Ann Occup Environ Med. 2023 Dec 27;35:e53
https://doi.org/10.35371/aoem.2023.35.e53
eISSN 2052-4374

Annals of Occupational and Environmental Medicine AOEM

Original Article

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Relationship between the use of plastics in refrigerator food storage and urine phthalate metabolites: the Korean National Environmental Health Survey (KoNEHS) cycle 3

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Received: Oct 18, 2023
1st Revised: Nov 30, 2023
2nd Revised: Dec 11, 2023
Accepted: Dec 20, 2023
Published online: Dec 27, 2023

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ABSTRACT

Background: Plastics are high-molecular-weight materials composed of long carbon chains. They are prevalent in daily life, present in various items such as food containers and microwavable packaging. Phthalates, an additive used to enhance their flexibility, are endocrine-disrupting chemicals. We utilized the data from the Korean National Environmental Health Survey (KoNEHS) cycle 3, representing the general South Korean population, to investigate the relationship between the use of plastics in refrigerator food storage and phthalate exposure.
Methods: We assessed 3,333 adult participants (aged ≥ 19 years) including 1,526 men and 1,807 women, using data from KoNEHS cycle 3. Using the 75th percentile concentration, urine phthalate metabolites were categorized into high and low-concentration groups. χ^2 test was conducted to analyze variations in the distribution of each variable, considering sociodemographic factors, health-related factors, food intake, the use of plastics, and the concentration of urine phthalate metabolites as the variables. To calculate odds ratios (ORs) for the high-concentration group of urine phthalate metabolites based on the use of plastics in refrigerator food storage, logistic regression analysis was conducted.
Results: In men, the use of plastics in refrigerator food storage had significantly higher adjusted ORs compared to those using the others. The adjusted ORs were calculated as follows: mono-(2-ethyl-5-hydroxyhexyl) phthalate (MEHHP) had an OR of 1.35 (95% confidence interval [CI]: 1.05–1.72), mono-(2-ethyl-5-oxohexyl) phthalate (MEOHP) had an OR of 1.48 (95% CI: 1.16–1.88), mono-(2-ethyl-5-carboxypentyl) phthalate (MECPP) had an OR of 1.32 (95% CI: 1.04–1.66), ∑di(2-ethylhexyl) phthalate (∑DEHP) had an OR of 1.37 (95% CI: 1.08–1.74) and mono-n-butyl phthalate (MnBP) had an OR of 1.44 (95% CI: 1.13–1.84).
Conclusion: The concentrations of urine phthalate metabolites (MEHHP, MEOHP, MECPP, ∑DEHP, and MnBP) were significantly higher in men who used plastics in refrigerator food storage compared to those using the others.

Keywords: Plastics; Phthalate; Korean National Environmental Health Survey

Abbreviations

BBzP: butyl benzyl phthalate; BMI: body mass index; CI: confidence interval; DBP: di-n-butyl phthalate; DEHP: di(2-ethylhexyl) phthalate; DEP: diethyl phthalate; DIBP: di-isobutyl phthalate; DiDP: di-iso-decyl phthalate; DiNP: di-iso-nonyl phthalate; DMP: dimethyl phthalate; DNOP: di-n-octyl phthalate; EDC: endocrine-disrupting compound; KoNEHS: Korean National Environmental Health Survey; MBzP: mono-benzyl phthalate; MCNP: mono-carboxy-isononly 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; PET: polyethylene terephthalate; PVC: polyvinyl chloride.

Funding

This research was supported by the Soonchunhyang University Research Fund and Inha University Hospital's Environmental Health Center for Training Environmental Medicine Professional funded by the Ministry of Environment, Republic of Korea (2023).

Competing interests

The authors declare that they have no competing interests.

Author Contributions

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

BACKGROUND

Plastics are high-molecular-weight materials composed of long carbon chains.[1] They include various types, such as polyvinyl chloride (PVC), polypropylene, polystyrene, polyethylene, polyethylene terephthalate (PET), polycarbonate, phenolic resin, polyester resin and melamine resin. Plastics are prevalent in daily life, including plastic food containers, plastic bottles, cosmetic containers, home appliances, and microwavable packaging.[2] The use of plastics has been steadily increasing due to their light weight, durability, and cost-effectiveness.[3]

Most plastics contain various additives to enhance color, flexibility, and softness. Among these additives, plasticizers are utilized to increase the flexibility of plastics.[4] Plasticizers are produced worldwide each year approximately 7.5 million tons. Among these plasticizers, phthalates are most commonly used.[5] Phthalates are categorized as high-molecular-weight phthalates and low-molecular-weight phthalates. High-molecular-weight phthalates, including di(2-ethylhexyl) phthalate (DEHP), di-iso-decyl phthalate (DiDP), di-n-octyl phthalate (DNOP), di-iso-nonyl phthalate (DiNP) and butyl benzyl phthalate (BBzP) are predominantly utilized as a PVC plasticizer and found in food containers, food packaging, adhesives, and other vinyl products. Low-molecular-weight phthalates, including di-isobutyl phthalate (DIBP), di-n-butyl phthalate (DBP), dimethyl phthalate (DMP), and diethyl phthalate (DEP) are commonly utilized as cosmetic and pharmaceutical products.[6,7]

Phthalates are widely recognized as endocrine-disrupting compounds (EDCs).[6] So, safety concerns have arisen due to the phthalate migration from plastics into food, depending on factors like food storage duration, temperature, and pH.[8] Especially at home, plastics are widely used when storing food in the refrigerator. Additionally, considering that the primary purpose of a refrigerator is storage, the food is relatively exposed to plastics for a long time in the refrigerator which makes phthalates migrate easily to the food. While numerous studies investigated the use of plastics in refrigerator food storage and phthalate exposure, large-scale studies on this topic have not been conducted in South Korea. Therefore, we aimed to investigate the relationship between urine phthalate metabolites and the use of plastics in refrigerator food storage, utilizing the data from the Korean National Environmental Health Survey (KoNEHS) cycle 3.

METHODS

Study participants

We utilized data from adults (aged ≥ 19 years) who were involved in KoNEHS cycle 3. Following Section 14 of the Environmental Health Act, it is a nationwide legal survey performed every 3 years since 2009. The aim of KoNEHS is to collect nationwide fundamental data regarding the general population's exposure to environmental risks in South Korea. It analyzes the present status of environmental health, the distribution of environmentally harmful substances in the human body, relevant changes, and influencing factors. The data provided by KoNEHS is instrumental in developing environmental health policies. For this study, 15 sample households were selected using systematic sampling within the 233 sample plots. Survey targets were household members older than 19 years. In KoNEHS cycle 3, 16 clinical test items and 26 types of environmentally harmful substances in the human body were examined via blood samples and urine samples. Among the data

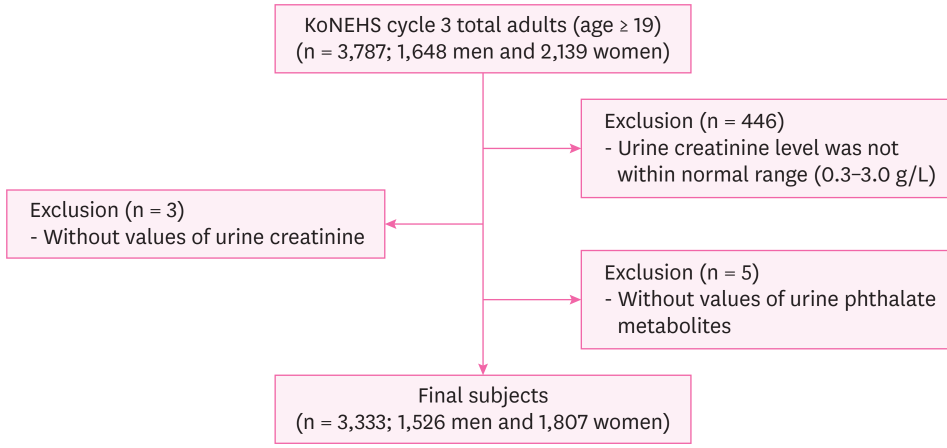

Fig. 1. Flow chart of the selection of study participants.
KoNEHS: Korean National Environmental Health Survey.

of 3,787 adults which includes 1,648 men and 2,139 women, participants with missing data on urine creatinine concentration and urine phthalate metabolites concentration were not included. Among them, Individuals who had urine creatinine concentrations outside the normal range (0.3–3.0 g/L) were not included. So, the final analysis dataset consists of 3,333 adults comprising 1,526 men and 1,807 women (**Fig. 1**).[9]

Urine phthalate metabolites

For the quantitative assessment of urine phthalate metabolite concentrations, ultra-performance liquid chromatography-mass spectrometry was utilized. To prevent light exposure, we first collected urine samples in specialized aseptic containers and subsequently deposited them in shielded storage containers. The samples went through a 20-minute cooling period in iced water to lower their temperature before they were transported to the lab in an icebox. Once in the lab, the urine samples were kept at −20°C before they were examined. In KoNEHS cycles 3, analyzed urine phthalate metabolites included DEHP metabolites: mono-(2-ethyl-5-hydroxyhexyl) phthalate (MEHHP), mono-(2-ethyl-5-oxohexyl) phthalate (MEOHP) and mono-(2-ethyl-5-carboxypentyl) phthalate (MECPP), DBP metabolite: mono-n-butyl phthalate (MnBP), BzBP metabolite: mono-benzyl phthalate (MBzP), DOP metabolite: mono (3-carboxypropyl) phthalate (MCPP), DNP metabolite: mono-carboxyoctyl phthalate (MCOP), DDP metabolite: monocarboxy-isononyl phthalate (MCNP).[10] The DEHP concentration (∑DEHP) was determined by summing the values of MEHHP, MEOHP, and MECPP together.[6] In this analysis, we utilized urine creatinine concentration for correction of urine dilution when calculating the final urine phthalate metabolites concentrations. Using the 75th percentile concentration, urine phthalate metabolites were categorized into high and low-concentration groups.[11,12]

Use of plastics in refrigerator food storage

The response items to the question regarding the type of food storage container in the refrigerator at home included glass containers, metal containers, plastic containers, zipper bags, plastic bags, porcelain (ceramic) containers, and others. Participants reporting the use of plastic containers, zipper bags, and plastic bags were considered as using plastics in refrigerator food storage.

Potential confounders

The participants' sociodemographic factors, health-related factors, food intake, and the use of plastics were included as potential cofounders. Food intake included consumption of grilled meat, milk and dairy products, hamburgers, and pizza with high-fat contents, reflecting the lipophilic property of phthalates. And, due to the high concentrations of phthalate detected in seafood as a result of aquatic environmental contamination, the consumption of seafood was included.[13,14] Also, we included the consumption of plastic bag drinks, wrap packing delivery food, PET drinks, microwave food, cup noodles, type of drinking water, and type of food storage in the freezer.

Statistical analysis

χ^2 test was conducted to analyze variations in the distribution of each variable, considering sociodemographic factors, health-related factors, food intake, the use of plastics, and the concentration of urine phthalate metabolites as the variables. To calculate odds ratios (ORs) for the high-concentration group of urine phthalate metabolites based on the use of plastics in refrigerator food storage, logistic regression analysis was conducted. The logistic regression was performed by applying weights presented in the original dataset in accordance with the KoNEHS analysis guideline.[9] This study employed IBM SPSS version 27 for Windows (IBM Corp., Armonk, NY, USA) to conduct statistical analyses.

Ethics statement

This study received approval from the Institutional Review Board of Soonchunhyang University Gumi Hospital (IRB No. 2023-08-01 Medicine).

RESULTS

In this study, 1,526 (46%) were men and 1,807 (54%) were women. Compared with men, MEHHP, MECPP, ∑DEHP, MBzP, MCPP, and MCOP were higher in women. The percentages of overweight, current smokers, use of plastics in refrigerator food storage, consumption of commercial bottled water, and the frequency of consuming PET drinks, cup noodles, and grilled meat over once a week were higher in men compared to women (**Table 1**).

Tables 2-4 presents the distribution variation of urine phthalate metabolites in high and low groups based on sociodemographic factors, health-related factors, food intake, and the use of plastics among men. The mean age of men in the high-concentration group for MEHHP, MEOHP, MECPP, ∑DEHP, MnBP, MBzP, and MCPP was higher than that of men in the low-concentration group. The proportions of participants who were non- or ex-smokers were higher in the high concentration group compared to current smokers for ∑DEHP and MnBP in men. The proportions of using plastics in refrigerator food storage were higher in the high concentration group of urine phthalate metabolites compared to using the others in refrigerator food storage for MEHHP, MEOHP, MECPP, ∑DEHP, MnBP, and MBzP in men.

To calculate ORs for the high-concentration group of urine phthalate metabolites based on the use of plastics in refrigerator food storage, logistic regression analysis was conducted. In men, the use of plastics in refrigerator food storage had significantly higher adjusted ORs compared to those using the others. The adjusted ORs were calculated as follows: MEHHP had an OR of 1.35 (95% confidence interval [CI]: 1.05–1.72), MEOHP had an OR of 1.48 (95% CI: 1.16–1.88), MECPP had an OR of 1.32 (95% CI: 1.04–1.66), ∑DEHP had an OR of 1.37 (95%

Table 1. Baseline characteristics of the participants

Category	Total (n = 3,333)	Men (n = 1,526)	Women (n = 1,807)	*p*-value
Urine 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
MCPP (μg/g Cr)	1.1 (0.6–1.9)	1.0 (0.6–1.7)	1.3 (0.7–2.2)	0.001
MCOP (μg/g Cr)	0.5 (0.2–0.8)	0.4 (0.2–0.7)	0.5 (0.2–1.0)	< 0.001
MCNP (μg/g Cr)	1.1 (0.7–1.9)	1.0 (0.6–1.6)	1.3 (0.9–2.2)	0.298
Age (years)	52.9 ± 14.8	52.8 ± 15.1	53.0 ± 14.6	0.687[a]
BMI (kg/m^2)				< 0.001[b]
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 (8.1)	
Married	2,583 (77.5)	1,225 (80.3)	1,358 (75.2)	
The others	379 (11.4)	78 (5.1)	301 (16.7)	
Smoking				< 0.001
None or ex-smokers	2,777 (83.3)	1,021 (66.9)	1,756 (97.2)	
Current smokers	556 (16.7)	505 (33.1)	51 (2.8)	
Food storage (refrigerator)				0.017
Plastics	1,736 (52.1)	829 (54.3)	907 (50.2)	
The others	1,597 (47.9)	697 (45.7)	900 (49.8)	
Food storage (freezer)				0.400
Plastics	3,299 (99.0)	1,508 (98.8)	1,791 (99.1)	
The others	34 (1.0)	18 (1.2)	16 (0.9)	
Plastic bag 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)	
Wrap packing delivery food				0.253
≤ Once a week	3,209 (96.3)	1,463 (95.9)	1,746 (96.6)	
> Once a week	124 (3.7)	63 (4.1)	61 (3.4)	
PET drinks				< 0.001
≤ Once a week	1,546 (46.4)	505 (33.1)	1,041 (57.6)	
> Once a week	1,787 (53.6)	1,021 (66.9)	766 (42.4)	
Microwave food				0.887
≤ Once a week	3,253 (97.6)	1,490 (97.6)	1,763 (97.6)	
> Once a week	80 (2.4)	36 (2.4)	44 (2.4)	
Cup noodles				< 0.001
≤ Once a week	3,190 (95.7)	1,428 (93.6)	1,762 (97.5)	
> Once a week	143 (4.3)	98 (6.4)	45 (2.5)	
Type of drinking water (at home)				0.004
Commercial bottled water	486 (14.6)	252 (16.5)	234 (12.9)	
The others	2,847 (85.4)	1,274 (83.5)	1,573 (87.1)	
Type of drinking water (at outdoor)				< 0.001
Commercial bottled water	760 (22.8)	402 (26.3)	358 (19.8)	
The others	2,573 (77.2)	1,124 (73.7)	1,449 (80.2)	
Grilled meat				< 0.001
≤ Once a week	2,887 (86.6)	1,281 (83.9)	1,606 (88.9)	
> Once a week	446 (13.4)	245 (16.1)	201 (11.1)	
Milk, dairy products				< 0.001
≤ Once a week	1,524 (45.7)	791 (51.8)	733 (40.6)	
> Once a week	1,809 (54.3)	735 (48.2)	1,074 (59.4)	
Hamburgers, pizza				0.139
≤ Once a week	3,289 (98.7)	1,501 (98.4)	1,788 (98.9)	
> Once a week	44 (1.3)	25 (1.6)	19 (1.1)	
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)	

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Table 1. (Continued) Baseline characteristics of the participants

Category	Total (n = 3,333)	Men (n = 1,526)	Women (n = 1,807)	*p*-value
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)	
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)	
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; MCPP: mono (3-carboxypropyl) phthalate; MCOP: mono-carboxyoctyl phthalate; MCNP: mono-carboxy-isononly phthalate; BMI: body mass index.
[a]*p*-value calculated by t-test.
[b]*p*-value calculated by χ^2 test.

CI: 1.08–1.74), and MnBP had an OR of 1.44 (95% CI: 1.13–1.84). In women, the adjusted ORs did not show significant results, but the unadjusted OR for MnBP was high at 1.30 (95% CI: 1.03–1.64) (**Table 5**).

Table 2. Baseline characteristics of the men according to urine phthalate metabolites (MEHHP, MEOHP, MECPP)

Category	MEHHP			MEOHP			MECPP		
	Low (n = 1,145)	High (n = 381)	*p*-value	Low (n = 1,145)	High (n = 381)	*p*-value	Low (n = 1,145)	High (n = 381)	*p*-value
Age (years)	51.1 ± 15.2	57.8 ± 13.7	< 0.001	51.2 ± 15.2	57.4 ± 13.9	< 0.001	51.6 ± 15.1	56.2 ± 14.5	< 0.001[a]
BMI			0.192			0.097			0.058[b]
Normal	596 (73.7)	213 (26.3)		593 (73.3)	216 (26.7)		591 (73.1)	218 (26.9)	
Overweight	549 (76.6)	168 (23.4)		552 (77.0)	165 (23.0)		554 (77.3)	163 (22.7)	
Marital status			0.012			0.105			0.375
Single	185 (83.0)	38 (17.0)		180 (80.7)	43 (19.3)		173 (77.6)	50 (22.4)	
Married	904 (73.8)	321 (26.2)		907 (74.0)	318 (26.0)		910 (74.3)	315 (25.7)	
The others	56 (71.8)	22 (28.2)		58 (74.4)	20 (25.6)		62 (79.5)	16 (20.5)	
Smoking			0.608			0.698			0.129
None or ex-smokers	762 (74.6)	259 (25.4)		763 (74.7)	258 (25.3)		754 (73.8)	267 (26.2)	
Current smokers	383 (75.8)	122 (24.2)		382 (75.6)	123 (24.4)		391 (77.4)	114 (22.6)	
Food storage (refrigerator)			0.001			< 0.001			0.002
Plastics	593 (71.5)	236 (28.5)		588 (70.9)	241 (29.1)		596 (71.9)	233 (28.1)	
The others	552 (79.2)	145 (20.8)		557 (79.9)	140 (20.1)		549 (78.8)	148 (21.2)	
Food storage (freezer)			0.787			0.413			0.413
Plastics	1,131 (75.0)	377 (25.0)		1,130 (74.9)	378 (25.1)		1,130 (74.9)	378 (25.1)	
The others	14 (77.8)	4 (22.2)		15 (83.3)	3 (16.7)		15 (83.3)	3 (16.7)	
Plastic bag drink			0.161			0.315			0.854
≤ Once a week	817 (74.1)	286 (25.9)		820 (74.3)	283 (25.7)		829 (75.2)	274 (24.8)	
> Once a week	328 (77.5)	95 (22.5)		325 (76.8)	98 (23.2)		316 (74.7)	107 (25.3)	
Wrap packing delivery food			0.828			0.607			0.417
≤ Once a week	1,097 (75.0)	366 (25.0)		1,096 (74.9)	367 (25.1)		1,095 (74.8)	368 (25.2)	
> Once a week	48 (76.2)	15 (23.8)		49 (77.8)	14 (22.2)		50 (79.4)	13 (20.6)	
PET drinks			0.992			0.714			0.385
≤ Once a week	379 (75.0)	126 (25.0)		376 (74.5)	129 (25.5)		372 (73.7)	133 (26.3)	
> Once a week	766 (75.0)	255 (25.0)		769 (75.3)	252 (24.7)		773 (75.7)	248 (24.3)	
Microwave food			0.020			0.052			0.438
≤ Once a week	1,112 (74.6)	378 (25.4)		1,113 (74.7)	377 (25.3)		1,116 (74.9)	374 (25.1)	
> Once a week	33 (91.7)	3 (8.3)		32 (88.9)	4 (11.1)		29 (80.6)	7 (19.4)	

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Table 2. (Continued) Baseline characteristics of the men according to urine phthalate metabolites (MEHHP, MEOHP, MECPP)

Category	MEHHP			MEOHP			MECPP		
	Low (n = 1,145)	High (n = 381)	*p*-value	Low (n = 1,145)	High (n = 381)	*p*-value	Low (n = 1,145)	High (n = 381)	*p*-value
Cup noodles			0.006			0.012			0.119
≤ Once a week	1,060 (74.2)	368 (25.8)		1,061 (74.3)	367 (25.7)		1,065 (74.6)	363 (25.4)	
> Once a week	85 (86.7)	13 (13.3)		84 (85.7)	14 (14.3)		80 (81.6)	18 (18.4)	
Type of drinking water (at home)			0.027			0.155			0.271
Commercial bottled water	203 (80.6)	49 (19.4)		198 (78.6)	54 (21.4)		196 (77.8)	56 (22.2)	
The others	942 (73.9)	332 (26.1)		947 (74.3)	327 (25.7)		949 (74.5)	325 (25.5)	
Type of drinking water (at outdoor)			0.558			0.393			0.750
Commercial bottled water	306 (76.1)	96 (23.9)		308 (76.6)	94 (23.4)		304 (75.6)	98 (24.4)	
The others	839 (74.6)	285 (25.4)		837 (74.5)	287 (25.5)		841 (74.8)	283 (25.2)	
Grilled meat			0.101			0.101			0.727
≤ Once a week	951 (74.2)	330 (25.8)		951 (74.2)	330 (25.8)		959 (74.9)	322 (25.1)	
> Once a week	194 (79.2)	51 (20.8)		194 (79.2)	51 (20.8)		186 (75.9)	59 (24.1)	
Milk, dairy products			0.021			0.314			0.139
≤ Once a week	574 (72.6)	217 (27.4)		585 (74.0)	206 (26.0)		581 (73.5)	210 (26.5)	
> Once a week	571 (77.7)	164 (22.3)		560 (76.2)	175 (23.8)		564 (76.7)	171 (23.3)	
Hamburgers, pizza			0.563			0.131			0.563
≤ Once a week	1,125 (75.0)	376 (25.0)		1,123 (74.8)	378 (25.2)		1,125 (75.0)	376 (25.0)	
> Once a week	20 (80.0)	5 (20.0)		22 (88.0)	3 (12.0)		20 (80.0)	5 (20.0)	
Large fish and tuna			0.443			0.647			0.647
≤ Once a week	1,099 (74.9)	369 (25.1)		1,100 (74.9)	368 (25.1)		1,100 (74.9)	368 (25.1)	
> Once a week	46 (79.3)	12 (20.7)		45 (77.6)	13 (22.4)		45 (77.6)	13 (22.4)	
Fish			0.171			0.267			0.135
≤ Once a week	806 (76.0)	254 (24.0)		804 (75.8)	256 (24.2)		807 (76.1)	253 (23.9)	
> Once a week	339 (72.7)	127 (27.3)		341 (73.2)	125 (26.8)		338 (72.5)	128 (27.5)	
Shellfish			0.854			0.561			0.561
≤ Once a week	1,079 (75.0)	360 (25.0)		1,082 (75.2)	357 (24.8)		1,082 (75.2)	357 (24.8)	
> Once a week	66 (75.9)	21 (24.1)		63 (72.4)	24 (27.6)		63 (72.4)	24 (27.6)	
Crustacean			0.622			0.403			0.864
≤ Once a week	1,106 (74.9)	370 (25.1)		1,110 (75.2)	366 (24.8)		1,108 (75.1)	368 (24.9)	
> Once a week	39 (78.0)	11 (22.0)		35 (70.0)	15 (30.0)		37 (74.0)	13 (26.0)	
Seaweed			0.440			0.956			0.861
≤ Once a week	482 (74.0)	169 (26.0)		488 (75.0)	163 (25.0)		487 (74.8)	164 (25.2)	
> Once a week	663 (75.8)	212 (24.2)		657 (75.1)	218 (24.9)		658 (75.2)	217 (24.8)	
Other seafood items			0.548			0.006			0.548
≤ Once a week	1,085 (74.9)	364 (25.1)		1,077 (74.3)	372 (25.7)		1,085 (74.9)	364 (25.1)	
> Once a week	60 (77.9)	17 (22.1)		68 (88.3)	9 (11.7)		60 (77.9)	17 (22.1)	

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; PET: polyethylene terephthalate.
[a]*p*-value calculated by t-test.
[b]*p*-value calculated by χ^2 test.

DISCUSSION

This study showed that the group using plastics in refrigerator food storage in men had higher adjusted ORs for the high concentration group of MEHHP, MEOHP, MECPP, ∑DEHP (the sum of MEHHP, MEOHP, MECPP), and MnBP compared to the group without the use of plastics in refrigerator food storage. The urine metabolites of DEHP, namely MEHHP, MEOHP, and MECPP, are known to undergo hydrolysis and oxidation in the body, resulting in relatively long periods of retention. As a result, they are used as biomarkers of DEHP exposure.[15] These metabolites have various harmful effects on human health. MEOHP, for instance, has been linked to negative impacts on intelligence quotient and attention in children,[16] and pregnant women exposed to it may face an elevated risk of gestational diabetes.[17] Moreover, a positive correlation has been found between MECPP and the breast

Table 3. Baseline characteristics of the men according to urine phthalate metabolites (ΣDEHP, MnBP, MBzP)

Category	ΣDEHP			MnBP			MBzP		
	Low (n = 1,144)	High (n = 382)	*p*-value	Low (n = 1,145)	High (n = 381)	*p*-value	Low (n = 1,145)	High (n = 381)	*p*-value
Age (years)	51.3 ± 15.1	57.1 ± 14.4	< 0.001	51.3 ± 14.9	57.3 ± 14.8	< 0.001	51.5 ± 15.1	56.5 ± 14.5	< 0.001[a]
BMI			0.214			0.044			0.904[b]
Normal	596 (73.7)	213 (26.3)		590 (72.9)	219 (27.1)		606 (74.9)	203 (25.1)	
Overweight	548 (76.4)	169 (23.6)		555 (77.4)	162 (22.6)		539 (75.2)	178 (24.8)	
Marital status			0.323			0.117			0.745
Single	176 (78.9)	47 (21.1)		178 (79.8)	45 (20.2)		171 (76.7)	52 (23.3)	
Married	909 (74.2)	316 (25.8)		913 (74.5)	312 (25.5)		914 (74.6)	311 (25.4)	
The others	59 (75.6)	19 (24.4)		54 (69.2)	24 (30.8)		60 (76.9)	18 (23.1)	
Smoking			0.029			0.043			0.444
None or ex-smokers	748 (73.3)	273 (26.7)		750 (73.5)	271 (26.5)		760 (74.4)	261 (25.6)	
Current smokers	396 (78.4)	109 (21.6)		395 (78.2)	110 (21.8)		385 (76.2)	120 (23.8)	
Food storage (refrigerator)			< 0.001			0.009			0.032
Plastics	592 (71.4)	237 (28.6)		600 (72.4)	229 (27.6)		604 (72.9)	225 (27.1)	
The others	552 (79.2)	145 (20.8)		545 (78.2)	152 (21.8)		541 (77.6)	156 (22.4)	
Food storage (freezer)			0.410			0.413			0.056
Plastics	1,129 (74.9)	379 (25.1)		1,130 (74.9)	378 (25.1)		1,128 (74.8)	380 (25.2)	
The others	15 (83.3)	3 (16.7)		15 (83.3)	3 (16.7)		17 (94.4)	1 (5.6)	
Plastic bag drink			0.192			0.315			0.125
≤ Once a week	817 (74.1)	286 (25.9)		820 (74.3)	283 (25.7)		816 (74.0)	287 (26.0)	
> Once a week	327 (77.3)	96 (22.7)		325 (76.8)	98 (23.2)		329 (77.8)	94 (22.2)	
Wrap packing delivery food			0.946			0.417			0.268
≤ Once a week	1,097 (75.0)	366 (25.0)		1,095 (74.8)	368 (25.2)		1,094 (74.8)	369 (25.2)	
> Once a week	47 (74.6)	16 (25.4)		50 (79.4)	13 (20.6)		51 (81.0)	12 (19.0)	
PET drinks			0.483			0.045			0.537
≤ Once a week	373 (73.9)	132 (26.1)		363 (71.9)	142 (28.1)		374 (74.1)	131 (25.9)	
> Once a week	771 (75.5)	250 (24.5)		782 (76.6)	239 (23.4)		771 (75.5)	250 (24.5)	
Microwave food			0.051			0.244			0.996
≤ Once a week	1,112 (74.6)	378 (25.4)		1,115 (74.8)	375 (25.2)		1,118 (75.0)	372 (25.0)	
> Once a week	32 (88.9)	4 (11.1)		30 (83.3)	6 (16.7)		27 (75.0)	9 (25.0)	
Cup noodles			0.069			0.403			0.119
≤ Once a week	1,063 (74.4)	365 (25.6)		1,068 (74.8)	360 (25.2)		1,065 (74.6)	363 (25.4)	
> Once a week	81 (82.7)	17 (17.3)		77 (78.6)	21 (21.4)		80 (81.6)	18 (18.4)	
Type of drinking water (at home)			0.109			0.207			0.433
Commercial bottled water	199 (79.0)	53 (21.0)		197 (78.2)	55 (21.8)		194 (77.0)	58 (23.0)	
The others	945 (74.2)	329 (25.8)		948 (74.4)	326 (25.6)		951 (74.6)	323 (25.4)	
Type of drinking water (at outdoor)			0.534			0.932			0.961
Commercial bottled water	306 (76.1)	96 (23.9)		301 (74.9)	101 (25.1)		302 (75.1)	100 (24.9)	
The others	838 (74.6)	286 (25.4)		844 (75.1)	280 (24.9)		843 (75.0)	281 (25.0)	
Grilled meat			0.068			0.188			0.034
≤ Once a week	949 (74.1)	332 (25.9)		953 (74.4)	328 (25.6)		948 (74.0)	333 (26.0)	
> Once a week	195 (79.6)	50 (20.4)		192 (78.4)	53 (21.6)		197 (80.4)	48 (19.6)	
Milk, dairy products			0.033			0.374			0.139
≤ Once a week	575 (72.7)	216 (27.3)		586 (74.1)	205 (25.9)		581 (73.5)	210 (26.5)	
> Once a week	569 (77.4)	166 (22.6)		559 (76.1)	176 (23.9)		564 (76.7)	171 (23.3)	
Hamburgers, pizza			0.293			0.910			0.048
≤ Once a week	1,123 (74.8)	378 (25.2)		1,126 (75.0)	375 (25.0)		1,122 (74.8)	379 (25.2)	
> Once a week	21 (84.0)	4 (16.0)		19 (76.0)	6 (24.0)		23 (92.0)	2 (8.0)	
Large fish and tuna			0.882			0.282			0.021
≤ Once a week	1,101 (75.0)	367 (25.0)		1,098 (74.8)	370 (25.2)		1,094 (74.5)	374 (25.5)	
> Once a week	43 (74.1)	15 (25.9)		47 (81.0)	11 (19.0)		51 (87.9)	7 (12.1)	
Fish			0.493			0.135			0.832
≤ Once a week	800 (75.5)	260 (24.5)		807 (76.1)	253 (23.9)		797 (75.2)	263 (24.8)	
> Once a week	344 (73.8)	122 (26.2)		338 (72.5)	128 (27.5)		348 (74.7)	118 (25.3)	
Shellfish			0.756			0.035			0.943
≤ Once a week	1,080 (75.1)	359 (24.9)		1,088 (75.6)	351 (24.4)		1,080 (75.1)	359 (24.9)	
> Once a week	64 (73.6)	23 (26.4)		57 (65.5)	30 (34.5)		65 (74.7)	22 (25.3)	
Crustacean			0.615			0.133			0.403
≤ Once a week	1,105 (74.9)	371 (25.1)		1,112 (75.3)	364 (24.7)		1,110 (75.2)	366 (24.8)	
> Once a week	39 (78.0)	11 (22.0)		33 (66.0)	17 (34.0)		35 (70.0)	15 (30.0)	

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Table 3. (Continued) Baseline characteristics of the men according to urine phthalate metabolites (ΣDEHP, MnBP, MBzP)

Category	ΣDEHP			MnBP			MBzP		
	Low (n = 1,144)	High (n = 382)	*p*-value	Low (n = 1,145)	High (n = 381)	*p*-value	Low (n = 1,145)	High (n = 381)	*p*-value
Seaweed			0.717			0.010			0.014
≤ Once a week	485 (74.5)	166 (25.5)		467 (71.7)	184 (28.3)		468 (71.9)	183 (28.1)	
> Once a week	659 (75.3)	216 (24.7)		678 (77.5)	197 (22.5)		677 (77.4)	198 (22.6)	
Other seafood items			0.377			0.453			0.158
≤ Once a week	1,083 (74.7)	366 (25.3)		1,090 (75.2)	359 (24.8)		1,082 (74.7)	367 (25.3)	
> Once a week	61 (79.2)	16 (20.8)		55 (71.4)	22 (28.6)		63 (81.8)	14 (18.2)	

Data were presented as mean ± standard deviation or number (%).
ΣDEHP: Σdi(2-ethylhexyl) phthalate; MnBP: mono-n-butyl phthalate; MBzP: mono-benzyl phthalate; BMI: body mass index; PET: polyethylene terephthalate.
[a]*p*-value calculated by t-test.
[b]*p*-value calculated by χ^2 test.

cancer risk for women,[18] and exposure of the fetus to MEOHP or ∑DEHP has been linked to an elevated risk of intrauterine growth retardation.[19] Additionally, both MEHHP and MECPP have been shown to increase the secretion of β-hexosaminidase by mast cells, leading to skin rashes.[20] The urine metabolites of DBP, MnBP has a dose-relationship with small for gestational age and low birth weight for male infants.[21] Moreover, MnBP has been connected with an elevated risk of clinical pregnancy loss.[22]

A study conducted on 2,140 adults in Shanghai, China showed that the use of plastic food containers increased the concentrations of urine metabolites of DEHP, including MEHP, MEHHP, MEOHP, and MECPP, which aligns with the findings of this study.[23] In another study involving 39 elementary students in South Korea, the concentration of MEOHP increased

Table 4. Baseline characteristics of the men according to urine phthalate metabolites (MCPP, MCOP, MCNP)

Category	MCPP			MCOP			MCNP		
	Low (n = 1,145)	High (n = 381)	*p*-value	Low (n = 1,144)	High (n = 382)	*p*-value	Low (n = 1,144)	High (n = 382)	*p*-value
Age (years)	52.3 ± 15.1	54.2 ± 15.1	0.038	52.9 ± 14.9	52.2 ± 15.7	0.387	52.4 ± 15.1	53.9 ± 15.1	0.075[a]
BMI			< 0.001			0.214			0.021[b]
Normal	575 (71.1)	234 (28.9)		596 (73.7)	213 (26.3)		587 (72.6)	222 (27.4)	
Overweight	570 (79.5)	147 (20.5)		548 (76.4)	169 (23.6)		557 (77.7)	160 (22.3)	
Marital status			0.655			0.129			0.216
Single	162 (72.6)	61 (27.4)		156 (70.0)	67 (30.0)		166 (74.4)	57 (25.6)	
Married	925 (75.5)	300 (24.5)		926 (75.6)	299 (24.4)		913 (74.5)	312 (25.5)	
The others	58 (74.4)	20 (25.6)		62 (79.5)	16 (20.5)		65 (83.3)	13 (16.7)	
Smoking			0.373			0.420			0.859
None or ex-smokers	759 (74.3)	262 (25.7)		759 (74.3)	262 (25.7)		764 (74.8)	257 (25.2)	
Current smokers	386 (76.4)	119 (23.6)		385 (76.2)	120 (23.8)		380 (75.2)	125 (24.8)	
Food storage (refrigerator)			0.633			0.214			0.951
Plastics	618 (74.5)	211 (25.5)		611 (73.7)	218 (26.3)		622 (75.0)	207 (25.0)	
The others	527 (75.6)	170 (24.4)		533 (76.5)	164 (23.5)		522 (74.9)	175 (25.1)	
Food storage (freezer)			0.172			0.410			0.170
Plastics	1,129 (74.9)	379 (25.1)		1,129 (74.9)	379 (25.1)		1,128 (74.8)	380 (25.2)	
The others	16 (88.9)	2 (11.1)		15 (83.3)	3 (16.7)		16 (88.9)	2 (11.1)	
Plastic bag drink			0.458			0.803			0.437
≤ Once a week	822 (74.5)	281 (25.5)		825 (74.8)	278 (25.2)		821 (74.4)	282 (25.6)	
> Once a week	323 (76.4)	100 (23.6)		319 (75.4)	104 (24.6)		323 (76.4)	100 (23.6)	
Wrap packing delivery food			0.160			0.599			0.087
≤ Once a week	1,093 (74.7)	370 (25.3)		1,095 (74.8)	368 (25.2)		1,091 (74.6)	372 (25.4)	
> Once a week	52 (82.5)	11 (17.5)		49 (77.8)	14 (22.2)		53 (84.1)	10 (15.9)	
PET drinks			0.213			0.842			0.229
≤ Once a week	369 (73.1)	136 (26.9)		377 (74.7)	128 (25.3)		369 (73.1)	136 (26.9)	
> Once a week	776 (76.0)	245 (24.0)		767 (75.1)	254 (24.9)		775 (75.9)	246 (24.1)	
Microwave food			0.244			0.433			0.241
≤ Once a week	1,115 (74.8)	375 (25.2)		1,115 (74.8)	375 (25.2)		1,114 (74.8)	376 (25.2)	
> Once a week	30 (83.3)	6 (16.7)		29 (80.6)	7 (19.4)		30 (83.3)	6 (16.7)	

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Table 4. (Continued) Baseline characteristics of the men according to urine phthalate metabolites (MCPP, MCOP, MCNP)

Category	MCPP			MCOP			MCNP		
	Low (n = 1,145)	High (n = 381)	*p*-value	Low (n = 1,144)	High (n = 382)	*p*-value	Low (n = 1,144)	High (n = 382)	*p*-value
Cup noodles			0.041			0.898			0.395
≤ Once a week	1,063 (74.4)	365 (25.6)		1,070 (74.9)	358 (25.1)		1,067 (74.7)	361 (25.3)	
> Once a week	82 (83.7)	16 (16.3)		74 (75.5)	24 (24.5)		77 (78.6)	21 (21.4)	
Type of drinking water (at home)			0.863			0.990			0.333
Commercial bottled water	188 (74.6)	64 (25.4)		189 (75.0)	63 (25.0)		195 (77.4)	57 (22.6)	
The others	957 (75.1)	317 (24.9)		955 (75.0)	319 (25.0)		949 (74.5)	325 (25.5)	
Type of drinking water (at outdoor)			0.961			0.724			0.751
Commercial bottled water	302 (75.1)	100 (24.9)		304 (75.6)	98 (24.4)		299 (74.4)	103 (25.6)	
The others	843 (75.0)	281 (25.0)		840 (74.7)	284 (25.3)		845 (75.2)	279 (24.8)	
Grilled meat			0.188			0.788			0.096
≤ Once a week	953 (74.4)	328 (25.6)		962 (75.1)	319 (24.9)		950 (74.2)	331 (25.8)	
> Once a week	192 (78.4)	53 (21.6)		182 (74.3)	63 (25.7)		194 (79.2)	51 (20.8)	
Milk, dairy products			0.768			0.722			0.288
≤ Once a week	596 (75.3)	195 (24.7)		596 (75.3)	195 (24.7)		584 (73.8)	207 (26.2)	
> Once a week	549 (74.7)	186 (25.3)		548 (74.6)	187 (25.4)		560 (76.2)	175 (23.8)	
Hamburgers, pizza			0.131			0.730			0.293
≤ Once a week	1,123 (74.8)	378 (25.2)		1,126 (75.0)	375 (25.0)		1,123 (74.8)	378 (25.2)	
> Once a week	22 (88.0)	3 (12.0)		18 (72.0)	7 (28.0)		21 (84.0)	4 (16.0)	
Large fish and tuna			0.162			0.282			0.882
≤ Once a week	1,106 (75.3)	362 (24.7)		1,104 (75.2)	364 (24.8)		1,101 (75.0)	367 (25.0)	
> Once a week	39 (67.2)	19 (32.8)		40 (69.0)	18 (31.0)		43 (74.1)	15 (25.9)	
Fish			0.171			0.066			0.763
≤ Once a week	806 (76.0)	254 (24.0)		809 (76.3)	251 (23.7)		797 (75.2)	263 (24.8)	
> Once a week	339 (72.7)	127 (27.3)		335 (71.9)	131 (28.1)		347 (74.5)	119 (25.5)	
Shellfish			0.018			0.066			0.412
≤ Once a week	1,089 (75.7)	350 (24.3)		1,086 (75.5)	353 (24.5)		1,082 (75.2)	357 (24.8)	
> Once a week	56 (64.4)	31 (35.6)		58 (66.7)	29 (33.3)		62 (71.3)	25 (28.7)	
Crustacean			0.622			0.404			0.615
≤ Once a week	1,106 (74.9)	370 (25.1)		1,104 (74.8)	372 (25.2)		1,105 (74.9)	371 (25.1)	
> Once a week	39 (78.0)	11 (22.0)		40 (80.0)	10 (20.0)		39 (78.0)	11 (22.0)	
Seaweed			0.949			0.636			0.405
≤ Once a week	489 (75.1)	162 (24.9)		492 (75.6)	159 (24.4)		495 (76.0)	156 (24.0)	
> Once a week	656 (75.0)	219 (25.0)		652 (74.5)	223 (25.5)		649 (74.2)	226 (25.8)	
Other seafood items			0.952			0.377			0.377
≤ Once a week	1,087 (75.0)	362 (25.0)		1,083 (74.7)	366 (25.3)		1,083 (74.7)	366 (25.3)	
> Once a week	58 (75.3)	19 (24.7)		61 (79.2)	16 (20.8)		61 (79.2)	16 (20.8)	

Data were presented as mean ± standard deviation or number (%).
MCPP: mono (3-carboxypropyl) phthalate; MCOP: mono-carboxyoctyl phthalate; MCNP: mono-carboxy-isononly phthalate; BMI: body mass index; PET: polyethylene terephthalate.
[a]*p*-value calculated by t-test.
[b]*p*-value calculated by χ^2 test.

by 0.001 μg/g with the intake of a dairy product and by 0.002 μg/g with the intake of meat. In contrast, the concentration of MEOHP increased by 0.225 μg/g through the use of plastic material in food storage and food packaging, indicating a stronger correlation between phthalate exposure and the use of plastic material in food storage and food packaging rather than the intake of dairy products and meat.[24] In a study conducted on Slovakian 32 firefighters, MnBP has been associated with the consumption of food heated in plastic material.[25] Additionally, in a study conducted on 528 women in Taiwan, the use of plastic food packaging has been positively linked to MnBP.[26] Consequently, the use of plastics in refrigerator food storage is presumed to be the main cause of increased urine phthalate metabolites. Furthermore, MEHHP, MEOHP, MECPP, ∑DEHP (the sum of MEHHP, MEOHP, MECPP), and MnBP may be useful indicators of phthalate exposure associated with the use of plastics in refrigerator food storage.

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Table 5. Adjusted ORs and 95% CIs of the use of plastics in refrigerator food storage with high concentration of urine phthalate metabolites

Category	Men				Women			
	Unadjusted		Multivariable adjusted model[a]		Unadjusted		Multivariable adjusted model[a]	
	The others	Plastics	The others	Plastics	The others	Plastics	The others	Plastics
MEHHP	1	1.42 (1.13–1.79)	1	1.35 (1.05–1.72)	1	1.15 (0.91–1.46)	1	0.94 (0.72–1.22)
MEOHP	1	1.56 (1.24–1.97)	1	1.48 (1.16–1.88)	1	1.17 (0.88–1.41)	1	1.05 (0.81–1.34)
MECPP	1	1.36 (1.09–1.70)	1	1.32 (1.04–1.66)	1	1.12 (0.89–1.42)	1	1.06 (0.83–1.35)
ΣDEHP	1	1.43 (1.14–1.80)	1	1.37 (1.08–1.74)	1	1.19 (0.94–1.50)	1	1.08 (0.84–1.38)
MnBP	1	1.47 (1.17–1.86)	1	1.44 (1.13–1.84)	1	1.30 (1.03–1.64)	1	1.17 (0.92–1.50)
MBzP	1	1.34 (1.05–1.70)	1	1.22 (0.95–1.56)	1	1.09 (0.86–1.39)	1	0.93 (0.72–1.20)
MCPP	1	1.03 (0.83–1.28)	1	0.97 (0.77–1.22)	1	1.19 (0.95–1.49)	1	1.18 (0.93–1.48)
MCOP	1	1.10 (0.89–1.36)	1	1.09 (0.88–1.36)	1	0.82 (0.66–1.03)	1	0.85 (0.68–1.07)
MCNP	1	0.90 (0.72–1.12)	1	0.84 (0.67–1.05)	1	0.88 (0.70–1.10)	1	0.86 (0.68–1.09)

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; MCPP: mono (3-carboxypropyl) phthalate; MCOP: mono-carboxyoctyl phthalate; MCNP: mono-carboxy-isononly phthalate.
[a]Multivariable adjusted model: adjusted for age, body mass index, marital status, smoking, food storage(freezer), type of drinking water, and consumption of plastic bag drink, wrap packing delivery food, PET drinks, microwave food, cup noodles, grilled meat, milk, dairy products, hamburgers, pizza, seafood.

In this study, no relation was observed between the use of plastics in refrigerated food storage and urine phthalate metabolite concentrations in women compared to men. This result can be explained by differences in dietary habits between men and women. In a study investigating the dietary differences between men and women, it was reported that men tend to consume foods with higher fat content compared to women.[27] Therefore, even when using the same plastic containers, men are estimated to have consumed a larger quantity of food with higher fat content compared to women.[12] Also, in this study, the concentration of urine phthalate metabolites was higher in women than men. We utilized urine creatinine concentration for correction of urine dilution when calculating the final urine phthalate metabolite concentrations. So, because urine creatinine concentration in women is lower than in men, the creatinine-corrected concentrations are estimated to have been consequently higher in women.[28] Additionally, the higher concentration of phthalates in women may be attributed to the use of personal care products such as cosmetics, fragrances, and lotions.[29]

Human exposure to phthalates occurs through numerous pathways such as oral intake, skin absorption, or inhalation but oral intake is the main route of exposure.[7] Remarkably, it has been reported that 90% of DEHP exposure occurs through food intake.[30] Phthalates do not form covalent bonds with plastic polymer, enabling them to have high mobility within the plastic material.[7] Consequently, plastics used in food storage allow phthalates to migrate easily into foods. First, within the polymer, migration occurs via the diffusion process. Second, migration in food may differ depending on the physical properties of the food.[31,32]

The quantity of the migration of phthalates from plastics to food depends on several factors. This includes fat content, food storage duration, pH, and temperature. Phthalates exhibit a lipophilic nature,[33] making them prone to easily bind to foods with high-fat content. When water and cooking oil were placed in plastic food containers to measure phthalate migration levels, it was observed that the levels were 0.020 μg/L for cooking oil and 0.001 μg/L for water.[34] These findings suggest that phthalate exposure can increase with eating foods with high-fat content stored in plastic containers. Prolonged food storage duration can also increase phthalate migration from plastics to foods. In a study conducted in Ghana, the DEHP migration level from a plastic food container was 1.00 ± 0.02 mg/kg after 30 minutes, 1.17 ± 0.02 mg/kg after 1 hour, 1.20 ± 0.01 mg/kg after 2 hours and 1.39 ± 0.10 mg/kg after 4 hours.[35] Additionally, phthalates are known to migrate more as acidity and temperature increase.[36,37] A study investigating phthalate migration using pickles in plastic containers found a negative correlation between pH and the DEHP, DMP, BBP, DEP, DnBP, and DnOP in pickles.[38] Another study on phthalate migration after placing 60°C and 80°C water in plastic food containers and heating them for 2 hours revealed higher levels of DEHP, BBP, DBP, DEP, and DMP in the 80°C water compared to 60°C water.[39] This is due to the facilitation of ester hydrolysis in acidic conditions and an increase in the rate of hydrolysis with higher temperatures.[40] In this study, these factors could not be analyzed because of the absence of detailed information on the types of foods and storage duration, food acidity, and temperature in the KoNEHS questionnaire. Therefore, a follow-up monitoring study on phthalate exposure levels with consideration of food storage duration in plastics, food types, acidity, and temperature is necessary.

This study had several limitations. First, we could not prove causal relationships as it was a cross-sectional study. Secondly, analyzed data consisted of concentrations measured from a single urine sample, which may have resulted in concentration variations. Future research should think about using a 24-hour urine collection method and examining blood concentration too. Third, the KoNEHS data did not provide information on occupational conditions, such as types of exposed chemicals and personal protective gear, occupational factors could not be analyzed in this study. Fourth, due to the absence of detailed information on food type, temperature, acidity, and storage duration in the KoNEHS questionnaire, these factors could not be analyzed in this study.

To the best of our knowledge, there have been limited large-scale studies conducted in Korea that examine the relationship between the use of plastics in food storage and phthalate exposure. Therefore, despite its limitations, this study is significant because it presents the relationship between the use of plastics in refrigerator food storage and the concentrations of MEHHP, MEOHP, MECPP, ∑DEHP, and MnBP by using the data that reflects the general South Korean population.

Phthalates have various adverse effects on human health. Based on the results of this study, it is important to continuously monitor phthalate exposure resulting from the use of plastics in refrigerator food storage. Considering that phthalate migration levels vary according to the type of stored food, temperature, acidity, and storage duration, further studies should be conducted to examine foods stored in plastics in refrigerator food storage.

CONCLUSIONS

This study revealed the association between the use of plastics in refrigerator food storage and the concentrations of urine phthalate metabolites. The concentrations of urine phthalate metabolites (MEHHP, MEOHP, MECPP, ∑DEHP, and MnBP) were significantly higher in men who used plastics in refrigerator food storage compared to those using the others.

ACKNOWLEDGEMENTS

This study used the Korean National Environmental Health Survey Cycle 3 (2015~2017), made by National Institute of Environmental Research (NIER-2017-01-01-001). We appreciate National Institute of Environmental Research making available the raw data of Korean National Environmental Health Survey.

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