et al., 2013). Workers and local residents are continually exposed to PAHs through inhalation, dietary ingestion, and dermal absorption. Once taken into the body, PAHs can accumulate in the fatty tissues of humans and pose a serious threat to the health of local residents (Moon et al., 2012). It is known that PAHs represent a class of toxicological compounds that could cause a variety of hazardous effects *in vivo* and *in vitro* even at low concentrations, leading to an increased risk of cancer, teratogenicity, and disruption of the endocrine system (Santodonato, 1997; Brody and Rudel, 2003; Ramirez et al., 2011; Tian et al., 2013; Yang et al., 2014). In particular, growing evidence supports the developmental toxicity from prenatal or early postnatal exposure to PAHs, may cause intrauterine growth retardation (IUGR) and lower birth weight (Choi et al., 2008, 2012; Jedrychowski et al., 2015; Perera et al., 2006). Before this study, we have investigated PAHs in umbilical cord blood samples collected from Guiyu. Our results showed that high levels of PAHs is correlated with a reduced fetal physical development and adverse birth outcomes (Guo et al., 2012), which were evidenced by altering the expression of insulin-like growth factor (Xu et al., 2013). Furthermore, a prospective cohort study of nonsmoking African–American and Dominican mother-newborn pairs residing in New York City has reported that prenatal exposure to airborne PAHs is significantly associated with lower birth weight, birth length, head circumference, and developmental delay at 3 years of age, and reduce IQ at 5 years of age (Perera et al., 2006, 2009; Edwards et al., 2010).

Until now, most studies have focused on the distribution of PAHs in air, foods, human urine samples and umbilical cord blood (Tang et al., 2008; Reinik et al., 2007; Jung et al., 2012; Al-Saleh et al., 2013; Ciecierska and Obiedzinski, 2013; Hofmann et al., 2013). Considering possible health risks due to PAHs exposure among children, the present study determine its exposure in children by estimating blood levels of 16 PAHs. Thus, the exposure from variable composition of PAH mixtures emitted from different environmental sources can be more closely monitored, and avoid the underestimating by any single compound or metabolite (Singh et al., 2008a). For these reasons, the measurement of blood PAH levels was carried out as a possible biomarker, especially for those higher molecular weight PAHs (HMWs), which has been proposed in Environmental Protection Agency (EPA, USA) priority list. The aim of this study was to investigate the associations between child growth development and the co-exposure of environmental PAHs and lead in an e-waste recycling area.

2. Materials and methods

2.1. Geographic location and site description

All children from two kindergartens, respectively located in Guiyu and Chendian were recruited for the routine health check-up in 2008. Children from Guiyu, one of the popular destinations of e-waste, served as exposed group. Meanwhile, the reference group was the neighboring town, Chendian, situated 9 miles southwest of Guiyu. The local residents make a living by textiles industry in majority. The population, lifestyle, traffic density, and socioeconomic status were very similar between these two areas (Liu et al., 2011).

2.2. Study population

A total of 295 children joined in the routine health check-up, over 50 percent of these participants ($N = 167$) entered this study. The eligibility criteria for the subjects in this study were as follows: children 3 to 7-years of age, healthy, born and living in Guiyu or Chendian. Because of insufficient amount of the blood samples collected, 95 children (66 boys, 29 girls) in Guiyu, and 72 children (42 boys, 30 girls) in Chendian were included in the measurement of PAHs. Venipuncture blood were taken by nurses, specimens were stored in tubes with heparin as anticoagulant. All samples were transported on ice to laboratory, and stored at −20 °C until analysis. The study protocol was approved by the Human Ethics Committee of Shantou University Medical College. All the guardians of participants gave their written informed consent after receiving detailed explanation and possible consequences about the survey before enrollment.

2.3. Data collection

A structured interview questionnaire was used to identify Environmental Tobacco Smoke (ETS) and vehicle exhaust as the potential sources of PAH exposure, as well as general demographic and health parameters. The questionnaires were completed by the parents or guardians, and 25 factors were included, such as dwelling, child behavior and hobbies, diet and nutrition; parent educational level and occupation, and social status. Parental occupations were classified by the connection with e-waste recycling, such as transporting, selecting, splitting, acid bath, and burning to recover metals.

The physical developmental indices contain body height, weight, and head and chest circumferences were measured simultaneously when collecting blood samples based on a previous published paper (Huo et al., 2007).

2.4. Blood lead measurement

Lead in whole blood was determined by graphite furnace atomic absorption spectrometry (GFAAS, ZEEnit 650, Germany). The methods were based on previously published papers (Liu et al., 2011, 2015).

2.5. PAH measurement

2.5.1. Chemicals

A standard mixture was purchased from Chiron, Norway, which contains 16 PAH congeners of the EPA priority list, namely naphthalene (Nap), acenaphthylene (Ace), acenaphthene (A), fluorene (Fl), anthracene (Ant), phenanthrene (Phe), fluoranthene (Fla), pyrene (Pyr), benzo[a]anthracene (BaA), chrysene (Chr), benzo[k]fluoranthene (BkF), benzo[b]fluoranthene (BbF), benzo[a]pyrene (BaP), dibenzo[a,h]anthracene (DA), indeno[1,2,3-c,d]pyrene (IP), and benzo[g,h,i]perylene (BP). Among them, 7 were carcinogenic PAHs: BaA, Chr, BkF, BbF, BaP, DA and IP. Acetonitrile, di-chloromethane (DCM) and n-hexane were all pesticide grade (TEDIA); all other chemicals used were analytical grade (Guangzhou, China); and Solid Phase Extraction (SPE) cartridges (Supelclean™, LC-18) used for cleanup were procured from