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Research Article

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Relationship between seafood consumption and bisphenol A exposure: the Second Korean National Environmental Health Survey (KoNEHS 2012–2014)

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Abbreviations
BMI: body mass index; CI: confidence interval; KoNEHS: Korean National Environmental Health Survey; OR: odds ratio; BPA: bisphenol A; MDL: method detection limit; QC: quality control; BVW: Bocht van Wattum.

ABSTRACT

Background: This study aimed to identify the relationship between exposure to bisphenol A (BPA) and seafood consumption using a nationally representative data of the general Korean population.
Methods: This study was conducted on 5,402 adults aged 19 years and older (2,488 men, 2,914 women) based on the second Korean National Environmental Health Survey (2012–2014). We stratified the data according to gender and analyzed urinary BPA concentrations in terms of sociodemographic characteristics, health behavior, dietary factor, and seafood consumption. In the high and low BPA exposure groups, the odds ratios (ORs) were calculated using logistic regression analysis according to the top 75th percentile concentration.
Results: In men, large fish and tuna and other seafood categories had significantly higher ORs before and after adjustment in the group who consumed seafood more than once a week than in the group who rarely consumed seafood, with an adjusted value of 1.97 (95% confidence interval [CI]: 1.12–3.48) and 1.74 (95% CI: 1.10–2.75), respectively. In the shellfish category, the unadjusted OR was 1.61 (95% CI: 1.00–2.59), which was significantly higher in the group who consumed seafood more than once a week than in the group who rarely consumed seafood. However, the OR after adjusting for the variables was not statistically significant. In women, the frequency of seafood consumption and the concentration of urinary BPA were not significantly associated.
Conclusions: BPA concentration was higher in men who frequently consumed large fish and tuna, shellfish and other seafood in this study.

Keywords: Bisphenol A; Seafood; Korean National Environmental Health Survey

BACKGROUND

Bisphenol A (BPA) is a chemical compound synthesized via the acid catalyzed condensation of one acetone group and 2 phenol groups [1,2]. BPA has been actively used for commercial purposes since it was first developed in 1891, and it is now one of the most commonly used chemicals worldwide [3]. BPA can be used in 2 ways in modern society. First, polymers, such as polycarbonate plastics, epoxy resins, and polysulfone are synthesized from BPA monomers

Competing interests
The authors declare that they have no competing interests.

Author Contributions
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[4]. The synthesized BPA polymers are used in mobile phones/computers, bottles, packaging materials, can coatings for foods and drinks, and in the manufacturing of water pipes, toys, and dental products [3-5]. Second, unpolymerized BPA is used as an additive and utilized as a phenolic developer when producing thermal paper [4] or as a stabilizer or antioxidant when producing polyvinylchloride [3].

Human exposure to BPA can occur via ingestion and inhalation of, and dermal exposure to environmental factors, such as atmosphere, water, and dust, consumption of contaminated foods and drinks, and contact with contaminated items [1,5,6]. Although there are various exposure sources of BPA, the primary exposure sources of BPA in humans are consumption of contaminated foods and drinks [5] from polycarbonate baby bottles [7], epoxy resins coated cans [8], and microwaveable plastic commercial containers [9].

BPA is known as an endocrine disruptor chemical, and it can bind to androgen and thyroid receptors as well as estrogen receptors, which can affect health in various ways. For example, it can cause reproductive abnormalities, such as infertility, male sexual dysfunction, decreased sperm quality, and recurrent miscarriages; developmental abnormalities, including presence of abnormal karyotypes; and male genital abnormalities. In addition, it may increase the incidence of metabolic diseases, such as obesity, type 2 diabetes mellitus, and cardiovascular disease, and may affect thyroid and immune function [5,6,10-12].

Urine or blood test is commonly used as a biological monitoring method for evaluating exposure to BPA. In particular, spot urine or 24-hour urine collection is most commonly performed because urine sampling is an easy and non-invasive method that can obtain large sample volumes [4,8].

Recently, interest about chemical pollution in marine ecosystems has increased, and since BPA is widely found in marine water, studies about human exposure to BPA via the ingestion of contaminated seafood may be significant [13]. To date, various studies about marine BPA pollution and BPA contamination of marine organisms are conducted. However, research between BPA exposure and its associated factors with seafood consumption in humans is limited. Therefore, this study aimed to analyze the association between BPA exposure and seafood consumption in the general Korean population using representative data.

METHODS

Study participants

This present study used the data of the second Korean National Environmental Health Survey (KoNEHS 2012–2014). According to article 14 of the Environmental Health Act, the KoNEHS is conducted every 3 years by the National Institute of Environmental Research under the Ministry of Environment to investigate human exposure levels of environmental pollutants in the Korean population, explore the associated factors, and continuously investigate the spatial and temporal distribution and changes in these factors [14].

The survey area comprised 16 cities and provinces nationwide; for the survey sample, the enumeration districts of the National Population and Housing Census 2010 were used as the sample population. The initial and secondary stratifications were classified according to local administration and socioeconomic factors, respectively, using stratified multistage cluster sampling applied with proportional allocation of the square root of the population to extract 400 sample enumeration districts [15].

Approximately 15 people from each sample enumeration district were included in the survey that targeted a total of 6,478 Koreans aged 19 years and older. The survey comprised an environmental exposure-related examination using questionnaires, clinical tests, and analysis of harmful environmental substances in biological samples [14].

Of the 6,478 participants in this study, only 5,402 (2,488 men, 2,914 women) were finally included, and 1,076 participants whose urinary creatinine concentration exceeded the proper range at 0.3–3.0 g/L or whose urinary BPA concentration data were missing were excluded.

Variables

Urinary BPA concentration

The concentration of urinary BPA was measured using ultraperformance liquid chromatography–tandem mass spectrometry with Xevo TQ-S (Waters Corporation, Milford, MA, the USA) using a spot urine sample [16]. The sample was hydrolyzed with ß-glucuronidase/aryl sulfatase-degrading enzyme, and BPA was extracted with ethyl ether and measured. The analysis aimed to identify the value of sample concentration using the calibration curve established using the standard addition method, which adds a certain amount of standard solution to the sample. The outcome of the calibration standard solution was set at a reference value ± 15%, and the precision measuring reproducibility of the testing method was identified using a relative standard deviation of 15%. Meanwhile, accuracy measurements were conducted using a quality control (QC) sample. The QC standard solution was used for internal QC and was analyzed while examining for precision and accuracy. The method detection limit (MDL) of the BPA was 0.15 μg/L. The value below the MDL was substituted with the MDL values divided by square root of 2 [17], and the final BPA concentration was calculated after adjusting for urinary creatinine concentration for correction of urine dilution in this study.

Seafood consumption

To analyze the relationship between BPA exposure and the frequency of seafood consumption, we used the question for the consumption frequency of seafood, such as large fish and tuna, general fish, crustacean, seaweed, shellfish, and other seafood items [18], and the frequency of consumption was reclassified into rarely consumed, consumed once a week or less, and consumed more than once a week.

Potential confounders

The sociodemographic and health behavior-related variables of the study participants were classified as follows. The data were stratified according to gender, and age was given as the mean value. The participants were classified according to body mass index (BMI) as follows: underweight, less than 18.5 kg/m^2; normal weight, 18.5–25 kg/m^2; and overweight, greater than or equal to 25 kg/m^2. Marital status was classified into single, married, and others (divorced/death of spouse/separated) and household income into 4 groups according to the quartile. Alcohol consumption was classified into non-drinker (participants who had never drunk at all or had used to drink in the past but not currently), light drinker (participants who are drinking less than the amount drunk by heavy drinkers), and heavy drinker (participants drinking 3 times or more per week and drinking more than 7 glasses per occasion in men and more than 5 glasses in women). Smoking was classified into smoker (participants currently smoking) and nonsmoker (those who quit smoking or never smoked). Exercise status was classified into exercising group (participants exercising more than 3 times a week over 20 minutes and sweating during workout) and non-exercising group (participants who do not fit in the exercising group).

The frequency of frozen food and canned food consumption was selected as potential confounding variables as the dietary factor, which is correlated to the method of seafood consumption and is a major source of exposure to BPA in life [5,19], and was reclassified into groups that rarely consumed, consumed once a week or less, and consumed more than once a week.

Statistical analysis

The final data analysis was performed by applying the weights presented in the original publicly open final dataset in accordance with the KoNEHS analysis guidelines [14]. The participants were divided into the high and low BPA exposure groups based on the top 75th percentile concentration of urinary BPA (male: 2.4 μg/g creatinine, female: 3.2 μg/g creatinine). The frequency and proportion of each variable were then determined according to gender. The χ^2 tests were performed to analyze the difference in the distribution of each variable. Odds ratios (ORs) and 95% confidence intervals (CIs) were calculated using logistic regression in the high and low BPA exposure groups. The unadjusted models were presented, and a multivariate model was used in adjusting for age, BMI, socioeconomic variables, health behavior-related variables, and dietary factor-related variables. IBM SPSS version 19 for Windows (SPSS Inc., Chicago, IL, the USA) was used for statistical analysis, and p-value < 0.05 was considered statistically significant.

RESULTS

The distribution of participants according to basic characteristics in this study is presented in **Table 1**. Of the participants, 2,488 (46.1%) were men and 2,914 (53.9%) were women. The median concentration was 1.46 μg/g creatinine (male: 1.22 μg/g creatinine, female: 1.68 μg/g creatinine), and the average age of the participants was 51.1 (male: 51.4, female: 50.9) years. When the male-to-female ratio was compared for confounding, the proportion of current smokers, heavy drinkers and the consumption of canned foods was higher in men than in women. However, the consumption of frozen foods was similar. In terms of the frequency of seafood consumption, more than half of men and women rarely consumed large fish and tuna. Almost half of the study participants rarely consumed crustacean and shellfish. The proportions of consumption of general fish and other seafood items were highest in once a week or less group, while seaweed was consumed more than once a week.

In terms of urine BPA concentration, the participants were classified into the high and low BPA exposure groups based on the top 75th percentile concentration. The distribution of high and low BPA exposure groups according to basic characteristics and the frequencies of consumption of seafood is presented in **Table 2**. The average age was significantly lower in female participants in the high BPA exposure group than in the low exposure group. In addition, the high BPA exposure group had a significantly higher percentage of household income, which is above the third quartile, than the low BPA exposure group, and the proportion of married women was significantly higher in the high BPA exposure group

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Table 1. Baseline characteristics of the participants

Characteristics	Category	Total (n = 5,402)	Men (n = 2,488)	Women (n = 2,914)	*p*-value[a]
BPA (μg/g creatinine)		1.46 (0.73–2.83)	1.22 (0.62–2.37)	1.68 (0.88–3.15)	< 0.001
Age (years)		51.1 ± 15.2	51.4 ± 15.4	50.9 ± 15.0	0.214
BMI	Underweight	139 (2.6)	45 (1.8)	94 (3.2)	< 0.001
	Normal	3,136 (58.1)	1,393 (56)	1,743 (59.8)	
	Overweight	2,127 (39.3)	1,050 (42.2)	1,077 (37)	
Household income	1st quartile	1,489 (27.6)	695 (27.9)	794 (27.2)	0.355
	2nd quartile	2,510 (46.5)	1,168 (46.9)	1,342 (46.1)	
	3rd quartile	1,352 (25)	598 (24)	754 (25.9)	
	4th quartile	51 (0.9)	27 (1.2)	24 (0.8)	
Marital status	Single	568 (10.6)	319 (12.8)	249 (8.5)	< 0.001
	Married	4,302 (79.6)	2,053 (82.5)	2,249 (77.2)	
	Others	532 (9.8)	116 (4.7)	416 (14.3)	
Smoking	Non- or ex-smoker	4,380 (81.1)	1,579 (63.5)	2,801 (96.1)	< 0.001
	Current smoker	1,022 (18.9)	909 (36.5)	113 (3.9)	
Alcohol	Non-drinker	2,149 (39.8)	646 (26)	1,503 (51.6)	< 0.001
	Moderate drinker	2,766 (51.3)	1,422 (57.2)	1,344 (46.1)	
	Heavy drinker	487 (9)	420 (16.8)	67 (2.3)	
Exercise	No	3,911 (72.4)	1,739 (69.9)	2,172 (74.5)	< 0.001
	Yes	1,491 (27.6)	749 (30.1)	742 (25.5)	
Consumption of frozen food	Rarely	4,334 (80.3)	1,991 (80)	2,343 (80.4)	0.707
	≤ Once a week	937 (17.3)	432 (17.4)	505 (17.3)	
	> Once a week	131 (2.4)	65 (2.6)	66 (2.3)	
Consumption of canned food	Rarely	2,717 (50.3)	1,235 (49.6)	1,482 (50.9)	0.017
	≤ Once a week	2,347 (43.4)	1,072 (43.1)	1,275 (43.8)	
	> Once a week	338 (6.3)	181 (7.3)	157 (5.3)	
Consumption of large fish and tuna	Rarely	3,690 (68.3)	1,626 (65.4)	2,064 (70.8)	< 0.001
	≤ Once a week	1,570 (29.1)	780 (31.4)	790 (27.1)	
	> Once a week	142 (2.6)	82 (3.2)	60 (2.1)	
Consumption of fish	Rarely	501 (9.2)	198 (8.0)	303 (10.4)	< 0.001
	≤ Once a week	3,217 (59.6)	1,446 (58.1)	1,771 (60.8)	
	> Once a week	1,684 (31.2)	844 (33.9)	840 (28.8)	
Consumption of crustacean	Rarely	3,056 (56.6)	1,348 (54.2)	1,708 (58.6)	0.004
	≤ Once a week	2,143 (39.7)	1,045 (42.0)	1,098 (37.7)	
	> Once a week	203 (3.7)	95 (3.8)	108 (3.7)	
Consumption of seaweed	Rarely	242 (4.5)	125 (5.0)	117 (4.0)	0.152
	≤ Once a week	1,854 (34.3)	862 (34.6)	992 (34.1)	
	> Once a week	3,306 (61.2)	1,501 (60.3)	1,805 (61.9)	
Consumption of shellfish	Rarely	2,720 (50.4)	1,191 (47.9)	1,529 (52.5)	0.003
	≤ Once a week	2,339 (43.3)	1,125 (45.2)	1,214 (41.6)	
	> Once a week	343 (6.3)	172 (6.9)	171 (5.9)	
Consumption of other seafood items	Rarely	2,341 (43.3)	979 (39.3)	1,362 (46.7)	< 0.001
	≤ Once a week	2,793 (51.7)	1,373 (55.2)	1,420 (48.8)	
	> Once a week	268 (5.0)	136 (5.5)	132 (4.5)	

Data were presented as median (interquartile range), mean ± standard deviation, or number (%).
BPA: bisphenol A; BMI: body mass index.
[a]*p*-value calculated by t-test or χ^2 tests.

than in the low BPA exposure group. The proportion of male participants who drink heavily and consume a higher frequency of frozen food was higher in the high BPA exposure group than in the low exposure group. According to the distribution of the frequency of seafood consumption, men in the high BPA exposure group consume large fish and tuna, shellfish, and other seafood items more often than those in the low exposure group.

Logistic regression analysis was used to analyze the degree of association between the frequency of seafood consumption and urinary BPA concentration in the low and high BPA exposure groups (**Table 3**). In men, the consumption of large fish and tuna and other seafood items had significantly higher ORs before and after adjustment in the group who

Table 2. Baseline characteristics of the participants according to urinary concentration of BPA (male: ≥ 2.4 μg/g creatinine, female: ≥ 3.2 μg/g creatinine)

Characteristics	Category	Men			Women		
		Low (n = 1,876)	High (n = 612)	*p*-value	Low (n = 2,228)	High (n = 686)	*p*-value
Age (years)		51.6 ± 15.6	50.9 ± 14.9	0.331	51.2 ± 15.2	49.7 ± 14.2	0.015
BMI	Underweight	35 (1.9)	10 (1.6)	0.930	75 (3.4)	19 (2.8)	0.558
	Normal	1,049 (55.9)	344 (56.2)		1,339 (60.1)	404 (58.9)	
	Overweight	792 (42.2)	258 (42.2)		814 (36.5)	263 (38.3)	
Household income	1st quartile	535 (28.5)	160 (26.1)	0.642	619 (27.8)	175 (25.5)	0.006
	2nd quartile	877 (46.7)	291 (47.6)		1,048 (47)	294 (42.9)	
	3rd quartile	445 (23.7)	153 (25)		546 (24.5)	208 (30.3)	
	4th quartile	19 (1)	8 (1.3)		15 (0.7)	9 (1.3)	
Marital status	Single	245 (13.1)	74 (12.1)	0.794	193 (8.7)	56 (8.2)	0.035
	Married	1,545 (82.3)	508 (83)		1,697 (76.1)	552 (80.4)	
	Others	86 (4.6)	30 (4.9)		338 (15.2)	78 (11.4)	
Smoking	None or ex-smoker	1,191 (63.5)	388 (63.4)	0.969	2,141 (96.1)	660 (96.2)	0.892
	Current smoker	685 (36.5)	224 (36.6)		87 (3.9)	26 (3.8)	
Alcohol	None	495 (26.4)	151 (24.7)	0.009	1,162 (52.2)	341 (49.7)	0.476
	Moderate	1,089 (58)	333 (54.4)		1,017 (45.6)	327 (47.7)	
	Heavy	292 (15.6)	128 (20.9)		49 (2.2)	18 (2.6)	
Exercise	No	1,313 (70)	426 (69.6)	0.858	1,654 (74.2)	518 (75.5)	0.503
	Yes	563 (30)	186 (30.4)		574 (25.8)	168 (24.5)	
Consumption of frozen food	Rarely	1,520 (81)	471 (77)	0.050	1,807 (81.1)	536 (78.1)	0.122
	≤ Once a week	313 (16.7)	119 (19.4)		376 (16.9)	129 (18.8)	
	> Once a week	43 (2.3)	22 (3.6)		45 (2)	21 (3.1)	
Consumption of canned food	Rarely	931 (49.6)	304 (49.7)	0.809	1,153 (51.8)	329 (48)	0.112
	≤ Once a week	805 (42.9)	267 (43.6)		963 (43.2)	312 (45.4)	
	> Once a week	140 (7.5)	41 (6.7)		112 (5)	45 (6.6)	
Consumption of large fish and tuna	Rarely	1,226 (65.4)	400 (65.4)	0.030	1,587 (71.3)	477 (69.5)	0.283
	≤ Once a week	598 (31.9)	182 (29.7)		600 (26.9)	190 (27.7)	
	> Once a week	52 (2.7)	30 (4.9)		41 (1.8)	19 (2.8)	
Consumption of fish	Rarely	137 (7.3)	61 (10.0)	0.102	237 (10.6)	66 (9.6)	0.167
	≤ Once a week	1,101 (58.7)	345 (56.3)		1,368 (61.4)	403 (58.7)	
	> Once a week	638 (34.0)	206 (33.7)		623 (28)	217 (31.6)	
Consumption of crustacean	Rarely	1,013 (54.0)	335 (54.7)	0.831	1,327 (59.6)	381 (55.6)	0.150
	≤ Once a week	789 (42.1)	256 (41.8)		818 (36.7)	280 (40.8)	
	> Once a week	74 (3.9)	21 (3.5)		83 (3.7)	25 (3.6)	
Consumption of seaweed	Rarely	96 (5.1)	29 (4.7)	0.933	91 (4.1)	26 (3.8)	0.562
	≤ Once a week	649 (34.6)	213 (34.8)		747 (33.5)	245 (35.7)	
	> Once a week	1,131 (60.3)	370 (60.5)		1,390 (62.4)	415 (60.5)	
Consumption of shellfish	Rarely	903 (48.1)	288 (47.1)	0.026	1,189 (53.4)	340 (49.6)	0.130
	≤ Once a week	858 (45.7)	267 (43.6)		916 (41.1)	298 (43.4)	
	> Once a week	115 (6.1)	57 (9.3)		123 (5.5)	48 (7)	
Consumption of other seafood items	Rarely	744 (39.7)	235 (38.4)	0.021	1,054 (47.3)	308 (44.9)	0.542
	≤ Once a week	1,043 (55.6)	330 (53.9)		1,074 (48.2)	346 (50.4)	
	> Once a week	89 (4.7)	47 (7.7)		100 (4.5)	32 (4.7)	

Data were presented as mean ± standard deviation or number (%).
BPA: bisphenol A; BMI: body mass index.

consumed more than once a week than in the group who rarely consumed, with adjusted values of 1.97 (95% CI: 1.12–3.48) and 1.74 (95% CI: 1.10–2.75), respectively. The unadjusted OR for shellfish consumption was 1.61 (95% CI: 1.00–2.59), which was significantly higher in the group who consumed more than once a week than in the group who rarely consumed. However, the OR was not statistically significant after adjustment. In women, the frequency of seafood consumption and the concentration of urinary BPA were not significantly associated. Furthermore, we conducted the same analysis in different cutoff values (70th and 80th percentile concentration of urinary BPA) to confirm the optimal cutoff value. The result from this sensitivity analysis also showed similar association as **Table 3** respectively (data not shown).

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Table 3. ORs and 95% CIs of seafood consumption in individuals with high urinary concentration of BPA (male: ≥ 2.4 μg/g creatinine, female: ≥ 3.2 μg/g creatinine) compared to low urinary concentration of BPA

Category	Men		Women	
	Unadjusted	Multivariate adjusted model	Unadjusted	Multivariate adjusted model
Consumption of large fish and tuna				
Rarely	1	1	1	1
≤ Once a week	0.78 (0.60–1.02)	0.79 (0.59–1.05)	0.91 (0.71–1.17)	0.82 (0.62–1.09)
> Once a week	1.72 (1.01–2.92)	1.97 (1.12–3.48)	1.52 (0.78–2.95)	1.27 (0.61–2.61)
Consumption of fish				
Rarely	1	1	1	1
≤ Once a week	0.68 (0.43–1.06)	0.66 (0.42–1.02)	1.15 (0.79–1.68)	1.12 (0.76–1.65)
> Once a week	0.69 (0.42–1.12)	0.66 (0.41–1.07)	1.32 (0.90–1.93)	1.27 (0.87–1.87)
Consumption of crustacean				
Rarely	1	1	1	1
≤ Once a week	1.12 (0.87–1.44)	1.10 (0.85–1.41)	1.29 (1.00–1.66)	1.23 (0.96–1.59)
> Once a week	1.11 (0.48–2.57)	1.11 (0.48–2.58)	0.73 (0.42–1.28)	0.71 (0.40–1.24)
Consumption of seaweed				
Rarely	1	1	1	1
≤ Once a week	1.30 (0.75–2.25)	1.28 (0.73–2.22)	1.52 (0.79–2.93)	1.43 (0.72–2.82)
> Once a week	1.41 (0.83–2.40)	1.38 (0.80–2.37)	1.17 (0.61–2.26)	1.08 (0.54–2.14)
Consumption of shellfish				
Rarely	1	1	1	1
≤ Once a week	1.05 (0.80–1.38)	1.02 (0.77–1.34)	1.09 (0.86–1.38)	1.05 (0.83–1.33)
> Once a week	1.61 (1.00–2.59)	1.53 (0.94–2.48)	1.47 (0.92–2.37)	1.44 (0.91–2.29)
Consumption of other seafood items				
Rarely	1	1	1	1
≤ Once a week	1.02 (0.78–1.34)	0.99 (0.75–1.31)	1.10 (0.86–1.41)	1.02 (0.79–1.32)
> Once a week	1.81 (1.16–2.83)	1.74 (1.10–2.75)	0.89 (0.49–1.60)	0.81 (0.46–1.44)

Multivariate adjusted model: adjusted for age, BMI, household income, marital status, smoking, alcohol, exercise, and consumption of frozen food and canned food.
OR: odds ratio; CI: confidence interval; BPA: bisphenol A; BMI: body mass index.

DISCUSSION

In this study, women had higher urinary BPA concentrations than men. In addition, younger women, those with low household income level, and those who are married have a higher urinary BPA concentration. Meanwhile, a higher urinary BPA concentration was observed in men who are heavy drinkers and who consumed frozen food more often. This trend was consistent with that of previous studies. In a study that used data from the Korea Biomonitoring Program of Hazardous Materials Survey (2009–2010) to monitor urinary BPA concentrations among adults, the creatinine-adjusted BPA levels of women were higher than those of men [20]. This gender difference is attributed to higher urinary creatinine concentrations in men than in women. According to a study of the Sabadell birth cohort (2004–2006) that analyzed BPA concentrations in pregnant women, younger women had a higher BPA concentration, and this result is consistent with that of the current study [21]. In a study of temporal trends in BPA exposure that utilized data from NHANES (2003–2012), female participants and those with lower household income level had a significantly higher BPA concentration [22]. The association between frozen food consumption and BPA exposure can be caused by packaging materials and cooking methods [23].

This study showed the association between the frequency of seafood consumption and urinary BPA concentration. The primary results showed that the high urinary BPA concentration in men was significantly associated with the consumption of large fish and tuna, other seafood items, and shellfish consumption. To our knowledge, there is no previous study to explore the association between the frequency of seafood consumption and urinary BPA concentration in humans. However, several studies have analyzed BPA pollution in the marine ecosystems and the possibility of ingesting seafood contaminated with BPA. In a study of seawater samples obtained from 28 regions in Singapore, BPA was detected in all samples except for 3 [24]. According to a study that analyzed the BPA concentration in 5 different types of fish (mullet, salpa, white bream, bass, and ombrina) caught in the 2 other regions in Italy, the proportion of fish contaminated with BPA ranged from 73% (bass) to 90% (salpa) in Naples and from 58% (ombrina) to 90% (salpa) in the Latium coast [25]. In a study of the BPA concentration in surface water and fish samples from various regions in the Netherlands, BPA concentration in the surface water in Bocht van Wattum (BVW), which is one of the marine zones, was 330 ng/L, which was higher than that of other areas. Furthermore, the BPA concentration in the fish caught in the BVW region was 75 ng/g dry weight, which was higher than that in fish caught in other regions [26]. This result showed that fish caught in areas with high BPA contamination have higher BPA concentration than those caught in other areas. Moreover, in previous studies, BPA was detected in fish caught in water areas where BPA was not detected [26]. These results indicated that a survey of marine organisms, including fish, as well as water samples can obtain more accurate results when investigating BPA pollution in the marine environment. In particular, fish is considered a good indicator of a contaminated aquatic environment due to its high bioaccumulation potential and high sensitivity to pollutants [27]. Unlike in men, no relationship was observed between seafood consumption and BPA concentration in women, as it is assumed that women consume less amount of seafood than men (**Table 1**).

In this study, urinary BPA concentration was significantly correlated to the consumption frequency of large fish and tuna, but not that of general fish. Results suggested the possibility of BPA bioaccumulation via the food chain of marine organisms. Moreover, a study of BPA concentration in 20 kinds of fish purchased at a market in Hong Kong has found that BPA was detected in most species, and the highest concentration of BPA was found in fish at the top of the food chain of fish species [10]. This shows that BPA bioaccumulates in marine organisms [28], which is a major problem associated with chemical contamination of marine organisms.

One of the causes of BPA pollution in marine ecosystems is that BPA exists in the water system that flows into the ocean. BPA can flow directly into the marine environment via landfill leachates and sewage treatment plant effluents [28]. Yamamoto et al. [29] have indicated that leachate from hazardous waste landfill is a source of BPA in the environment and that BPA can be released to leachate through the leaching process after plastics are buried in landfills. According to an experimental study, up to 139 μg of BPA per gram of plastic waste was leached [30]. Another cause of BPA pollution in marine ecosystem is the remaining plastics in the ocean. There were approximately at least 5.25 trillion plastics in the world's oceans, and these plastics weighed 268,940 tons between 2007 and 2013 [31]. BPA can flow into the aquatic environment due to the instability of plastic products [11]. In the plastic samples collected from the open ocean, the BPA concentration ranged from 5 to 284 ng/g, which is a significant level [32]. In experimental studies that measured BPA leaching from polycarbonate in water samples, BPA leaching velocity is fastest in sea water, and the BPA concentration increased with increasing temperature and over time [33]. BPA was also leached from epoxy resins present in water samples [34].

Recently, studies have focused on the potential effects of plastic pollution in marine environments that produces organic contaminants, such as BPA, on marine ecosystems [35]. About 60%–80% of the total marine debris worldwide are plastics [36]. Marine organisms may ingest residual plastics in the ocean and may be exposed to BPA via residual BPA monomers or toxic additives left from the plastic manufacturing process [35]. In an experimental study of rainbow fish, the experimental group exposed to microbeads contaminated with chemical pollutant had a higher concentration of BPA than the control group, and the concentration increased during the experimental period. This result confirmed the chemical transfer ability of microbeads and the risk of chemical accumulation in exposed fish [37]. Microplastics, defined as plastics with a size between 1 µm and 5 mm, can have serious adverse effects on marine ecosystems due to their small size [38]. Microplastics in seafood can be a route for chemical damage caused by plastic additives, including BPA, and physical damage by particles among humans [38,39]. As a result of monitoring 18 coasts in Korea in 2012–2014, microplastics were detected in all coasts [40]. In addition, humans can ingest microplastics via the consumption of various contaminated seafoods. Microplastics were found in 11.0% of the digestive tracts of 761 Northeast Atlantic mesopelagic fish [41] and in 2.9% of the 347 fish larva in the Western English Channel [42].

Korea government has banned the use of BPA in baby bottles, including nipples, tools for infants and young children, containers, and packaging in 2019 [43]. Therefore, the possibility of dissolution of bisphenol in food containers and packaging was extremely low these days [44]. In the future, BPA exposures due to the use of plastic containers can be thoroughly managed through regulations. However, there is no current BPA regulation on fish products. Thus, potential human exposure to BPA via the consumption of contaminated seafood must not be overlooked, and establishing safety management standards for fish products contaminated with BPA is important.

The present study had some limitations. First, more detailed seafood-related data, such as types, amount, and cooking methods of seafood, including ingestion of raw or cooked fish and canned or frozen food, could not be analyzed. Second, other sources of exposure to BPA, such as storage containers or storage periods of seafood, type of water consumed, and frequency of using plastic products, were not assessed. Third, BPA exposure due to occupational exposure was not considered. Fourth, since the questionnaire did not clearly specify the type of large fish and other seafood items, each participant could consider a type of those differently. Fifth, the half-life of BPA is short (< 6 hours) [12] and the survey questionnaire did not include the questions to consider this point.

Despite these limitations, this study suggested the relationship between urinary BPA concentration and seafood consumption using data representing the general population in Korea. BPA is a substance that has various adverse effects on health. Thus, the potential sources of BPA exposure must be managed.

CONCLUSIONS

This study revealed the association between seafood consumption and urinary BPA concentration in the general population in Korea. BPA concentration was higher in men who frequently consumed large fish and tuna, shellfish and other seafood. Based on the results, standards for the management of fish products should be established to prevent BPA exposure from the consumption of contaminated seafood. Further studies about the health effects of BPA exposure in populations who consume large amount of seafood must be conducted.

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