

Original Article



# Relationship between shellfish consumption and urinary phthalate metabolites: Korean National Environmental Health Survey (KoNEHS) cycle 3 (2015-2017)

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## ABSTRACT

**Background:** Phthalates are endocrine disrupting chemicals that are widely used in the production of items of daily life such as in polyvinylchloride plastics, insecticides, and medical devices. This study aimed to determine the association between phthalate exposure and shellfish consumption using data from the Korean National Environmental Health Survey (KoNEHS) cycle 3 (2015–2017), which is a nationally representative survey.

**Methods:** In this study, we analyzed the KoNEHS cycle 3 data of 3,333 (1,526 men and 1,807 women) adults aged more than 19 years. Data related to the variables of sociodemographic factors, health-related behaviors, dietary factors, seafood consumption frequency, and urinary phthalate metabolites concentrations were collected. The concentrations of urinary phthalate metabolites of all the participants were divided into quartiles to define high and low concentration groups based on the 75th percentile concentration. A  $\chi^2$  test was conducted to analyze the distribution of independent variables. To analyze the relationship between shellfish consumption and phthalate exposure, the odds ratios (ORs) were calculated using logistic regression analysis.

**Results:** Total adults with shellfish consumption frequency of over once a week showed the following adjusted ORs for high concentrations of the following metabolites compared with the group that consumed shellfish once a week or less: 1.43 (95% confidence interval [CI]: 1.01–2.06) for mono-(2-ethyl-5-oxohexyl) phthalate (MEOHP), 1.43 (95% CI: 1.01–2.03) for mono-(2-ethyl-5-carboxypentyl) phthalate (MECPP), 1.57 (95% CI: 1.10–2.24) for  $\Sigma$ di-2-ethylhexyl phthalate ( $\Sigma$ DEHP), 2.01 (95% CI: 1.46–2.77) for mono-carboxyooctyl phthalate (MCOP), 1.56 (95% CI: 1.11–2.18) for mono-carboxy-isononly phthalate (MCNP), and 2.57 (95% CI: 1.85–3.56) for mono (3-carboxypropyl) phthalate (MCPP).

**Conclusions:** The concentrations of urinary phthalate metabolites (MEOHP, MECPP,  $\Sigma$ DEHP, MCOP, MCNP, and MCPP) were higher in adults with a higher frequency of shellfish consumption.

**Keywords:** Phthalate; Shellfish; Korean National Environmental Health Survey

### Abbreviations

BMI: body mass index; BzBP: butyl benzyl phthalate; CI: confidence interval; DBP: di-n-butyl phthalate; DEHP: di-2-ethylhexyl phthalate; DEP: diethyl phthalate; DiBP: di-iso-butyl phthalate; DIDP: di-iso-decyl phthalate; DINP: di-iso-nonylphthalate; DMP: dimethyl phthalate; DPHP: di-2-propylheptyl phthalate; KoNEHS: Korean National Environmental Health Survey; MBzP: mono-benzyl phthalate; MCNP: mono-carboxy-isononyl phthalate; MCOP: mono-carboxyoctyl phthalate; MCPP: mono (3-carboxypropyl) phthalate; MECPP: mono-(2-ethyl-5-carboxypentyl) phthalate; MEHHP: mono-(2-ethyl-5-hydroxyhexyl) phthalate; MEOHP: mono-(2-ethyl-5-oxohexyl) phthalate; MnBP: mono-n-butyl phthalate; OR: odds ratio.

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### Competing interests

The authors declare that they have no competing interests.

### Author contributions

Conceptualization: Kang JS, Cho SY. Data curation: Kang J, Kim J, An JM. Formal analysis: Kang J, Yoon S. Investigation: Kim G. Methodology: Kim SY. Software: Kang J, Cho SY. Validation: Kim J. Writing - original draft: Kang J, Cho SY. Writing - review & editing: Kang J, Cho SY.

## BACKGROUND

Phthalates are esters of phthalic acid (1,2-benzene dicarboxylic acid) that contain two carbon chains of different lengths.<sup>1</sup> Phthalates are added to hard plastic materials to soften them and to allow easy processing. This process is called plasticization; phthalates account for approximately 75% of all plasticizers.<sup>2</sup> Hence, phthalates are widely used in daily supplies, food packaging materials, cosmetics, medical devices, and toys.<sup>3</sup> High-molecular-weight phthalates, including di-2-ethylhexyl phthalate (DEHP), di-iso-nonylphthalate (DINP), di-iso-decyl phthalate (DIDP), and di-2-propylheptyl phthalate (DPHP) are plasticizers for polyvinylchloride that are used in food packaging materials, medical devices, and construction materials. Low-molecular-weight phthalates, including dimethyl phthalate (DMP), diethyl phthalate (DEP), butyl benzyl phthalate (BzBP), di-n-butyl phthalate (DBP), and di-iso-butyl phthalate (DiBP) are mainly contained in cosmetics and drugs as additives.<sup>4</sup> Phthalate exposure in humans may occur through various routes such as oral intake, inhalation, and skin contact, while the most frequent cause is food intake.<sup>2</sup>

Phthalates are endocrine-disrupting chemicals.<sup>4</sup> Phthalates can act as an androgen analogue to induce changes in semen quality,<sup>5,6</sup> causing reproductive dysfunctions such as infertility.<sup>7</sup> As they can bind with estrogen receptors, phthalates may increase the risk of breast cancer,<sup>8,10</sup> and they are also known to not only increase insulin resistance but also cause or aggravate hypertension, diabetes, hyperlipidemia, and metabolic disease.<sup>11</sup>

Phthalates that enter the human body are rapidly metabolized to be excreted via urine or feces. The metabolic process involves phase 1 (hydrolysis) and phase 2 (conjugation) reactions. Low-molecular-weight phthalates undergo phase 1 reaction; then, they are excreted without any further metabolic steps. However, high-molecular-weight phthalates are metabolized by phase 1, followed by subsequent oxidation and phase 2 reaction for excretion.<sup>12</sup> Most phthalates are excreted via urine. Since urinary phthalate metabolites are relatively easy to collect and a single sample of urinary phthalate metabolites reflect the exposure to phthalate over several weeks or months, urinary phthalate metabolites are used as biomarkers to measure the level of exposure to phthalates of the human body.<sup>12,14</sup>

Given that phthalates have been detected across a wide spectrum of marine ecosystems,<sup>15</sup> examining phthalate exposure due to shellfish consumption may be crucial. Among seafood, shellfish is the representative indicator of marine ecosystem pollution.<sup>16,19</sup> Various ongoing studies are investigating the problem of phthalate pollution in marine ecosystems. However, no study has yet been conducted phthalate exposure due to shellfish consumption among individuals in Korea. Thus, this study aimed to determine the association between phthalate exposure and shellfish consumption in the Korea population using data from the Korean National Environmental Health Survey (KoNEHS) cycle 3 (2015–2017), which is a nationally representative survey.

## METHODS

### Study participants

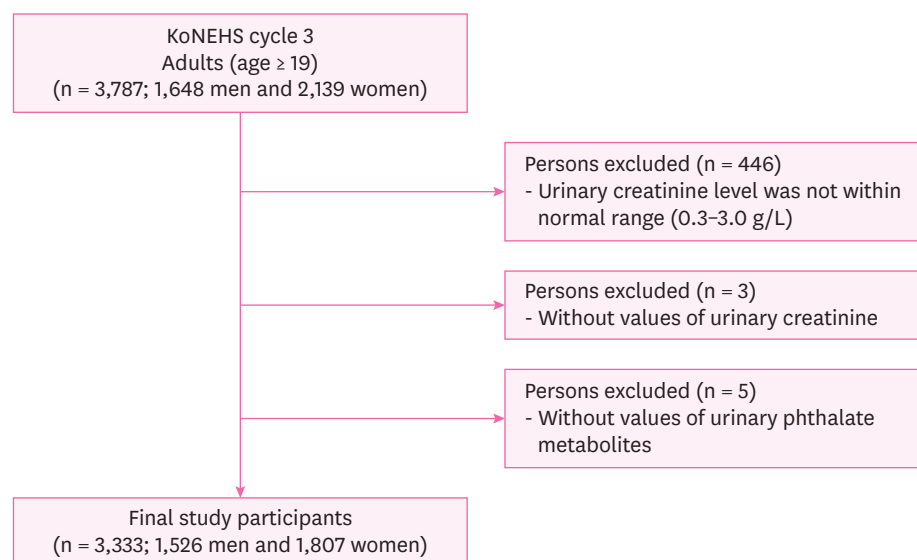
In this study, we used data of adults aged more than 19 years from the KoNEHS cycle 3. Based on Article 14 of the Environmental Health Act, the KoNEHS has been conducted every 3 years since 2009 by the National Institute of Environmental Research under the Ministry of

Environment as a nationwide official inquiry. The purpose of this survey is to make national basic data for establishing environmental health policies by continuously analyzing the current status of environmental health at national and regional units and influencing factors of environmental hazards in the human's body. A total of 3,787 participants in KoNEHS cycle 3 were sampled based on the 2015 population and selected from a total of 233 sample surveys, including 191 general surveys, 9 new apartments, 13 coastal layers, and 20 heavy metal network surveys. Around 15 persons were selected in each survey area. For the collection and analysis of biological samples, 16 clinical tests and 26 environmentally harmful substances were analyzed through blood and urine tests.

Among the data of 3,787 (1,648 men and 2,139 women) individuals aged more than 19 years, 454 persons with missing values of urinary creatinine or urinary phthalate metabolites concentrations or with values outside the normal urinary creatinine range of 0.3–3.0 g/L were excluded, resulting in a final set of 3,333 (1,526 men and 1,807 women) study participants (Fig. 1).<sup>20</sup>

### Urinary phthalate metabolites

Urinary phthalate metabolites concentrations were analyzed using ultra performance liquid chromatograph-mass spectrometry. Clinical laboratory technologists collected spot urine samples in sterilized containers and then transferred to an opaque storage container to shield them from light. The storage container was left to stand in iced water for 20 minutes to reduce the sample temperature and then moved to the lab in an ice box. The collected samples were stored in a –20°C freezer for subsequent analyses. Mono-(2-ethyl-5-hydroxyhexyl) phthalate (MEHHP), mono-(2-ethyl-5-oxohexyl) phthalate (MEOHP), mono-(2-ethyl-5-carboxypentyl) phthalate (MECPP), mono-n-butyl phthalate (MnBP), mono-benzyl phthalate (MBzP), mono-carboxyoctyl phthalate (MCOP), mono-carboxy-isononly phthalate (MCNP), mono (3-carboxypropyl) phthalate (MCPP) were analyzed.<sup>21</sup> The sum of MEHHP, MEOHP, and MECPP was expressed as  $\Sigma$ DEHP.<sup>4</sup> The concentrations of urinary phthalate metabolites of all the participants were divided into quartiles to define high and low concentration groups based on the 75th percentile concentration.<sup>22</sup>



**Fig. 1.** Flow chart of the selection of study participants. KoNEHS: Korean National Environmental Health Survey.

### Shellfish consumption

The frequency of shellfish consumption was categorized into 9 groups (almost never, once a month, 2–3 times a month, once a week, 2–3 times a week, 4–6 times a week, once a day, 2 times a day, 3 times a day). Group of once a week or less included almost never, once a month, 2–3 times a month, once a week, while group of over once a week included 2–3 times a week, 4–6 times a week, once a day, 2 times a day, 3 times a day.

### Potential confounders

Sociodemographic factors, health-related behaviors, and dietary factors of the study participants and types of seafood were defined as follows. Age was expressed as a mean value. Body mass index (BMI) was categorized into normal ( $\leq 25.0$  kg/m<sup>2</sup>) and overweight ( $> 25.0$  kg/m<sup>2</sup>). Marital status was categorized into single, married, and others (divorced/bereaved/separated). Based on smoking frequency, the subjects were categorized into non-smokers or ex-smoker (who have never smoked before or used to smoke but not currently) and current smokers. Based on the frequency of alcohol consumption, the participants were categorized into non-drinkers (who have never drunk before or used to drink but do not currently drink), moderate drinkers (who drink less alcohol than heavy drinkers), and heavy drinkers (who drink more than three times per week and more than seven glasses for men and more than 5 glasses for women at a time). Regarding dietary factors, the use of food storage containers at home in the refrigerator or freezer was divided into plastic bags or zipper bags and others, while consumption frequency of plastic pack drink was categorized into once a week or less and over once a week. Types of seafood were divided into shellfish, large fish and tuna, fish, crustaceans, seaweed, and other seafood items,<sup>20</sup> with the consumption frequency categorized into once a week or less and over once a week.

### Statistical analysis

Sociodemographic factors, health-related behaviors, dietary factors, seafood consumption frequency, and urinary phthalate metabolites concentrations were the variables examined in this study. A  $\chi^2$  test was conducted to analyze the distribution of independent variables. To analyze the relationship between shellfish consumption and phthalate exposure, the odds ratios (ORs) were calculated using logistic regression analysis. For total adult, odd ratios are calculated by adjusting not only gender and age but also sociodemographic factors, health-related behaviors, dietary factors, seafood consumption frequency. For men and women, odd ratios are calculated by adjusting by sociodemographic factors, health-related behaviors, dietary factors, seafood consumption frequency. The logistic regression model was analyzed by applying the weights presented in the original dataset according to the KoNEHS analysis guideline. For statistical analysis, the IBM SPSS version 28 for Windows (IBM Corp., Armonk, NY, USA) was used. The level of significance was set at  $p$ -value  $< 0.05$ .

### Ethics statement

All participants of the KoNEHS cycle 3 (2015–2017) included in this study provided written informed consent. This study was approved by the Institutional Review Board of Soonchunhyang University Hospital (IRB No. Medicine 2022-08).

## RESULTS

The study participants comprised 1,526 men (46%) and 1,807 women (54%) individuals. The median concentrations (MEHHP, MEOHP, MECPP,  $\Sigma$ DEHP, MnBP, MBzP, MCOP, MCNP,

and MCP) were as follows: MEHHP 18.2  $\mu\text{g/g Cr}$  (men: 15.6  $\mu\text{g/g Cr}$ , women: 20.8  $\mu\text{g/g Cr}$ ), MEOHP 13.5  $\mu\text{g/g Cr}$  (men: 11.3  $\mu\text{g/g Cr}$ , women: 16.1  $\mu\text{g/g Cr}$ ), MECPP 27.6  $\mu\text{g/g Cr}$  (men: 22.8  $\mu\text{g/g Cr}$ , women: 32.1  $\mu\text{g/g Cr}$ ),  $\Sigma\text{DEHP}$  61.0  $\mu\text{g/g Cr}$  (men: 51.2  $\mu\text{g/g Cr}$ , women: 71.6  $\mu\text{g/g Cr}$ ), MnBP 31.8  $\mu\text{g/g Cr}$  (men: 27.4  $\mu\text{g/g Cr}$ , women: 35.1  $\mu\text{g/g Cr}$ ), MBzP 2.7  $\mu\text{g/g Cr}$  (men: 2.4  $\mu\text{g/g Cr}$ , women: 3.0  $\mu\text{g/g Cr}$ ), MCOP 1.1  $\mu\text{g/g Cr}$  (men: 1.0  $\mu\text{g/g Cr}$ , women: 1.3  $\mu\text{g/g Cr}$ ), MCNP 0.5  $\mu\text{g/g Cr}$  (men: 0.4  $\mu\text{g/g Cr}$ , women: 0.5  $\mu\text{g/g Cr}$ ), MCP 1.1  $\mu\text{g/g Cr}$  (men: 1.0  $\mu\text{g/g Cr}$ , women: 1.3  $\mu\text{g/g Cr}$ ). The median concentrations of urinary phthalate metabolites were higher in women than in men. The mean age of the participants was 52.9 years (52.8 years in men and 53.0 years in women). More men than women were overweight, current smokers, and heavy drinkers. Regarding the consumption of large fish and tuna, men had a significantly higher consumption frequency of over once a week (Table 1).

The distribution of high and low urinary phthalate metabolites group according to basic characteristics and the frequencies of consumption of seafood is presented in Tables 2-4. For MEHHP, MEOHP, MECPP,  $\Sigma\text{DEHP}$ , MnBP, MBzP, MCNP, and MCP, the mean age of the adult participants in this study was higher in the high concentration group of urinary phthalate metabolites than low concentration group. The group with high concentrations of urinary phthalate metabolites exhibited higher predominance of women (MEHHP, MEOHP, MECPP,  $\Sigma\text{DEHP}$ , MnBP, MBzP, MCOP, MCNP, and MCP), normal BMI (MCOP, MCNP, and MCP), non-smokers or ex-smoker (MEHHP, MEOHP, MECPP,  $\Sigma\text{DEHP}$ , MnBP, MBzP, MCOP, MCNP, and MCP), a lower rate of heavy drinkers (MEHHP, MEOHP, MECPP,  $\Sigma\text{DEHP}$ , MnBP, MBzP, MCOP, MCNP, and MCP) and storage of food in plastic bag or zipper bags (MEHHP, MEOHP, MECPP, and  $\Sigma\text{DEHP}$ ) than the group with low concentration. Regarding seafood consumption, the high concentration group showed higher rates of shellfish consumption of over once a week (MCOP, MCNP, and MCP) and large fish and tuna consumption over once a week (MCP) and crustacean consumption over once a week (MnBP) than the low concentration group.

In this study, total adults that consumed shellfish over once a week showed the following adjusted ORs for significantly high concentrations of urinary phthalate metabolites compared with the group that consumed shellfish once a week or less: 1.43 (95% confidence interval [CI]: 1.01–2.06) for MEOHP, 1.43 (95% CI: 1.01–2.03) for MECPP, 1.57 (95% CI: 1.10–2.24) for  $\Sigma\text{DEHP}$ , 2.01 (95% CI: 1.46–2.77) for MCOP, 1.56 (95% CI: 1.11–2.18) for MCNP, and 2.57 (95% CI: 1.85–3.56) for MCP. For men, the group that consumed shellfish over once a week, compared with the group that consumed shellfish once a week or less, showed the following adjusted ORs for high concentrations of urinary phthalate metabolites: 1.66 (95% CI: 1.01–2.71) for MEHHP, 1.91 (95% CI: 1.14–3.18) for MEOHP, 1.82 (95% CI: 1.13–2.91) for MECPP, 1.77 (95% CI: 1.09–2.87) for  $\Sigma\text{DEHP}$ , 1.90 (95% CI: 1.17–3.07) for MnBP, 2.27 (95% CI: 1.44–3.58) for MCOP, 1.85 (95% CI: 1.16–2.96) for MCNP, and 3.01 (95% CI: 1.91–4.74) for MCP. For women, the adjusted ORs were not significantly high, but the unadjusted ORs were significantly high for MCOP at 1.99 (95% CI: 1.34–2.95) and for MCP at 1.58 (95% CI: 1.05–2.37) (Table 5).

## DISCUSSION

The adult participants in this study exhibited significantly higher ORs for MEOHP, MECPP,  $\Sigma\text{DEHP}$  and for MCOP, MCNP, and MCP, which are high-molecular-weight phthalate metabolites. Among them, DEHP may induce thyroid hormones abnormality and affect the

**Table 1.** Baseline characteristics of the participants

Category	Total (n = 3,333)	Men (n = 1,526)	Women (n = 1,807)	p-value <sup>a</sup>
Urinary phthalate metabolites				
MEHHP (µg/g Cr)	18.2 (10.7–30.3)	15.6 (9.1–25.1)	20.8 (12.3–34.5)	0.004
MEOHP (µg/g Cr)	13.5 (7.8–23.6)	11.3 (6.7–19.5)	16.1 (9.3–27.1)	0.143
MECPP (µg/g Cr)	27.6 (16.4–51.8)	22.8 (13.7–42.9)	32.1 (19.2–61.4)	< 0.001
ΣDEHP (µg/g Cr)	61.0 (37.7–106.8)	51.2 (31.6–88.1)	71.6 (43.8–122.8)	0.002
MnBP (µg/g Cr)	31.8 (16.8–56.7)	27.4 (14.7–49.1)	35.1 (19.3–62.3)	0.132
MBzP (µg/g Cr)	2.7 (1.4–5.4)	2.4 (1.2–4.8)	3.0 (1.5–6.0)	0.003
MCOP (µg/g Cr)	1.1 (0.6–1.9)	1.0 (0.6–1.7)	1.3 (0.7–2.2)	0.001
MCNP (µg/g Cr)	0.5 (0.2–0.8)	0.4 (0.2–0.7)	0.5 (0.2–1.0)	< 0.001
M CPP (µg/g Cr)	1.1 (0.7–1.9)	1.0 (0.6–1.6)	1.3 (0.9–2.2)	0.298
Age (yr)	52.9 ± 14.8	52.8 ± 15.1	53.0 ± 14.6	0.687
BMI (kg/m <sup>2</sup> )				< 0.001 <sup>b</sup>
Normal	1,919 (57.6)	809 (53.0)	1,110 (61.4)	
Overweight	1,414 (42.4)	717 (47.0)	697 (38.6)	
Marital status				< 0.001
Single	371 (11.1)	223 (14.6)	148 (8.2)	
Married	2,583 (77.5)	1,225 (80.3)	1,358 (75.2)	
Others	379 (11.4)	78 (5.1)	301 (16.7)	
Smoking				< 0.001
None or ex-smoker	2,777 (83.3)	1,021 (66.9)	1,756 (97.2)	
Current smoker	556 (16.7)	505 (33.1)	51 (2.8)	
Alcohol				< 0.001
None	673 (20.2)	138 (9.0)	535 (29.6)	
Moderate	2,330 (69.9)	1,100 (72.1)	1,230 (68.1)	
Heavy	330 (9.9)	288 (18.9)	42 (2.3)	
Food storage				0.339
Plastic bag or zipper bag	2,946 (88.4)	1,340 (87.8)	1,606 (88.9)	
Others	387 (11.6)	186 (12.2)	201 (11.1)	
Plastic pack drink				0.140
≤ Once a week	2,450 (73.5)	1,103 (72.3)	1,347 (74.5)	
> Once a week	883 (26.5)	423 (27.7)	460 (25.5)	
Shellfish				0.591
≤ Once a week	3,135 (94.1)	1,439 (94.3)	1,696 (93.9)	
> Once a week	198 (5.9)	87 (5.7)	111 (6.1)	
Large fish and tuna				0.017
≤ Once a week	3,232 (97.0)	1,468 (96.2)	1,764 (97.6)	
> Once a week	101 (3.0)	58 (3.8)	43 (2.4)	
Fish				0.369
≤ Once a week	2,341 (70.2)	1,060 (69.5)	1,281 (70.9)	
> Once a week	992 (29.8)	466 (30.5)	526 (29.1)	
Crustacean				0.613
≤ Once a week	3,218 (96.5)	1,476 (96.7)	1,742 (96.4)	
> Once a week	115 (3.5)	50 (3.3)	65 (3.6)	
Seaweed				0.093
≤ Once a week	1,370 (41.1)	651 (42.7)	719 (39.8)	
> Once a week	1,963 (58.9)	875 (57.3)	1,088 (60.2)	
Other seafood items				0.647
≤ Once a week	3,171 (95.1)	1,449 (95.0)	1,722 (95.3)	
> Once a week	162 (4.9)	77 (5.0)	85 (4.7)	

Data were presented as median (interquartile range), mean ± standard deviation, or number (%).

MEHHP: mono-(2-ethyl-5-hydroxyhexyl) phthalate; MEOHP: mono-(2-ethyl-5-oxohexyl) phthalate; MECPP: mono-(2-ethyl-5-carboxypentyl) phthalate; ΣDEHP: Σdi-2-ethylhexyl phthalate; MnBP: mono-n-butyl phthalate; MBzP: mono-benzyl phthalate; MCOP: mono-carboxyoctyl phthalate; MCNP: mono-carboxy-isononly phthalate; MCPP: mono (3-carboxypropyl) phthalate; BMI: body mass index.

<sup>a</sup>p-value calculated by t-test; <sup>b</sup>p-value calculated by  $\chi^2$  test.

development of male reproductive organs and increasing the risk of hypertension.<sup>23–25</sup> In addition, MCNP and MCOP are known to aggravate allergic dermatitis or asthma and damage the liver or kidney and MCPP can induce abnormalities in male reproductive organs.<sup>26–32</sup> As



## Relationship between shellfish consumption and urinary phthalate metabolites

**Table 2.** Baseline characteristics of the total adults according to urinary phthalate metabolites: MEHHP, MEOHP, MECPP

Category	MEHHP			MEOHP			MECPP		
	Low (n = 2,499)	High (n = 834)	p-value	Low (n = 2,500)	High (n = 833)	p-value	Low (n = 2,500)	High (n = 833)	p-value
Age (yr)	50.9 ± 14.9	58.8 ± 13.0	< 0.001	51.3 ± 14.9	57.7 ± 13.7	< 0.001	51.5 ± 14.8	57.1 ± 14.0	< 0.001 <sup>a</sup>
Gender			< 0.001			< 0.001			< 0.001 <sup>b</sup>
Men	1,241 (81.3)	285 (18.7)		1,252 (82.0)	274 (18.0)		1,248 (81.8)	278 (18.2)	
Women	1,258 (69.6)	549 (30.4)		1,248 (69.1)	559 (30.9)		1,252 (69.3)	555 (30.7)	
BMI			0.458			0.846			0.961
Normal	1,448 (75.5)	471 (24.5)		1,437 (74.9)	482 (25.1)		1,440 (75.0)	479 (25.0)	
Overweight	1,051 (74.3)	363 (25.7)		1,063 (75.2)	351 (24.8)		1,060 (75.0)	354 (25.0)	
Marital status			< 0.001			< 0.001			< 0.001
Single	324 (87.3)	47 (12.7)		319 (86.0)	52 (14.0)		307 (82.7)	64 (17.3)	
Married	1,953 (75.6)	630 (24.4)		1,939 (75.1)	644 (24.9)		1,956 (75.7)	627 (24.3)	
Others	222 (58.6)	157 (41.4)		242 (63.9)	137 (36.1)		237 (62.5)	142 (37.5)	
Smoking			0.001			< 0.001			< 0.001
None or ex-smoker	2,052 (73.9)	725 (26.1)		2,036 (73.3)	741 (26.7)		2,029 (73.1)	748 (26.9)	
Current smoker	447 (80.4)	109 (19.6)		464 (83.5)	92 (16.5)		471 (84.7)	85 (15.3)	
Alcohol			< 0.001			< 0.001			0.001
None	456 (67.8)	217 (32.2)		455 (67.6)	218 (32.4)		470 (69.8)	203 (30.2)	
Moderate	1,786 (76.7)	544 (23.3)		1,772 (76.1)	558 (23.9)		1,766 (75.8)	564 (24.2)	
Heavy	257 (77.9)	73 (22.1)		273 (82.7)	57 (17.3)		264 (80.0)	66 (20.0)	
Food storage			< 0.001			0.005			0.002
Plastic bag or zipper bag	2,181 (74.0)	765 (26.0)		2,187 (74.2)	759 (25.8)		2,185 (74.2)	761 (25.8)	
Others	318 (82.2)	69 (17.8)		313 (80.9)	74 (19.1)		315 (81.4)	72 (18.6)	
Plastic pack drink			0.019			0.486			0.215
≤ Once a week	1,811 (73.9)	639 (26.1)		1,830 (74.7)	620 (25.3)		1,824 (74.4)	626 (25.6)	
> Once a week	688 (77.9)	195 (22.1)		670 (75.9)	213 (24.1)		676 (76.6)	207 (23.4)	
Shellfish			0.442			0.552			0.051
≤ Once a week	2,346 (74.8)	789 (25.2)		2,355 (75.1)	780 (24.9)		2,363 (75.4)	772 (24.6)	
> Once a week	153 (77.3)	45 (22.7)		145 (73.2)	53 (26.8)		137 (69.2)	61 (30.8)	
Large fish and tuna			0.143			0.449			0.221
≤ Once a week	2,417 (74.8)	815 (25.2)		2,421 (74.9)	811 (25.1)		2,419 (74.8)	813 (25.2)	
> Once a week	82 (81.2)	19 (18.8)		79 (78.2)	22 (21.8)		81 (80.2)	20 (19.8)	
Fish			0.285			0.731			0.160
≤ Once a week	1,743 (74.5)	598 (25.5)		1,752 (74.8)	589 (25.2)		1,772 (75.7)	569 (24.3)	
> Once a week	756 (76.2)	236 (23.8)		748 (75.4)	244 (24.6)		728 (73.4)	264 (26.6)	
Crustacean			0.543			0.703			0.871
≤ Once a week	2,410 (74.9)	808 (25.1)		2,412 (75.0)	806 (25.0)		2,413 (75.0)	805 (25.0)	
> Once a week	89 (77.4)	26 (22.6)		88 (76.5)	27 (23.5)		87 (75.7)	28 (24.3)	
Seaweed			0.041			0.305			0.832
≤ Once a week	1,002 (73.1)	368 (26.9)		1,015 (74.1)	355 (25.9)		1,025 (74.8)	345 (25.2)	
> Once a week	1,497 (76.3)	466 (23.7)		1,485 (75.6)	478 (24.4)		1,475 (75.1)	488 (24.9)	
Other seafood items			0.520			0.404			0.051
≤ Once a week	2,381 (75.1)	790 (24.9)		2,374 (74.9)	797 (25.1)		2,389 (75.3)	782 (24.7)	
> Once a week	118 (72.8)	44 (27.2)		126 (77.8)	36 (22.2)		111 (68.5)	51 (31.5)	

Data were presented as mean ± standard deviation or number (%).

MEHHP: mono-(2-ethyl-5-hydroxyhexyl) phthalate; MEOHP: mono-(2-ethyl-5-oxohexyl) phthalate; MECPP: mono-(2-ethyl-5-carboxypentyl) phthalate; BMI: body mass index.

<sup>a</sup>p-value calculated by t-test; <sup>b</sup>p-value calculated by  $\chi^2$  test.

there is no previous study on the association between shellfish consumption and phthalate exposure in Korea, MEOHP, MECPP,  $\Sigma$ DEHP, MCOP, MCNP, and MCP can serve as valuable indicators in future assessments of phthalate exposure based on shellfish consumption.

In a study involving pregnant women in Taiwan, the MnBP concentration was higher in shellfish consumption more frequently in line with the findings of this study.<sup>33</sup> In previous studies, high concentrations of phthalates were detected in shellfish, which were mentioned to be associated with microplastics.<sup>34,35</sup> Recently, contamination of seafood by microplastics has become of great interest. While microplastics are mainly found in the gastrointestinal

## Relationship between shellfish consumption and urinary phthalate metabolites

**Table 3.** Baseline characteristics of the total adults according to urinary phthalate metabolites:  $\Sigma$ DEHP, MnBP, MBzP

Category	$\Sigma$ DEHP			MnBP			MBzP		
	Low (n = 2,499)	High (n = 834)	p-value	Low (n = 2,500)	High (n = 833)	p-value	Low (n = 2,499)	High (n = 834)	p-value
Age (yr)	51.3 ± 14.9	57.7 ± 13.5	< 0.001	51.5 ± 14.9	57.1 ± 13.8	< 0.001	51.5 ± 14.8	56.9 ± 14.2	< 0.001 <sup>a</sup>
Gender			< 0.001			< 0.001			< 0.001 <sup>b</sup>
Men	1,248 (81.8)	278 (18.2)		1,214 (79.6)	312 (20.4)		1,201 (78.7)	325 (21.3)	
Women	1,251 (69.2)	556 (30.8)		1,286 (71.2)	521 (28.8)		1,298 (71.8)	509 (28.2)	
BMI			0.508			0.722			0.410
Normal	1,447 (75.4)	472 (24.6)		1,435 (74.8)	484 (25.2)		1,449 (75.5)	470 (24.5)	
Overweight	1,052 (74.4)	362 (25.6)		1,065 (75.3)	349 (24.7)		1,050 (74.3)	364 (25.7)	
Marital status			< 0.001			< 0.001			0.015
Single	319 (86.0)	52 (14.0)		305 (82.2)	66 (17.8)		293 (79.0)	78 (21.0)	
Married	1,946 (75.3)	637 (24.7)		1,937 (75.0)	646 (25.0)		1,941 (75.1)	642 (24.9)	
Others	234 (61.7)	145 (38.3)		258 (68.1)	121 (31.9)		265 (69.9)	114 (30.1)	
Smoking			< 0.001			< 0.001			0.018
None or ex-smoker	2,039 (73.4)	738 (26.6)		2,042 (73.5)	735 (26.5)		2,060 (74.2)	717 (25.8)	
Current smoker	460 (82.7)	96 (17.3)		458 (82.4)	98 (17.6)		439 (79.0)	117 (21.0)	
Alcohol			< 0.001			< 0.001			< 0.001
None	453 (67.3)	220 (32.7)		473 (70.3)	200 (29.7)		464 (68.9)	209 (31.1)	
Moderate	1,780 (76.4)	550 (23.6)		1,756 (75.4)	574 (24.6)		1,770 (76.0)	560 (24.0)	
Heavy	266 (80.6)	64 (19.4)		271 (82.1)	59 (17.9)		265 (80.3)	65 (19.7)	
Food storage			0.013			0.972			0.270
Plastic bag or zipper bag	2,189 (74.3)	757 (25.7)		2,210 (75.0)	736 (25.0)		2,200 (74.7)	746 (25.3)	
Others	310 (80.1)	77 (19.9)		290 (74.9)	97 (25.1)		299 (77.3)	88 (22.7)	
Plastic pack drink			0.279			0.333			0.019
≤ Once a week	1,825 (74.5)	625 (25.5)		1,827 (74.6)	623 (25.4)		1,811 (73.9)	639 (26.1)	
> Once a week	674 (76.3)	209 (23.7)		673 (76.2)	210 (23.8)		688 (77.9)	195 (22.1)	
Shellfish			0.451			0.798			0.678
≤ Once a week	2,355 (75.1)	780 (24.9)		2,353 (75.1)	782 (24.9)		2,353 (75.1)	782 (24.9)	
> Once a week	144 (72.7)	54 (27.3)		147 (74.2)	51 (25.8)		146 (73.7)	52 (26.3)	
Large fish and tuna			0.143			0.091			0.090
≤ Once a week	2,417 (74.8)	815 (25.2)		2,417 (74.8)	815 (25.2)		2,416 (74.8)	816 (25.2)	
> Once a week	82 (81.2)	19 (18.8)		83 (82.2)	18 (17.8)		83 (82.2)	18 (17.8)	
Fish			0.946			0.218			0.984
≤ Once a week	1,756 (75.0)	585 (25.0)		1,770 (75.6)	571 (24.4)		1,755 (75.0)	586 (25.0)	
> Once a week	743 (74.9)	249 (25.1)		730 (73.6)	262 (26.4)		744 (75.0)	248 (25.0)	
Crustacean			0.961			0.014			0.789
≤ Once a week	2,413 (75.0)	805 (25.0)		2,425 (75.4)	793 (24.6)		2,414 (75.0)	804 (25.0)	
> Once a week	86 (74.8)	29 (25.2)		75 (65.2)	40 (34.8)		85 (73.9)	30 (26.1)	
Seaweed			0.322			< 0.001			0.027
≤ Once a week	1,015 (74.1)	355 (25.9)		985 (71.9)	385 (28.1)		1,000 (73.0)	370 (27.0)	
> Once a week	1,484 (75.6)	479 (24.4)		1,515 (77.2)	448 (22.8)		1,499 (76.4)	464 (23.6)	
Other seafood items			0.931			0.928			0.511
≤ Once a week	2,378 (75.0)	793 (25.0)		2,378 (75.0)	793 (25.0)		2,374 (74.9)	797 (25.1)	
> Once a week	121 (74.7)	41 (25.3)		122 (75.3)	40 (24.7)		125 (77.2)	37 (22.8)	

Data were presented as mean ± standard deviation or number (%).

$\Sigma$ DEHP:  $\Sigma$ di-2-ethylhexyl phthalate; MnBP: mono-n-butyl phthalate; MBzP: mono-benzyl phthalate; BMI: body mass index.

<sup>a</sup>p-value calculated by t-test; <sup>b</sup>p-value calculated by  $\chi^2$  test.

tracts and gills of seafood, most people eat the flesh of seafood after the removing the gastrointestinal tracts and gills of both common fish and large fish. In contrast, in the case of shellfish, most people eat the entire shellfish, including the gastrointestinal tracts and gills.<sup>36</sup> Therefore, the exposure to microplastics may be higher with shellfish consumption than with the other seafood consumption.<sup>37</sup> In this study, the high concentrations of urinary phthalate metabolites were attributed to the consumption of large amounts of phthalates in microplastics via shellfish consumption.

In this study, shellfish are defined as mollusks such as clams, mussels, oysters, abalones, conch shells, and whelks. Shellfish are well-known indicators of contamination by



## Relationship between shellfish consumption and urinary phthalate metabolites

**Table 4.** Baseline characteristics of the total adults according to urinary phthalate metabolites: MCOP, MCNP, MCPP

Category	MCOP			MCNP			MCPP		
	Low (n = 2,499)	High (n = 834)	p-value	Low (n = 2,500)	High (n = 833)	p-value	Low (n = 2,500)	High (n = 833)	p-value
Age (yr)	52.8 ± 14.8	53.0 ± 14.9	0.802	52.4 ± 14.9	54.3 ± 14.7	< 0.001	52.4 ± 14.9	54.4 ± 14.6	< 0.001 <sup>a</sup>
Gender			< 0.001			< 0.001			< 0.001 <sup>b</sup>
Men	1,236 (81.0)	290 (19.0)		1,242 (81.4)	284 (18.6)		1,234 (80.9)	292 (19.1)	
Women	1,263 (69.9)	544 (30.1)		1,258 (69.6)	549 (30.4)		1,266 (70.1)	541 (29.9)	
BMI			0.008			0.001			0.007
Normal	1,406 (73.3)	513 (26.7)		1,400 (73.0)	519 (27.0)		1,406 (73.3)	513 (26.7)	
Overweight	1,093 (77.3)	321 (22.7)		1,100 (77.8)	314 (22.2)		1,094 (77.4)	320 (22.6)	
Marital status			0.166			0.009			0.027
Single	275 (74.1)	96 (25.9)		291 (78.4)	80 (21.6)		281 (75.7)	90 (24.3)	
Married	1,954 (75.6)	629 (24.4)		1,947 (75.4)	636 (24.6)		1,956 (75.7)	627 (24.3)	
Others	270 (71.2)	109 (28.8)		262 (69.1)	117 (30.9)		263 (69.4)	116 (30.6)	
Smoking			< 0.001			< 0.001			< 0.001
None or ex-smoker	2,047 (73.7)	730 (26.3)		2,052 (73.9)	725 (26.1)		2,049 (73.8)	728 (26.2)	
Current smoker	452 (81.3)	104 (18.7)		448 (80.6)	108 (19.4)		451 (81.1)	105 (18.9)	
Alcohol			0.007			< 0.001			< 0.001
None	478 (71.0)	195 (29.0)		468 (69.5)	205 (30.5)		474 (70.4)	199 (29.6)	
Moderate	1,758 (75.5)	572 (24.5)		1,755 (75.3)	575 (24.7)		1,750 (75.1)	580 (24.9)	
Heavy	263 (79.7)	67 (20.3)		277 (83.9)	53 (16.1)		276 (83.6)	54 (16.4)	
Food storage			0.064			0.181			0.335
Plastic bag or zipper bag	2,194 (74.5)	752 (25.5)		2,199 (74.6)	747 (25.4)		2,202 (74.7)	744 (25.3)	
Others	305 (78.8)	82 (21.2)		301 (77.8)	86 (22.2)		298 (77.0)	89 (23.0)	
Plastic pack drink			0.860			0.290			0.380
≤ Once a week	1,835 (74.9)	615 (25.1)		1,826 (74.5)	624 (25.5)		1,828 (74.6)	622 (25.4)	
> Once a week	664 (75.2)	219 (24.8)		674 (76.3)	209 (23.7)		672 (76.1)	211 (23.9)	
Shellfish			0.002			0.034			< 0.001
≤ Once a week	2,369 (75.6)	766 (24.4)		2,364 (75.4)	771 (24.6)		2,376 (75.8)	759 (24.2)	
> Once a week	130 (65.7)	68 (34.3)		136 (68.7)	62 (31.3)		124 (62.6)	74 (37.4)	
Large fish and tuna			0.182			0.322			0.041
≤ Once a week	2,429 (75.2)	803 (24.8)		2,420 (74.9)	812 (25.1)		2,433 (75.3)	799 (24.7)	
> Once a week	70 (69.3)	31 (30.7)		80 (79.2)	21 (20.8)		67 (66.3)	34 (33.7)	
Fish			0.392			0.480			0.935
≤ Once a week	1,765 (75.4)	576 (24.6)		1,764 (75.4)	577 (24.6)		1,755 (75.0)	586 (25.0)	
> Once a week	734 (74.0)	258 (26.0)		736 (74.2)	256 (25.8)		745 (75.1)	247 (24.9)	
Crustacean			0.789			0.351			0.351
≤ Once a week	2,414 (75.0)	804 (25.0)		2,418 (75.1)	800 (24.9)		2,418 (75.1)	800 (24.9)	
> Once a week	85 (73.9)	30 (26.1)		82 (71.3)	33 (28.7)		82 (71.3)	33 (28.7)	
Seaweed			0.757			0.910			0.770
≤ Once a week	1,031 (75.3)	339 (24.7)		1,029 (75.1)	341 (24.9)		1,024 (74.7)	346 (25.3)	
> Once a week	1,468 (74.8)	495 (25.2)		1,471 (74.9)	492 (25.1)		1,476 (75.2)	487 (24.8)	
Other seafood items			0.229			0.513			0.226
≤ Once a week	2,384 (75.2)	787 (24.8)		2,382 (75.1)	789 (24.9)		2,385 (75.2)	786 (24.8)	
> Once a week	115 (71.0)	47 (29.0)		118 (72.8)	44 (27.2)		115 (71.0)	47 (29.0)	

Data were presented as mean ± standard deviation or number (%).

MCOP: mono-carboxyethyl phthalate; MCNP: mono-carboxy-isononly phthalate; MCPP: mono (3-carboxypropyl) phthalate; BMI: body mass index.

<sup>a</sup>p-value calculated by t-test; <sup>b</sup>p-value calculated by  $\chi^2$  test.

microplastics as they are found in any part of the sea in abundance and allow easy detection and quantification of marine contaminants.<sup>16-19</sup> Microplastics are synthetic polymeric particles measuring less than 5 mm in diameter.<sup>38</sup> Human exposure to microplastics can occur through various routes, including oral intake, inhalation, and skin contact.<sup>39</sup> Plastics that enter the sea degrade into microplastics in time<sup>35</sup>; the microplastics are then ingested by marine organisms,<sup>40,41</sup> and notably, a high level of microplastics has been detected in shellfish. Hence, it is possible that human ingest microplastics via shellfish consumption.<sup>42-44</sup>

In a study conducted in China, microplastics were detected in 233 of 290 shellfish samples (80%).<sup>19</sup> According to another study on microplastics in seafood sample, the number of

**Table 5.** Adjusted ORs and 95% CIs of shellfish consumption with high concentrations of urinary phthalate metabolites

Category	Total						Men						Women						
	Unadjusted		Adjusted model 1 <sup>a</sup>		Adjusted model 2 <sup>b</sup>		Unadjusted		Adjusted model 3 <sup>c</sup>		Adjusted model 3 <sup>c</sup>		Unadjusted		Adjusted model 3 <sup>c</sup>		Adjusted model 3 <sup>c</sup>		
	≤ Once a week	> Once a week	≤ Once a week	> Once a week	≤ Once a week	> Once a week	≤ Once a week	> Once a week	≤ Once a week	> Once a week	≤ Once a week	> Once a week	≤ Once a week	> Once a week	≤ Once a week	> Once a week	≤ Once a week	> Once a week	
MEHHP	1.21 (0.87-1.67)	1.18 (0.84-1.65)	1.19 (0.82-1.73)	1.19 (0.82-1.73)	1.52 (0.98-2.35)	1.66 (1.01-2.71)	1.12 (0.71-1.77)	1.12 (0.71-1.77)	1.12 (0.71-1.77)	1.12 (0.71-1.77)	1.12 (0.71-1.77)	1.12 (0.71-1.77)	1.12 (0.71-1.77)	1.12 (0.71-1.77)	1.12 (0.71-1.77)	1.12 (0.71-1.77)	1.12 (0.71-1.77)	1.12 (0.71-1.77)	1.12 (0.71-1.77)
MEOHP	1.32 (0.96-1.81)	1.29 (0.93-1.79)	1.43 (1.01-2.06)	1.43 (1.01-2.06)	1.31 (0.83-2.05)	1.91 (1.14-3.18)	1.21 (0.77-1.88)	1.21 (0.77-1.88)	1.21 (0.77-1.88)	1.21 (0.77-1.88)	1.21 (0.77-1.88)	1.21 (0.77-1.88)	1.21 (0.77-1.88)	1.21 (0.77-1.88)	1.21 (0.77-1.88)	1.21 (0.77-1.88)	1.21 (0.77-1.88)	1.21 (0.77-1.88)	1.21 (0.77-1.88)
MECPP	1.49 (1.10-2.01)	1.46 (1.07-2.00)	1.43 (1.01-2.03)	1.43 (1.01-2.03)	1.67 (1.09-2.54)	1.82 (1.13-2.91)	1.32 (0.86-2.03)	1.32 (0.86-2.03)	1.32 (0.86-2.03)	1.32 (0.86-2.03)	1.32 (0.86-2.03)	1.32 (0.86-2.03)	1.32 (0.86-2.03)	1.32 (0.86-2.03)	1.32 (0.86-2.03)	1.32 (0.86-2.03)	1.32 (0.86-2.03)	1.32 (0.86-2.03)	1.32 (0.86-2.03)
ΣDEHP	1.44 (1.06-1.96)	1.42 (1.03-1.95)	1.57 (1.10-2.24)	1.57 (1.10-2.24)	1.51 (0.98-2.32)	1.77 (1.09-2.87)	1.13 (0.72-1.77)	1.13 (0.72-1.77)	1.13 (0.72-1.77)	1.13 (0.72-1.77)	1.13 (0.72-1.77)	1.13 (0.72-1.77)	1.13 (0.72-1.77)	1.13 (0.72-1.77)	1.13 (0.72-1.77)	1.13 (0.72-1.77)	1.13 (0.72-1.77)	1.13 (0.72-1.77)	1.13 (0.72-1.77)
MnBP	1.10 (0.80-1.53)	1.07 (0.77-1.49)	1.08 (0.74-1.56)	1.08 (0.74-1.56)	1.83 (1.20-2.79)	1.90 (1.17-3.07)	0.66 (0.40-1.09)	0.66 (0.40-1.09)	0.66 (0.40-1.09)	0.66 (0.40-1.09)	0.66 (0.40-1.09)	0.66 (0.40-1.09)	0.66 (0.40-1.09)	0.66 (0.40-1.09)	0.66 (0.40-1.09)	0.66 (0.40-1.09)	0.66 (0.40-1.09)	0.66 (0.40-1.09)	0.66 (0.40-1.09)
MBZP	0.89 (0.63-1.27)	0.87 (0.61-1.24)	0.84 (0.57-1.25)	0.84 (0.57-1.25)	0.93 (0.56-1.53)	0.94 (0.54-1.63)	1.01 (0.63-1.60)	1.01 (0.63-1.60)	1.01 (0.63-1.60)	1.01 (0.63-1.60)	1.01 (0.63-1.60)	1.01 (0.63-1.60)	1.01 (0.63-1.60)	1.01 (0.63-1.60)	1.01 (0.63-1.60)	1.01 (0.63-1.60)	1.01 (0.63-1.60)	1.01 (0.63-1.60)	1.01 (0.63-1.60)
MCOP	2.05 (1.54-2.71)	2.03 (1.52-2.70)	2.01 (1.46-2.77)	2.01 (1.46-2.77)	1.84 (1.23-2.76)	2.27 (1.44-3.58)	1.99 (1.34-2.95)	1.99 (1.34-2.95)	1.99 (1.34-2.95)	1.99 (1.34-2.95)	1.99 (1.34-2.95)	1.99 (1.34-2.95)	1.99 (1.34-2.95)	1.99 (1.34-2.95)	1.99 (1.34-2.95)	1.99 (1.34-2.95)	1.99 (1.34-2.95)	1.99 (1.34-2.95)	1.99 (1.34-2.95)
MCNP	1.52 (1.13-2.04)	1.49 (1.11-2.02)	1.56 (1.11-2.18)	1.56 (1.11-2.18)	1.49 (0.98-2.28)	1.85 (1.16-2.96)	1.34 (0.88-2.03)	1.34 (0.88-2.03)	1.34 (0.88-2.03)	1.34 (0.88-2.03)	1.34 (0.88-2.03)	1.34 (0.88-2.03)	1.34 (0.88-2.03)	1.34 (0.88-2.03)	1.34 (0.88-2.03)	1.34 (0.88-2.03)	1.34 (0.88-2.03)	1.34 (0.88-2.03)	1.34 (0.88-2.03)
MCPPE	2.23 (1.68-2.96)	2.21 (1.66-2.94)	2.57 (1.85-3.56)	2.57 (1.85-3.56)	2.55 (1.71-3.80)	3.01 (1.91-4.74)	1.58 (1.05-2.37)	1.58 (1.05-2.37)	1.58 (1.05-2.37)	1.58 (1.05-2.37)	1.58 (1.05-2.37)	1.58 (1.05-2.37)	1.58 (1.05-2.37)	1.58 (1.05-2.37)	1.58 (1.05-2.37)	1.58 (1.05-2.37)	1.58 (1.05-2.37)	1.58 (1.05-2.37)	1.58 (1.05-2.37)

OR: odds ratio; CI: confidence interval; MEHHP: mono-(2-ethyl-5-hydroxyhexyl) phthalate; MEOHP: mono-(2-ethyl-5-oxohexyl) phthalate; MECPP: mono-(2-ethyl-5-carboxypentyl) phthalate; ΣDEHP: Σdi-2-ethylhexyl phthalate; MnBP: mono-n-butyl phthalate; MBZP: mono-benzyl phthalate; MCOP: mono-carboxyethyl phthalate; MCNP: mono-carboxyethyl phthalate; MCPPE: mono-(2-ethyl-5-carboxypentyl) phthalate; (3-carboxypropyl) phthalate.

<sup>a</sup>Adjusted model 1: adjusted for gender, age; <sup>b</sup>Adjusted model 2: adjusted for gender, age, BMI, marital status, smoking, alcohol, food storage, and consumption of plastic pack drink, large fish and tuna, fish, crustacean, seaweed, other seafood items; <sup>c</sup>Adjusted model 3: adjusted for age, BMI, marital status, smoking, alcohol, food storage, and consumption of plastic pack drink, large fish and tuna, fish, crustacean, seaweed, other seafood items.

microplastics in shellfish are highest compared to crustaceans and fish (0.1–8.6 MPs/g for crustaceans, 0–2.9 for fish, and 0–10.5 for shellfish).<sup>36</sup> A large amount of microplastics is accumulated in shellfish as the shellfish are filter-feeders that pump only the seawater out by ciliary action of gills after the ingestion of microplastics.<sup>16,17,45</sup> As a result, shellfish have higher a content of microplastics per weight than other types of seafood, which makes shellfish a reliable indicator of the level of contamination of seawater by microplastics.

When phthalate concentration was measured for microplastics collected in the eastern Mediterranean Sea and Red Sea, the maximum levels were 6 µg/g dw for DBP and 13 µg/g dw for DEHP.<sup>46</sup> On analyzing the microplastics from the northern shores of China, it was found that microplastics and phthalates had a strong positive correlation.<sup>47</sup> In Korea, the report of the Korea Institute of Ocean Science & Technology stated that the mean concentration of microplastics across 18 shores was 1,841 MPs/m<sup>3</sup> and phthalates were detected in the analyses of those microplastics.<sup>48</sup> Phthalates have a high octanol/water partition coefficient to indicate high hydrophobicity such that they exhibit a high level of affinity with the microplastics considering their hydrophobic surface.<sup>49-51</sup> In addition, the NaCl content of seawater produces a salting-out effect that increases the strength of affinity between hydrophobic substances. Therefore, seawater can make the strong affinity between microplastics and phthalates. Hence, seawater may contain higher levels of phthalates in microplastics than other natural environments.<sup>52</sup> According to a previous study on microplastics detected in shellfish, fish, and holothurians collected from a protected marine area in the Mediterranean Sea, the level of DEHP was the highest in shellfish and the lowest in fish flesh.<sup>53</sup> In conclusion, compared with other seafood types, shellfish contain an abundance of microplastics as well as phthalates.

In each country, the use of phthalates is strictly regulated. The Food and Drug Administration in the U.S. restricts the use of phthalates in food packaging materials, cosmetics, and drugs.<sup>54</sup> The regulation in Korea restricts the use of phthalates in hygiene items, packaging containers, cosmetics, and medical devices. Nevertheless, the risk of phthalate exposure through shellfish consumption is not yet clearly understood. The possibility that humans can be exposed to phthalates through shellfish consumption should not be overlooked and continuous research and monitoring are needed in this regard.

There are some limitations to this study. First, while this study focused on the frequency of shellfish consumption, detailed information such as the amount and cooking method could not be analyzed. In this study, unlike in men, no relationship was observed between shellfish consumption and urinary phthalate concentrations in women, as it is assumed that women consume less amount of shellfish than men. Second, this study could not evaluate work environments such as personal protective equipment, ventilation system, and kind of exposed chemicals, so occupational factor possibility of phthalate exposure due to occupation was not taken into account. Third, as the consumption frequency was based on the memory recall of the participants, the risk of inaccuracy cannot be ruled out. Fourth, only the concentrations of phthalate metabolites in single urine samples were analyzed such that there is a possibility of concentration variability. Hence, it is necessary to change the method of sample collection to 24-hour urine sample collection or analysis of blood concentrations.

To the best of our knowledge, not many studies have reported on the association of shellfish consumption with urinary levels of phthalate metabolites, with no such study published in Korea. Thus, despite the limitations, the significance of this study lies in its analysis of the

data of a sample representing the general population in Korea to examine the association between the levels of shellfish consumption and urinary phthalate metabolites concentrations.

Based on the results of this study, the phthalate concentration in shellfish should be continuously monitored as part of efforts to prevent phthalate exposure in the general population, and plastic pollution of marine ecosystems should be proactively and urgently managed. Furthermore, as phthalates are detected in a variety of environments, additional studies should be conducted to identify the association with the pollution of environments other than marine ecosystems (e.g., food contamination in relation to soil contamination and others).

## CONCLUSIONS

In this study, the association of urinary phthalate metabolites concentrations with shellfish, as a representative indicator of marine ecosystem pollution, was identified in the general population in Korea. The concentrations of urinary phthalate metabolites (MEOHP, MECPP,  $\Sigma$ DEHP, MCOP, MCNP, and MCPP) were high in adults who frequently consumed shellfish.

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