Environmental Pollution 259 (2020) 113854

Contents lists available at ScienceDirect

Environmental Pollution

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

Urinary monohydroxylated polycyclic aromatic hydrocarbons in primiparas from Shenzhen, South China: Levels, risk factors, and oxidative stress☆

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ARTICLE INFO

Article history:
Received 16 August 2019
Received in revised form
7 December 2019
Accepted 18 December 2019
Available online 27 December 2019

Keywords:
Biomarker
Health risk assessment
Hydroxylated polycyclic aromatic hydrocarbons
Primiparas
Urine

ABSTRACT

The main objectives of the present study were to investigate urinary monohydroxylated polycyclic aromatic hydrocarbons (OH-PAHs) in 77 primiparas who live in Shenzhen, Guangdong Province, China, and their association with 8-hydroxy-2′-deoxyguanosine (8-OHdG) and human health risks. High detection frequencies of OH-PAHs demonstrated the wide occurrence of chemicals in the human exposure to PAHs. The urinary concentrations of Σ_7OH-PAHs ranged from 1.37 to 45.5 ng/mL, and the median concentrations of 1-hydroxynaphthalene (1-OHN), 2-hydroxynaphthalene (2-OHN), 2-hydoxyfluorene (2-OHF), ΣOHPhe (the sum of 1-, 2+ 3-hydroxyphenanthrene), and 1-hydroxypyrene (1-OHP) were 3.00, 2.58, 0.31, 0.44, and 0.51 ng/mL, respectively. In the sum concentration of seven OH-PAHs, 1-OHN accounted for the largest proportion (43.7% of Σ_7OH-PAHs), followed by 2-OHN (37.1%), 2-OHF (4.94%), 1-OHP (8.01%), 1-OHPhe (4.79%), and 2+3-OHPhe (1.46%). The present results showed that vehicle exhaust and petrochemical emission are the main sources of PAHs in primiparas in Shenzhen, and inhalation is the most important exposure route. The living conditions have a significant influence on human exposure to PAHs. The concentrations of 8-OHdG were positively correlated with OH-PAH concentrations in urine because evidence suggested that urinary 8-OHdG levels can be considered as a biomarker of oxidative DNA damage. Hazard quotient was used to assess the human health risks from exposure to single compound, and hazard index was used to assess the cumulative risks of the compounds, which demonstrated that the exposure risks from PAHs in primiparas were relatively low.

1. Introduction

Polycyclic aromatic hydrocarbons (PAHs) are produced by the incomplete combustion and pyrolysis of organic material (Chen et al., 2019a; Wang et al., 2012). Due to the carcinogenicity, endocrine disrupting, reproductive and developmental toxicity of PAHs, scientists and governments have acknowledged the health risks of exposure to PAHs (Kim et al., 2013; Zhang et al., 2017). Humans are exposed to PAHs mainly via air, food, and skin (Kamal et al., 2015; Lao et al., 2018; Sun et al., 2015; Yu et al., 2012). In the human body, PAHs undergo hydroxylation reactions and transfer into monohydroxylated, dihydroxylated, and tetrahydroxylated metabolites (Carmella et al., 2004; Klotz et al., 2011). These are then excreted in the urine mainly as forms of sulfate conjugates and glucuronides (Li et al., 2006). To assess human exposure to PAHs, urinary OH-PAHs (monohydroxylated metabolites of PAHs) have been widely used as biomarkers (Bortey-Sam et al., 2017; Wang et al., 2019).

Generally, the ambient atmosphere is considered one of the most important sources of PAHs, and human external exposure to PAHs via inhalation is assessed. However, internal exposure estimated by PAH metabolites in urine is more accurate than ambient detection and external exposure because it reflects an internal dose

☆ This paper has been recommended for acceptance by Jun Huang.

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https://doi.org/10.1016/j.envpol.2019.113854
0269-7491/

from contamination by all external exposure pathways, such as inhalation via air, ingestion through the diet, and dermal contact and absorption by skin (Lao et al., 2018; Ma and Harrad, 2015). As environmental toxicants, PAHs can lead to many adverse effects in humans. Several studies have shown that PAHs can combine with DNA and formed DNA adducts, which are potential biomarkers for estimating the degree of malignancy in cancer (Bach et al., 2003; Ewa and Danuta, 2016). 8-Hydroxyl-2′-deoxyguanosine (8-OHdG) is generally used as a biomarker to assess the harm from oxidative DNA in humans (Guo et al., 2014; Kuusimäki et al., 2004; Yang et al., 2015). As reported in the literature, human exposure to polluted air can lead to an excess of reactive oxygen species, which consequently attack the carbon atoms in the DNA molecule, leading to the production of 8-OHdG. There are many studies on the relationship between PAH exposure and 8-OHdG in occupational groups, including populations living close to e-waste recycling facilities (Kuang et al., 2013; Lu et al., 2016). However, investigations on general populations are limited, especially for primiparas.

It is known that developing fetuses are more susceptible to PAHs due to their immature physiology, weak detoxification of toxic compounds, and low metabolization (Archibong et al., 2002; Lamichhane et al., 2016; Makri et al., 2004). Many studies have demonstrated that fetuses are more sensitive to PAH-induced DNA damage than their mothers (Perera et al., 2005; Wu et al., 2010). Additionally, some studies have demonstrated that exposure to PAHs during pregnancy increases the risk of poor childbirth (Hoffman et al., 2018; Jedrychowski et al., 2017). For example, intrauterine developmental delay and reduced birth length and weight were observed because of the PAH exposure of mothers during pregnancy (Choi et al., 2006; Mu et al., 2015). Thus, an investigation of the exposure of primiparas to PAHs is very important for understanding both the maternal exposure to the pollutants and to assess potential fetal health.

Shenzhen is a national economic center and an important industrial city in China. In addition, it is the center of the Guangdong-Hong Kong-Macao Greater Bay Area linking Guangzhou, Shenzhen, with another 11 cities, as well as Macao and Hong Kong. The Greater Bay Area is an important region as its development has been a feature of one of the national strategies of China. To our knowledge, no studies have investigated the exposure of the general population to PAHs in this region. More information about the general population levels of exposure to PAHs and source apportionment in this region is needed, especially for primiparas. Therefore, the main objectives of this study were: (1) to measure the urinary concentrations of seven OH-PAHs in primiparas from Shenzhen, China; (2) to evaluate the influence factors including age, body mass index (BMI), cooking, and smoking on urinary OH-PAHs; (3) to investigate the associations of OH-PAHs with 8-OHdG in urine; and (4) to evaluate the health risks of primiparas exposed to PAHs.

2. Materials and methods

2.1. Chemicals and materials

OH-PAH isomers, including 2-hydroxynathalene (2-OHN), 1-hydroxynathalene (1-OHN), 1-hydroxyphenanthrene (1-OHPhe), 2-hydroxyfluorene (2-OHF), 3-hydroxyphenanthrene (3-OHPhe), 2-hydroxyphenanthrene (2-OHPhe), and 1-hydroxypyrene (1-OHP), were bought from Dr. Ehrenstorfer (Augsburg, Germany). 8-OHdG was obtained from Sigma-Aldrich (St. Louis, MO, USA). The internal standards including D_8-2-OHN, $^{13}C_6$-3-OHPhe, $^{13}C_6$-1-OHP, D_9-2-OHF, and $^{15}N_5$-8-OHdG, were purchased from Cambridge Isotope Laboratories (Andover, MA, USA). Sodium acetate (NaAc), methanol, and glacial acetic acid (HAc) were bought from Fisher Scientific (Houston, TX, USA). β-Glucuronidase/arylsulfatase (124400 β-glucuronidase units/mL, 36010 sulfatase units/mL) was purchased from Sigma-Aldrich. Bond Elut C_{18}, 500 mg/6 mL solid phase extraction (SPE) cartridges were obtained from Agilent (Santa Clara, CA, USA). Before use, SPE cartridges were preconditioned using methanol (5 mL) and deionized water (5 mL).

2.2. Study subjects and sampling

All the present samples are sub-samples reported in one of our previous articles (Chen et al., 2019b). During September 2013 to June 2015, first-void morning urine samples were collected from 77 primiparas aged 19–36 years old in the Shenzhen Maternal and Child Health Hospital. About 50 mL of urine was sampled and stored in a glass bottle and sequentially cleaned with deionized water and 0.1 M HCl. To quantify the dilution of urine, the specific gravity of each urine sample was measured via a digital handheld refractometer (Atago, Bellevue, WA, USA). The samples were then stored at −20 °C in a laboratory until analysis. General information about the primipara (such as height, body weight, age, and living habits), and that of her infant (such as birth weight and body length), were collected and summarized in Table S1 (Chen et al., 2019b). The studies have been approved by the ethics committee of Shenzhen Center for Disease Control and Prevention.

2.3. Sample pretreatment and analysis

A previously described pretreatment protocol was used with some modifications (Lu et al., 2016). Briefly, urine sample (4 mL) was added to a glass tube and spiked with 10 μL of internal standards. Then 1.5 mL 0.5 M acetate buffer (pH = 5.0) and 20 μL of β-glucuronidase/sulfatase were added to the urine sample. The mixed solution was incubated at 37 °C overnight. The incubated sample was then loaded into a preconditioned SPE cartridge at a flow rate <1.0 mL/min. The sample loaded cartridge was rinsed successively with deionized water (5 mL) to remove complex matrices. Then the cartridge was dried completely, and the eluate containing OH-PAHs and 8-OHdG was washed with methanol (4 mL). The extract was concentrated to near dryness with N_2 and resolved in methanol (500 μL). The sample was stored at −20 °C for instrumental analysis before it was filtered using a 0.22 μm filter.

The chemical determination was performed on a 20 A HPLC (Shimadzu, Japan) equipped with a Q-Trap 5500 mass spectrometer (MS/MS; Applied Biosystems, Foster City, CA, USA). Phenomenex C_{18} reversed-phase columns (4.6 mm × 250 mm, 5 μm) were used for the analyte separation. The mobile phase was a mixture of methanol and water. The flow rate was set at 0.6 mL/min. The gradient eluting procedure was as follows: 0–5 min keeping at 60% methanol, 5–14 min a linearity from 60% to 78% methanol, 14–21 min from 78% to 85% methanol, 21–30 min from 85% to 100% methanol, 30–35 min keeping at 100% methanol, 35–39 min a linearity from 100% to 60% methanol and 39–45 min keeping at 60% methanol. A 10 μL injection volume was used. The column temperature was held at 25 °C. Other mass spectrometric parameters are listed in Table S2.

2.4. Quality assurance and quality control

The linearity of calibration curves was determined by analyzing solutions containing 8-OHdG and OH-PAHs in methanol at a concentration ranging from 0.56 to 406 ng/mL. The calibration curve correlation coefficients (r^2) were higher than 0.999 for all OH-PAH individuals and 8-OHdG. Urine samples spiked with standards and isotope-labeled standards were prepared and analyzed according

to the procedure mentioned above to verify the method. The intra-day precision and the inter day precision of method were assessed by analysis of the standard solution six times within a single day and on six consecutive days, respectively. The relative standard deviations were all less than 10% for the intra-day precision and the inter-day precision. To study the detector response stability during analysis, a standard solution with medium concentration was analyzed after 10 samples were measured, with a relative standard deviation of less than 10%. The limit of quantification (LOQ) was defined as ten times the signal-noise, and was 0.10–1.49 ng/mL for all target analytes. A procedural blank and a solvent blank were analyzed to check for potential contamination, and no analyte was detected.

2.5. Calculations and statistical analysis

The total estimated daily intakes (TEDI; μg/day) of PAHs were calculated from the urinary OH-PAHs according to the following formula (Guo et al., 2013):

$$\mathrm{TEDI} = \frac{C \times V \times M1}{f \times M2} \quad (1)$$

where C (μg/L) is the OH-PAH concentration in urine; V (L/day) is the volume of urine excreted from the human body per day, and 2.00 L/day was used (Chen et al., 2019b); M1 (g/mol) is PAH molecular weight; M2 (g/mol) is OH-PAH molecular weight; and *f* (dimensionless) is the ratio of OH-PAH excreted in urine to the total exposure dose (Anderson et al., 2001). The *f* of four PAH compounds including naphthalene (Nap), phenanthrene (Phe), fluorine (Flu), and pyrene (Pyr) were 100%, 11%, 60%, and 6.8%, respectively (Li et al., 2012).

The hazard quotient (HQ) was used to assess the risk from a single exposure (Wang et al., 2015). It is calculated as the ratio of TEDI to the reference limit of a chemical. The hazard index (HI) was used to estimate the cumulative risk of a compound. They were calculated by the following equations:

$$\mathrm{HQ} = \mathrm{TEDI}/\mathrm{BW} \times \mathrm{RfD} \quad (2)$$

$$\mathrm{HI} = \sum_{i=1}^{n} HQ_i \quad (3)$$

where BW (kg) represents the prenatal weight of primiparas; the reference doses (RfDs) of Phe, Nap, and Pyr were 40, 20, and 30 μg/kg-bw/day, respectively (USEPA, 2019. Because there are no available RfD data for Flu, it was replaced in the present study by a tolerable daily intake limit (TDI) of 40 μg/kg-bw/day (Bulder et al., 2006).

Statistical analysis was performed using SPSS 13 (Statistical Package for Social Sciences). The concentrations of OH-PAHs for descriptive analysis are expressed as ng/mL. Quantification of each analyte was according to the peak area ratio reference to calibration curves. In the present study, because 2-OHPhe and 3-OHPhe were co-eluted in instrumental analysis, 2+3-OHPhe was used to represent the sum of these two compounds. A half value of LOQ was used when an OH-PAH compound concentration was lower than the LOQ. The Spearman non-parametric method was used to analyze the correlations of individual urinary OH-PAH isomers. A *p*-value lower than 0.05 was considered statistically significant.

3. Results

3.1. Levels of urinary OH-PAHs

The OH-PAH concentrations and detection frequencies in the urine of primiparas are shown in Table 1. 2-OHF, 2-OHPhe, 1-OHN, 2-OHN, and 2+3-OHPhe were detectable in almost all urine samples with detection frequencies higher than 95%, while 1-OHPhe and 1-OHP were detectable only in some samples (82% and 66%, respectively). The high urinary OH-PAH detection frequencies indicated the extensive presence of PAHs in the environment and the wide exposure of local residents to PAHs in the regions. The urinary concentration of Σ_7OH-PAHs in all primiparas ranged from 1.37 to 45.5 ng/mL (n = 77), with a median concentration of 6.23 ng/mL 2-OHN was the highest PAH isomer with a median concentration of 3.00 ng/mL, followed by 1-OHN (2.58 ng/mL), 1-OHP (0.51 ng/mL), ΣOHPhe (the sum of 1- and 2+3-OHPhe) (0.35 ng/mL), and 2-OHF (0.31 ng/mL).

3.2. Composition characteristics of urinary OH-PAHs

The composition profiles of OH-PAHs are shown in Fig. S1. 1-OHN accounted for 43.7% of the total Σ_7OH-PAHs concentrations, followed by 2-OHN (37.1%), 1-OHP (8.01%), 2-OHF (4.90%), 1-OHPhe (4.79%), and 2+3-OHPhe (1.46%).

4. Discussion

4.1. Levels of urinary OH-PAHs

Urinary concentrations of Σ_7OH-PAHs in primiparas in the present study were in line with those in a USA general population in 2013–2014 (6.13 ng/mL) and Hanoi (6.84 ng/mL) (Table S3) (CDC, 2015; Thai et al., 2015), but much higher than those in Malaysia (2.26 ng/mL) and Germany (3.22 ng/mL) (Guo et al., 2013; Myers et al., 2008). However, compared with those residents from areas surrounding e-waste dismantling sites in Qingyuan (20 ng/mL), Vietnam (8.56 ng/mL), and Korea (9.34 ng/mL), and coke oven workers in Poland (155 ng/mL) (Campo et al., 2010; Lu et al., 2016), the present concentrations of Σ_7OH-PAHs in urine collected from primiparas were much lower. From a global perspective, the results indicated that the concentrations of OH-PAHs in primiparas from Shenzhen were in a moderate position.

To assess human exposure to contaminants of PAHs, 1-OHP is the most widely used biomarker (Hansen et al., 2008; Kamal et al., 2014). The mean concentration of 1-OHP (0.51 ng/mL) in primiparas from Shenzhen was comparable with those reported in India (0.42 ng/mL, n = 38) and Vietnam (0.46 ng/mL, n = 23) (Guo et al., 2013). However, studies from other Asian countries and the USA have reported relatively low 1-OHP concentrations in general populations. For example, the urinary 1-OHP from Korea (0.103 ng/

Table 1
Concentrations (ng/mL) of urinary OH-PAHs and 8-OHdG in primiparas in Shenzhen, Guangdong province, China.

Compounds	DF (%)	Mean ± SD	Median	95th percentage	Range
1-OHN	100	3.72 ± 3.17	3.00	7.69	0.34–22.2
2-OHN	100	3.12 ± 2.64	2.58	6.17	0.27–18.6
2-OHF	96.1	0.35 ± 0.28	0.31	0.87	<LOD–1.32
2+3-OHPhe	100	012 ± 0.07	0.10	0.25	0.03–0.37
1-OHPhe	81.8	0.39 ± 0.25	0.34	0.89	<LOD–1.36
1-OHP	66.2	0.61 ± 0.41	0.51	1.40	<LOD–2.12
Σ_7OH-PAHs	100	8.02 ± 6.49	6.23	15.8	1.37–45.5
8-OHdG	87.0	2.91 ± 1.50	2.66	5.54	<LOD–9.72

LOD: limit of detection.

mL), Malaysia (0.065 ng/mL), and the USA from the National Health and Nutrition Examination Survey (0.07 ng/mL) were about 5–10 times lower than that in this study (Guo et al., 2013; CDC, 2015). Additionally, as expected, high urinary 1-OHP (1.01 ng/mL) was observed for people residing near e-waste dismantling areas (Lu et al., 2016). Several studies observed similar results, that the urinary 1-OHP levels of people living in contaminated areas increased significantly (Campo et al., 2010; Kamal et al., 2014). The results demonstrated that the human internal exposure to 1-OHP should not be assumed to be at high levels globally, with the exception of occupational exposure and the residents surrounding special sites, such as e-waste dismantling area.

4.2. Composition characteristics of urinary OH-PAHs and potential sources

Our findings suggest that the low-ring metabolites of PAHs were the major OH-PAHs. The present distributions of OH-PAHs in primiparas reflected the composition profiles of PAHs in the air from Guangzhou and Shenzhen, where naphthalene, fluorene, and phenanthrene were the dominant PAH isomers (Li et al., 2004; Liu et al., 2010). Generally, dermal contact, inhalation, and oral ingestion were the most important routes of human exposure to contaminants. Naphthalene, fluorine, and phenanthrene are more likely to be in the gas phase than high-ring PAHs, such as pyrene, because low-ring PAHs have a lower molecular weight, and thus, higher volatility. Therefore, the characteristics of the distribution of urinary OH-PAHs in primiparas from Shenzhen suggested that air inhalation might be an important exposure route for the general population in the city. However, it should also be emphasized that fluorene and phenanthrene were observed as the predominant isomers in food. As reported in one of our previous studies from Shanghai, China, the two isomers accounted for approximately 50.6% of total PAHs in animal-based food from markets, with the exception of snails and clams (Yu et al., 2012). Therefore, more studies are warranted.

In the present study, OHN (sum of 2-OHN and 1-OHN accounting for 81% of the total) was the dominant compound, which was much higher than fluorene and phenanthrene metabolites. In the atmosphere, naphthalene primarily exists in the gas phase because of its high volatility. Therefore, considering the high composition of naphthalene, air might be a more important source of human exposure to PAHs. Naphthalene is predominantly derived from petroleum and its products, so it usually represents petroleum volatilization. The dominance of OHN among the isomers suggested that vehicle exhaust and petrochemical emission might be the major contributor to the PAH exposure of primiparas. To further understand the source of PAHs, the correlations among individual OH-PAH isomers in the samples of primiparous urine were analyzed by using Spearman correlations. As shown in Table 2, there are significant and positive correlations among most OH-PAH isomers with the coefficients (r) of 0.315–0.995 ($p < 0.05$), especially for the low molecular weight PAHs. The results demonstrate that the sources of individual PAH in primiparas are similar. Vehicle exhaust and petrochemical emissions could be the main source and inhalation is the most important exposure route for PAHs in the primiparas of Shenzhen, China.

4.3. Factors influencing the levels of urinary OH-PAHs

To probe into factors that influence the exposure of primiparas to PAHs, the relationship between the demographic characteristics and OH-PAH concentrations were further analyzed (Table S4). There was no obvious association between OH-PAH concentrations and age ($p > 0.05$). This is expected because the half-lives of PAHs in the human body is only approximately 10 h. The metabolites are eliminated via urine. Although a study observed a significantly negative correlation between the concentrations of PAH metabolites with age in children (Li et al., 2015b), similar results were not found in the present study. The present results indicated that there were no significant exposure differences to PAHs in primiparas of different ages.

Obesity may influence the urinary concentration of PAH metabolites, since PAHs are a fat-soluble substance, although they can easily be metabolized. Therefore, the relationships between the OH-PAHs and BMIs of the primiparas were analyzed (Table S4). No significant differences were observed between the OH-PAH concentrations and BMI ($p > 0.05$). A study on prenatal exposure to PAHs indicated that children whose mothers are exposed to high PAH concentrations during pregnancy have a significantly increased risk of obesity, compared to children whose mothers were not exposed to PAHs (Rundle et al., 2012). Poursafa et al. (2018) reported that the increased risk of cardiometabolic risk factors and excess weight are associated with PAHs. Therefore, more attention should be focused on the association between PAH exposure, obesity, and associated health risks.

To further understand the influence of other factors on urinary OH-PAHs, the relationships between OH-PAH concentration and other factors were analyzed. There were significantly different ($p < 0.05$) concentrations of some PAH metabolites in pregnant women with different annual household incomes (Table S4). A previous study reported that the OH-PAH concentrations in children from low-income families were much higher than those of children with high-income families with better living conditions (Wilson et al., 1999). To further understand the influence of annual household income, mothers were divided into three annual household income groups, i.e., high, medium, and low (Fig. 1). The concentration of ΣOH-PAHs in the low group (median: 12.4 ng/mL) was higher than that in the high group (median: 5.28 ng/mL). The results are in agreement with the patterns reported by Wilson et al. (1999), who showed that living in a place with poor air pollution has a great impact on health. Furthermore, we did not observe a

Table 2
Spearman's correlation matrix of each chemical in all samples (n = 77).

	1-OHN	2-OHN	2-OHF	2+3-OHPhe	1- OHPhe	1-OHP	Σ_7 OHPAHs	8-OHdG
1-OHN	1.000							
2-OHN	0.995**	1.000						
2-OHF	0.648**	0.647**	1.000					
2+3-OHPhe	0.598**	0.599**	0.9145**	1.000				
1- OHPhe	0.569**	0.572**	0.761**	0.768**	1.000			
1-OHP	0.315**	0.316**	0.500**	0.585**	0.635*	1.000		
Σ_7 OHPAHs	0.897**	0.901**	0.725**	0.700**	0.651**	0.470**	1.000	
8-OHdG	0.182	0.198	0.381**	0.372*	0.221	0.183	0.471**	1.000

**$p < 0.01$ level (2-tailed); *$p < 0.05$ level (2-tailed).

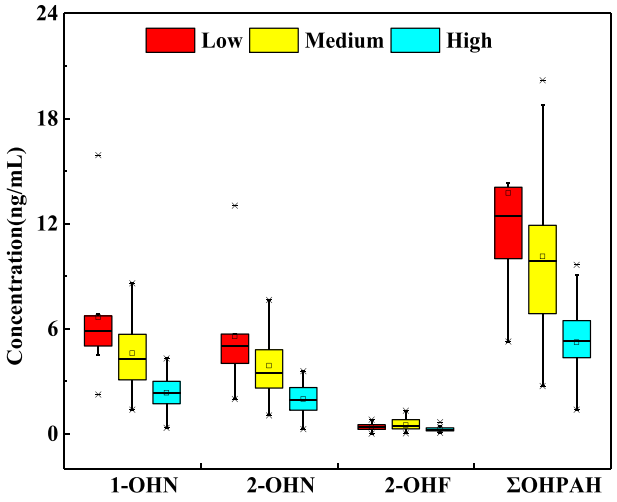

Fig. 1. The concentration of OH-PAHs in urine of primiparas from different annual household income group.

significant association between urinary OH-PAHs and length of time at local residence, usage of induction cookers, microwave ovens, and so on (Table S4). The present results showed that living conditions have a significant influence on human exposure to PAHs.

4.4. Association between OH-PAHs and oxidative stress

The relationships between individual OH-PAH isomers and 8-OHdG in primiparas were investigated. Table 3 shows the correlation coefficients. Significant positive correlations were observed between the concentration of individual OH-PAH isomers or Σ_7OH-PAHs and 8-OHdG. Their coefficients (r) were 0.372–0.471 with $p < 0.05$. On considering the present correlations between OH-PAHs and 8-OHdG, relationships were further analyzed by the quartiles of the individual OH-PAH of Σ_7 OH-PAHs and the 8-OHdG concentration in urine (Fig. 2A). The results showed that for individual OH-PAH isomers and Σ_7 OH-PAHs, urine 8-OHdG levels increased from Q1 to Q4 (p trend < 0.01). Additionally, the relationships between the concentrations of 8-OHdG and the total OH-PAHs were analyzed. The regression analysis showed that there was a significant dose-related increase of 8-OHdG levels with increasing urinary ΣOH-PAH ($r = 0.471$, $p < 0.01$) when the total concentrations of OH-PAHs were transformed into natural logarithms (Fig. 2B). Similar results were also observed in other studies (Hong et al., 2009; Sun et al., 2017). For instance, a dose-response relationship between 1-OHP and 8-OHdG has been reported in children by Hong et al. (2009). Sun et al. (2017) found a similar relationship between urinary PAH metabolites and 8-OHdG in residents from Wuhan, Hubai Province, in China. As a result, 8-OHdG could be a useful biomarker to indicate some of the harms caused by exposure to PAHs in humans. Higher levels of exposure to PAHs can result in an increase in urinary 8-OHdG, which is more harmful to health.

4.5. Estimated daily intakes of PAHs and the associated health risks

To estimate the exposure dose and the associated health risks, the EDI values for the four target PAHs were first calculated (Table 3). The median TEDIs of PAHs was 21.2 μg/day, which were

Table 3
Total estimated daily intake (TEDI, μg/day) of PAHs estimated from urinary metabolite concentrations for primiparas living in Shenzhen.

Compounds		Mean			50th			95th			Range		
Parent	Metabolite	All	19–29	30–36	All	19–29	30–36	All	19–29	30–36	All	19–29	30–36
Nap	1-OHN	7.03	7.17	6.83	5.44	5.56	5.33	15.1	13.5	14.8	0.60–39.5	0.60–39.5	2.20–28.3
	2-OHN	5.93	6.07	5.75	4.66	4.73	4.59	13	11.7	12.3	0.47–33.1	0.47–33.1	1.91–23.1
Flu	2-OHF	1.1	1.18	1.01	0.93	1.07	0.85	2.67	2.72	2.43	0.00–4.01	0.00–3.70	0.05–4.01
Phe	2+3-OHPhe	2.1	2.15	2.03	1.77	1.74	1.91	4.69	4.46	4.46	0.51–6.24	0.51–6.24	0.64–6.04
	1- OHPhe	6.74	6.68	6.83	5.87	5.72	6.21	15.2	14.6	13.0	1.71–22.7	0.00–22.7	0.00–17.1
Pyr	1-OHP	18.6	19.1	17.7	14.9	15.6	14.4	46.3	45.4	33.6	0.00–57.8	0.00–57.8	0.00–46.7
PAHs	OH-PAHs	26.0	34.1	32.4	21.2	28.0	26.7	72.9	76.2	63.9	2.37–112	4.28–112	2.37–83.1

The numbers of the subgroups (n): 19–29 (42), 30–36 (35).

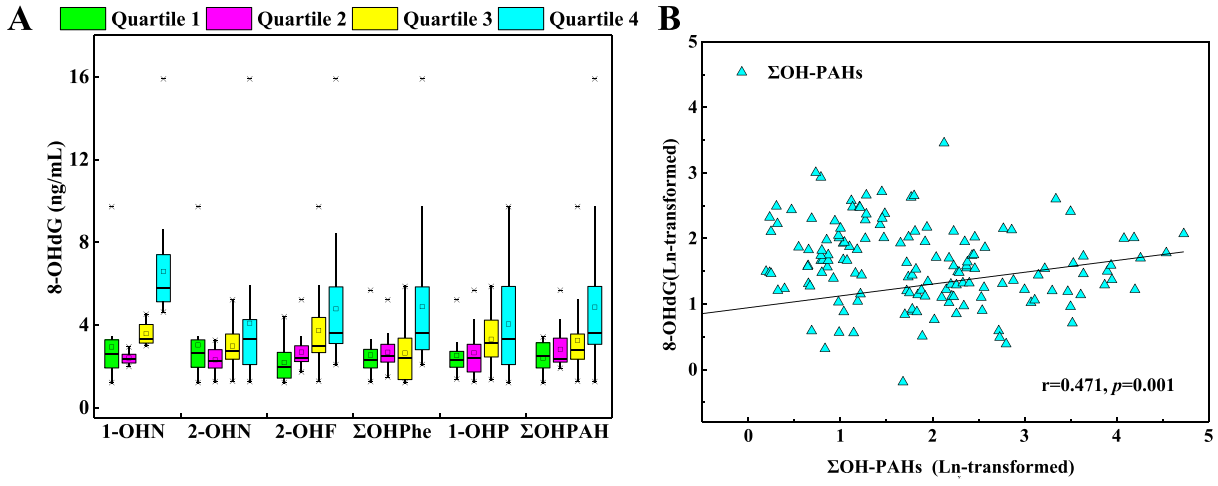

Fig. 2. Relationship between OH-PAHs and 8-OHdG (A: concentrations of 8-OHdG stratified by the quartiles of OH-PAHs; B: correlations of ΣOH-PAHs with 8-OHdG).

similar to those reported for populations in Kuwait (26.4 μg/day) and Korea (28.1 μg/day) (Guo et al., 2013). In this study, among the PAHs, Pyr had the highest EDI value with a range of 2.89–57.8 μg/day, followed by Phe (1.71–22.7 μg/day), Nap (0.60–39.5 μg/day) and Flu (0.05–4.01 μg/day). The results were much lower than those from college students in Guangzhou, in which the EDI varied from 1.53 to 54.6 μg/day for Nap, from 13.8 to 361 μg/day for Phe, from 2.68 to 35.9 μg/day for Flu, and from 66.7 to 371 μg/day for Pyr (Li et al., 2015a). The TEDIs estimated in our study agree with those assessed from dietary intakes of PAHs in Beijing (55.9 μg/day) and Shenzhen (16.9 μg/day) (Ding et al., 2013; Li et al., 2009). However, for remote regions, much lower EDIs were reported. Huang et al. (2018) reported that the median EDI values of PAH metabolites in Tibetan adults were 12, 3.9, 3.3, and 1.9 μg/day for Phe, Nap, Pyr, and Flu, respectively, and the median EDIs of the four target PAHs were 4.7, 5.4, 1.1, and 2.0 μg/day from dietary intake and 0.4, 4.1, 0.04, and 0.5 μg/day through inhalation. In their study, the estimated EDI of PAHs through ingestion and inhalation were nearly the same as those estimated from OH-PAHs. The present results suggest that the TEDI of PAHs in primiparas from Shenzhen were comparable with other regions.

To better understand the exposure risk from PAHs, the HQ and HI values for primiparas based on RfD are shown in Fig. 3. The results revealed that the HQ values for PAHs were well below 1, which indicated that primipara exposure to an individual PAH compound would not pose obvious health risks. However, humans are always simultaneously exposed to multiple chemicals. Cumulative risk using HI can assess the risk of simultaneous exposure to multiple chemicals that have a negative impact on health (Hartmann et al., 2015). The present HI values of all the primiparas were less than a unit, suggesting there were no obvious potential health risks from PAHs.

5. Conclusion

The levels of OH-PAHs in primiparas from Shenzhen were measured and the association with 8-OHdG was analyzed. The high detection frequencies of OH-PAHs indicated the ubiquitous occurrence of human exposure to PAHs. The urinary OH-PAH concentration in Shenzhen primiparas fell to a moderate level, compared with other countries and areas. There was no significant correlation between the metabolites and other factors, such as age, weight, and lifestyle. However, a statistically significant correlation between OH-PAH and 8-OHdG concentrations were observed in primipara urine, and significant dose-effects were suggested. The results of HQ and HI values indicated that PAHs did not pose obvious health risks to primiparas in Shenzhen.

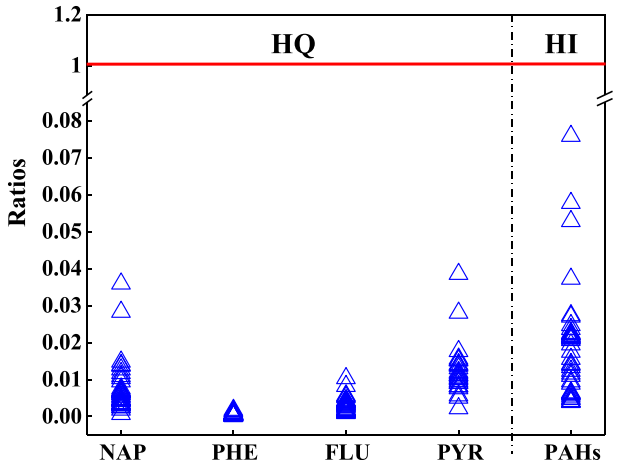

Fig. 3. Individual hazard quotients (HQ) and hazard indexes (HI) of PAHs for the primiparas from Shenzhen, China.

Declaration of competing interest

Compliance with ethical standards.
The authors declare no conflict of interest.

CRediT authorship contribution statement

Mengmeng Peng: Formal analysis, Writing - original draft. **Shaoyou Lu:** Supervision. **Yingxin Yu:** Methodology. **Shan Liu:** Formal analysis. **Yang Zhao:** Formal analysis. **Chun Li:** Formal analysis. **Shengtao Ma:** Writing - review & editing.

Acknowledgements

This research was financially supported by the National Natural Science Foundation of China (No. 21677094), the 100 Top Talents Program of Sun Yat-sen University, Shenzhen Municipal Government Research Projects (No. JCYJ20160428143348745), and Local Innovative and Research Teams Project of Guangdong Pearl River Talents Program (2017BT01Z032). We also thank Shenzhen Center for Disease Control and Prevention for these urine sample collection.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envpol.2019.113854.

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