Bisphenol A and Chronic Disease Risk Factors in US Children

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KEY WORDS

bisphenol A, NHANES, children, obesity, endocrine disrupting chemical

ABBREVIATIONS

BPA—bisphenol A
CI—confidence interval
DXA—dual-energy radiograph absorptiometry
HDL—high-density lipoprotein
LDL—low-density lipoprotein
OR—odds ratio
TC—total cholesterol
TG—triglycerides
WC—waist circumference

Dr Eng designed the study, conducted the statistical analysis, and drafted the manuscript; Mr Gebremariam assisted with statistical analysis and interpretation; Drs Meeker and Peterson contributed intellectual content, assisted in data interpretation, and critically reviewed the manuscript; Dr Padmanabhan conceptualized the study, contributed intellectual content to interpretation of data, and critically reviewed the manuscript; and Dr Lee conceptualized and designed the study and the statistical analysis, supervised and reviewed the statistical analysis, and reviewed and revised the manuscript. All authors approved the final manuscript as submitted.

www.pediatrics.org/cgi/doi/10.1542/peds.2013-0106

doi:10.1542/peds.2013-0106

Accepted for publication May 31, 2013

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WHAT'S KNOWN ON THIS SUBJECT: Bisphenol A (BPA) is a known endocrine disruptor found in many products with which children come into contact. Although BPA in adults is associated with obesity, diabetes, and cardiovascular disease, little is known about its effects in children.

WHAT THIS STUDY ADDS: This study found that higher BPA levels are associated with obesity and abnormal waist circumference–to–height ratio in children.

abstract

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OBJECTIVE: To evaluate the relationship between urinary bisphenol A (BPA) levels and measures of adiposity and chronic disease risk factors for a nationally representative US pediatric sample.

METHODS: We used the NHANES 2003–2010 to evaluate cross-sectional associations between urinary BPA and multiple measures of adiposity, cholesterol, insulin, and glucose for children aged 6 to 18 years, adjusting for relevant covariates (eg, demographics, urine creatinine, tobacco exposure, and soda consumption).

RESULTS: We found a higher odds of obesity (BMI ≥95th percentile) with increasing quartiles of BPA for quartiles 2 vs 1 (odds ratio [OR] 1.74, 95% confidence interval [CI] 1.17–2.60, $P = .008$), 3 vs 1 (OR 1.64, 95% CI 1.09–2.47, $P = .02$), and 4 vs 1 (OR 2.01, 95% CI 1.36–2.98, $P = .001$). We also found a higher odds of having an abnormal waist circumference–to–height ratio (quartiles 2 vs 1 [OR 1.37, 95% CI 0.98–1.93, $P = .07$], 3 vs 1 [OR 1.41, 95% CI 1.07–1.87, $P = .02$], and 4 vs 1 [OR 1.55, 95% CI 1.12–2.15, $P = .01$]). We did not find significant associations of BPA with any other chronic disease risk factors.

CONCLUSIONS: Higher levels of urinary BPA were associated with a higher odds of obesity (BMI >95%) and abnormal waist circumference–to–height ratio. Longitudinal analyses are needed to elucidate temporal relationships between BPA exposure and the development of obesity and chronic disease risk factors in children. *Pediatrics* 2013;132:e637–e645

Bisphenol A (BPA) is widely used in the manufacturing of polycarbonate and epoxy resins used in a variety of products for children, including baby bottles, protective coatings on metal food containers, plastic toys, and dental sealants. There is increasing concern regarding the adverse health effects of BPA on children, given the link between higher levels of urinary BPA and an elevated risk of obesity, type 2 diabetes, and cardiovascular disease based on cross-sectional studies conducted in adults.[1–3] Moreover, studies have shown higher urinary concentrations of BPA in children and adolescents compared with adults.[4]

Manufacturers have been voluntarily recalling BPA products due to suspicion about the toxic effects on children and other vulnerable populations. Many countries, including Canada and members of the European Union, as well as several US states, are rethinking the use of BPA and have banned BPA use in products frequently used by infants and young children.[5] In July 2012, the US Food and Drug Administration (FDA) announced that baby bottles and children's drinking cups could no longer contain BPA; however, this restriction does not apply to other BPA-containing products,[6] as the FDA cited a lack of evidence of adverse health effects to institute a full ban.[7]

Despite all of the policy initiatives focused on BPA, its health effects in pediatric populations are relatively understudied. One recent study in a pediatric population reported an association between BPA and obesity as measured by BMI[8] but did not examine its association with gold standard measures of body fat or cardiovascular and diabetes risk factors. Therefore, our objective was to examine the relationship between urinary BPA levels and abnormal measures of BMI, waist circumference (WC), WC–to–height ratio, body fat, cholesterol, insulin, and glucose among a nationally representative sample of US children and adolescents. Additional studies to evaluate the potential health risks of BPA in children would contribute to a body of literature that can help guide national policy on the use of BPA.

METHODS

NHANES is a cross-sectional study conducted on nationwide probability samples of a noninstitutionalized US civilian population; details of the study design and methods are described elsewhere.[9] We chose to examine the 2003–2010 survey years because of the availability of simultaneous measurements of urinary BPA and chronic disease measures. Our study population consisted of children aged 6 to 18 years who participated between 2003 and 2010 and had urinary BPA levels, anthropometric measurements, total cholesterol (TC), and high-density lipoprotein (HDL) levels. We also evaluated a subset of adolescents aged 12 to 18 years who had fasting low-density lipoprotein (LDL), triglycerides (TG), and glucose and insulin measurements. Fasting status was determined through the use of detailed fasting questionnaires.[10–17] For the body fat analyses, only survey years 2003–2006 had simultaneous measurements of urinary BPA and whole body dual-energy radiograph absorptiometry (DXA) for individuals aged 8 years and older. We excluded pregnant females ($n = 27$) from the analysis, those with self-reported diabetes ($n = 24$), those taking insulin ($n = 15$), and those taking diabetic pills ($n = 2$).

Anthropometric and Laboratory Measures

BMI was calculated based on measured height and weight by trained examiners. BMI percentile adjusted for age and gender were calculated based on the 2000 Centers for Disease Control and Prevention growth curves.[18] WC was measured by trained examiners using a steel measuring tape to the nearest 0.1 cm at the high point of the iliac crest at minimal respiration when the participant was in a standing position.[19–22] WC-to-height ratio as a measure of central adiposity was also included as it has been shown to be more indicative of cardiometabolic risk than traditional BMI[23] and has been shown to be a marker of adiposity independent of pubertal stage and gender.[24]

Total body percent fat was measured by whole body DXA scans conducted on a subset of individuals 8 years and older by using Hologic QDR 4500 fan-beam densitometer (Hologic, Inc, Bedford, MA). Hologic software version 8.26:a3 was used to administer all scans. The participants were positioned supine on the tabletop with their feet in a neutral position and hands flat by their side. DXA examinations were administered by certified trained radiology technologists.[25]

Cholesterol, TG, and HDL cholesterol were measured in serum by using a Hitachi 704 Analyzer (Roche Diagnostics, Indianapolis, IN) in 2003–2004,[14] Hitachi 717 and Hitachi 912 (Roche Diagnostics) in 2005–2006,[15] and Roche Modular P chemistry analyzer (Roche Diagnostics) in 2007–2008[16] and 2009–2010.[17] LDL cholesterol level was calculated from measured values of TC, TG, and HDL cholesterol based on the Friedewald equation, which is valid for individuals with TC levels <400 mg/dL.[26]

During survey years 2003–2010, 3 different insulin and glucose assay methods were used: Tosoh Medics Inc (South San Francisco, CA; 2003–2004), Mercodia Insulin Elisa (Uppsala, Sweden; 2005–2009), and Roche Chemiluminicent immunoassay (Indianapolis, IN; late 2009–2010) for insulin and Roche Cobas (Montclair, NJ; 2003–2004), Roche/Hitachi 911 (Indianapolis, IN; 2005–2006), and Roche/Modular P (Indianapolis, IN;

2007–2010) for glucose.[27–30] More detailed information on the specific assays is available on the NHANES Web site, which provides regression equations to convert insulin and glucose levels so that they are comparable across survey years.[10–13]

Concentrations of BPA were measured at the Division of Environmental Health Laboratory Sciences (National Center for Environmental Health, Centers for Disease Control and Prevention, Atlanta, GA) by using online solid-phase extraction coupled with high-performance liquid chromatography–isotope–dilution tandem–mass spectrometry with peak focusing. The limit of detection was 0.4 ng/mL, and the coefficient of variation ranged from 6% to 16% for BPA. In NHANES, BPA concentrations below the level of detection were assigned a value of 0.3 ng/mL.[27–30]

Study Definitions

Individuals were classified as overweight if they had a BMI ≥85th percentile and obese if they had a BMI ≥95th percentile. Abnormal WC was defined as a WC ≥75th percentile and WC ≥90th percentile (age and gender adjusted).[31–33] Abnormal WC-to-height ratio was defined as ≥0.5, based on a previous study that showed a WC-to-height ratio of ≥0.5 was associated with higher cardiometabolic risk in a US pediatric population.[23] For the DXA measures of body fat, we defined abnormal body fat percentage as ≥85th percentile (age and gender adjusted),[34] which is a cutoff that provides an equivalent proportion of children with BMI ≥95th percentile (16.3%).[35] Children were designated as having abnormal levels of cholesterol based on the National Cholesterol Education Program guidelines: TC ≥200 mg/dL, HDL ≥35 mg/dL, LDL ≥130 mg/dL, and TG ≥150 mg/dL (to convert to millimoles per liter, multiply TC, HDL, or LDL by 0.0259 and TG by 0.01).[36]

Homeostasis model assessment of insulin resistance, a validated surrogate measure of insulin resistance in nondiabetic children, was calculated by dividing the product of fasting insulin (microunits per milliliter) and fasting glucose (millimoles per liter) by 22.5.[37] Individuals were classified as having insulin resistance if their homeostasis model assessment of insulin resistance was ≥4.39, based on a previous study evaluating the burden of insulin resistance in NHANES,[31] and were classified as having abnormal glucose if their fasting glucose was ≥100 mg/dL (to convert to millimoles per liter, multiply by 0.0555).[38]

Statistical Analysis

Our primary independent variable was a urinary BPA level, which was categorized into 1 of 4 quartiles based on the distribution of BPA in our population (<1.3, 1.3–2.6, 2.6–4.9, and >4.9 ng/mL). We performed separate logistic regression models (unadjusted and adjusted) to evaluate the relationship of BPA levels with each of the outcomes (ie, overweight/obese, abnormal WC, abnormal WC-to-height ratio, abnormal body fat percentage, insulin resistance, abnormal glucose, and abnormal TC, HDL, LDL, and TG). For the models predicting anthropometric outcomes (WC, WC-to-height ratio, overweight/obese) and body fat percentage, we included the following covariates: age, race/ethnicity, poverty-to-income ratio (≥1),[39] and serum cotinine (≥2 ng/mL designated as high smoke exposure)[40] as a proxy for tobacco smoke exposure.[41] Urinary creatinine was also included as a covariate as a proxy for using creatinine-corrected BPA levels to account for variable dilutions among spot samples.[42] Because high-energy intake from BPA-containing food sources may be a potential confounder, we performed a secondary analysis with frequency of sugar-sweetened soda consumption included as a covariate when those data were available (2003–2004 and 2005–2006 survey waves). Soda consumption ≥1 per day was designated high soda consumption as this level of soda consumption has previously been found to be associated with higher BMI.[43] For the remaining models predicting laboratory abnormalities, we adjusted for these covariates as well as BMI percentile. Separate models without BMI as a covariate were also performed to investigate if BMI was on the causal pathway. BMI percentile was not a covariate included in the WC, WC-to-height ratio, or body fat percentage models given the collinearity of these measures. BPA is a proven endocrine disrupting chemical in animals that can bind to the estrogen receptor and induce estrogen receptor–mediated gene expression, and a previous study in adults found that higher urinary BPA levels were associated with endocrine changes (higher testosterone levels) in men but not in women.[44] BPA may have different effects in males and females; therefore, a gender interaction term was used to investigate possible effect modification by gender.

The NHANES uses a complex sample survey design including a multistage cluster sample and weighting methodology[45] that oversamples certain subgroups of individuals (ie, adolescents and minority individuals) to ensure adequate statistical power. We used Stata 11.0 statistical software (Stata Corp, College Station, TX), which incorporates appropriate sampling weights to adjust for the complex sample design and uses Taylor series linearization to produce corrected estimates of SEs. Sampling weights associated with the smallest subsample (BPA subsample) were used as recommended by NHANES.[46] All analyses applied 2-sided tests with a significance level of .05.

For the models predicting abnormal body fat percentage, NHANES provides DXA data as multiply imputed data sets

to account for missing data. Because missing data can potentially be biased, multiple imputation is a technique that uses statistical methods to fill in missing data with plausible values. We performed analyses on each of the 5 multiple imputation data sets and combined the results using Stata software as recommended by the NHANES data documentation book for DXA examination.[25] This study was considered exempt by the University of Michigan Institutional Review Board.

RESULTS

There were 10 990 children aged 6 to 18 years in our sample. Of those, 3370 children had both BMI percentile and BPA measurements. We excluded participants who were pregnant (n = 27), had self-reported diabetes (n = 24), or were taking insulin (n = 15) or diabetic pills (n = 2). Of those excluded for pregnancy, self-reported diabetes, or insulin or diabetic pill usage, 66% were female and 33% were male. Although there was a higher percentage of females excluded for pregnancy, diabetes, insulin use, and diabetic pill use, the overall total number of children excluded for these reasons was small (n = 52, with an overlap of self-reported diabetes and insulin/diabetic medication use of n = 16). When we compared our subpopulation with the other 7620 children aged 6 to 18 years in the NHANES 2003–2010 surveys, there were no statistically significant differences by age (12.1 years vs 12.1 years, P = .92), gender (51.3% male vs 50.7% male, P = .67), or BMI (21.2 vs 20.9, P = .50). The percentage of those with BPA levels below the lower limit of detection (4.5%) is similar to previous reports of prevalence of BPA exposure.[4] For each model, the number of subjects with each of the outcome measures was different; for the sake of brevity, statistical comparisons of each of the subpopulations are available on request.

TABLE 1 Characteristics of the Study Population for Subsets Used for the Analysis of Each Outcome Measure

Characteristic	BMI	WC	WC-to-Height Ratio	Body Fat, %	Cholesterol	HDL	Fasting LDL	Fasting TG	HOMA-IR	Fasting Glucose
N	3370	3321	3321	775	3002	3002	782	783	664	675
Age, y	12.1 ± 3.7	12.1 ± 3.7	12.1 ± 3.7	13.0 ± 3.1	12.3 ± 3.5	12.3 ± 3.5	13.8 ± 3.1	13.8 ± 3.1	15.2 ± 1.9	15.2 ± 1.9
Gender										
Male	51.0% (1730)	50.7% (1705)	50.7% (1705)	50.1% (395)	51.0% (1548)	51.0% (1548)	52.3% (419)	52.2% (419)	53.5% (368)	53.6% (375)
Female	49.0% (1640)	49.2% (1616)	49.2% (1616)	49.9% (380)	49.0% (1454)	49.0% (1454)	47.7% (363)	47.9% (364)	46.5% (296)	46.4% (300)
Race/ethnicity										
Non-Hispanic white	60.8% (978)	61.0% (967)	61.0% (967)	63.8% (211)	60.5% (856)	60.5% (856)	64.1% (222)	64.2% (223)	63.2% (181)	63.5% (186)
Non-Hispanic black	14.5% (978)	14.4% (958)	14.4% (958)	15.0% (272)	14.1% (852)	14.1% (852)	14.7% (265)	14.6% (265)	15.2% (227)	15.2% (231)
Mexican American	12.7% (990)	12.7% (976)	12.7% (976)	11.6% (240)	13.2% (908)	13.2% (908)	11.2% (222)	11.2% (222)	11.5% (191)	11.4% (193)
Other Hispanic	5.1% (245)	5.1% (243)	5.1% (243)	3.5% (18)	5.3% (222)	5.3% (222)	5.4% (43)	5.6% (43)	5.2% (39)	5.1% (39)
Other	6.9% (179)	6.9% (177)	6.9% (177)	6.1% (34)	7.0% (164)	7.0% (164)	4.7% (30)	4.7% (30)	4.9% (26)	4.9% (26)
Poverty-to-income ratio	2.6 ± 1.5	2.6 ± 1.5	2.6 ± 1.5	2.6 ± 1.5	2.5 ± 1.5	2.5 ± 1.5	2.7 ± 1.5	2.7 ± 1.5	2.8 ± 1.5	2.8 ± 1.5
Abnormal levels	34.4% (1275)[a]; 17.8%; (707)[b]	37.6%; (1308)[c] 18.2%; (686)[d]	32.5% (1182)[e]	16.4% (124)[f]	9.4% (266)[g]	6.2% (166)[h]	6.4% (44)[i]	10.2% (71)[j]	16.3% (132)[k]	16.0% (111)[l]
BPA median[m]	2.6 (1.3–4.9)	2.6 (1.3–4.9)	2.6 (1.3–4.9)	3.9 (1.8–7.3)	2.6 (1.3–4.8)	2.6 (1.3–4.8)	2.8 (1.3–5.8)	2.8 (1.4–5.8)	2.6 (1.3–5.9)	2.7 (1.3–5.9)
Below level of detection	4.5% (142)	4.5% (140)	4.5% (140)	3.6% (28)	4.5% (126)	4.5% (126)	3.3% (25)	3.4% (25)	3.4% (21)	3.5% (21)

Data presented as weighted percentage (unweighted n) or mean ± SD where appropriate. HOMA-IR, homeostasis model assessment of insulin resistance.

[a] BMI ≥85%.
[b] BMI ≥90%.
[c] WC ≥75%.
[d] WC ≥90%.
[e] WC-to-height ratio ≥0.5.
[f] Body fat BF% >85%.
[g] Cholesterol ≥200 mg/dL.
[h] HDL ≤35 mg/dL.
[i] LDL ≥130 mg/dL.
[j] TG ≥150 mg/dL.
[k] HOMA-IR ≥4.39.
[l] Fasting glucose ≥100 mg/dL.
[m] Median (interquartile range).

The demographic characteristics of the study populations used for the analysis of each outcome measure, including the prevalence of abnormal levels for each respective outcome measure, median BPA concentrations, and percentage below the lower limit of detection, are shown in Table 1.

In regard to measures of body fatness, we found an increase in the odds of obesity (BMI ≥95th percentile) with increasing quartiles of BPA for quartiles 2 vs 1 (odds ratio [OR] 1.74, 95% confidence interval [CI] 1.17–2.60, P = .008), 3 vs 1 (OR 1.64, 95% CI 1.09–2.47, P = .02), and 4 vs 1 (OR 2.01, 95% CI 1.36–2.98, P = .001).

In addition, we found a higher odds of having abnormal WC-to-height ratio with increasing quartiles of BPA for quartiles 2 vs 1 (OR 1.37, 95% CI 0.98–1.93, P = .07), 3 vs 1 (OR 1.41, 95% CI 1.07–1.87, P = .02), and 4 vs 1 (OR 1.55, 95% CI 1.12–2.15, P = .01) (Table 2).

We did not find significant associations with abnormal body fat percentage, a lower threshold of BMI (≥85th percentile), or WC (≥75th percentile and ≥90th percentile).

We also did not find associations with cardiovascular and diabetes measures of TC, HDL, LDL, TG, insulin resistance, or fasting glucose (Table 3).

In sensitivity analyses, our results for anthropometric measures were similar even after controlling for soda consumption, with increasing quartiles of BPA remaining significantly associated with higher odds BMI ≥95th percentile and WC-to-height ratio ≥0.5. Again, no association was seen for WC or body fat percentage (Table 2). Associations of other measures of cardiovascular and diabetes risk remained nonsignificant (Table 3). The gender interaction term for all models was not found to be statistically significant.

DISCUSSION

Our work provides additional evidence of an association between BPA and excess levels of body fat in children, as measured by BMI and WC-to-height ratio. Although associations with BMI have been reported previously,[8] our study extends these findings to more robust anthropometric measures of cardiovascular risk, suggesting the need for longitudinal studies to confirm a possible causal association between BPA and excess body fat. We do, however, acknowledge that we did not find significant associations between BPA and

TABLE 2 ORs for the Associations Between Urinary BPA Levels and Measures of Adiposity

Measure of Adiposity	Q1 (<1.3 ng/mL)	Q2 (1.3–2.6 ng/mL)	*P* Value	Q3 (2.6-4.9 ng/mL)	*P* Value	Q4 (>4.9 ng/mL)	*P* Value
BMI ≥85th percentile							
Sample size[a]	766	870		854		880	
Unadjusted OR (95% CI)	1 (referent)	1.06 (0.81–1.39)	.6	1.41 (1.13–1.75)	0.003	1.26 (0.98–1.63)	.07
Adjusted OR (95% CI)[b]	1 (referent)	1.00 (0.74–1.36)	.9	1.17 (0.89–1.54)	0.2	1.09 (0.81–1.47)	.6
Adjusted OR (95% CI)[c]	1 (referent)	1.00 (0.74–1.36)	.9	1.17 (0.89–1.54)	0.2	1.07 (0.80–1.44)	.6
BMI ≥95th percentile							
Sample size[a]	766	870		854		880	
Unadjusted OR (95% CI)	1 (referent)	1.65 (1.19–2.28)	.003	1.73 (1.27–2.36)	0.001	2.08 (1.59–2.72)	<.001
Adjusted OR (95% CI)[b]	1 (referent)	1.74 (1.17–2.60)	.008	1.64 (1.09–2.47)	0.02	2.01 (1.36–2.98)	.001
Adjusted OR (95% CI)[c]	1 (referent)	1.73 (1.16–2.58)	.008	1.63 (1.08–2.46)	0.02	2.05 (1.38–3.04)	.001
WC ≥75th percentile							
Sample size[a]	757	859		838		867	
Unadjusted OR (95% CI)	1 (referent)	1.08 (0.80–1.45)	.6	1.42 (1.15–1.75)	0.001	1.26 (1.00–1.59)	.05
Adjusted OR (95% CI)[b]	1 (referent)	1.10 (0.78–1.55)	.6	1.31 (0.98–1.75)	0.06	1.20 (0.87–1.66)	.3
Adjusted OR (95% CI)[c]	1 (referent)	1.10 (0.78–1.55)	.6	1.31 (0.98–1.76)	0.07	1.20 (0.86–1.67)	.3
WC ≥90th percentile							
Sample size[a]	757	859		838		867	
Unadjusted OR (95% CI)	1 (referent)	1.36 (0.97–1.90)	.07	1.32 (0.91–1.92)	0.1	1.54 (1.12–2.12)	.008
Adjusted OR (95% CI)[b]	1 (referent)	1.34 (0.90–1.97)	.1	1.16 (0.75–1.81)	0.5	1.42 (0.93–2.17)	.1
Adjusted OR (95% CI)[c]	1 (referent)	1.33 (0.90–1.97)	.1	1.16 (0.75–1.81)	0.5	1.40 (0.91–2.15)	.1
WC-to-height ratio ≥0.5							
Sample size[a]	757	859		838		867	
Unadjusted OR (95% CI)	1 (referent)	1.20 (0.89–1.61)	.2	1.36 (1.10–1.68)	0.005	1.42 (1.11–1.81)	.006
Adjusted OR (95% CI)[b]	1 (referent)	1.37 (0.98–1.93)	.07	1.41 (1.07–1.87)	0.02	1.55 (1.12–2.15)	.01
Adjusted OR (95% CI)[c]	1 (referent)	1.37 (0.97–1.92)	.07	1.41 (1.07–1.87)	0.02	1.56 (1.11–2.17)	.01
Body fat % ≥85th percentile							
Sample size[a]	134	141		178		322	
Unadjusted OR (95% CI)	1 (referent)	3.11 (1.36–7.12)	.01	2.45 (0.70–8.54)	0.1	2.02 (0.71–5.71)	.2
Adjusted OR (95% CI)[b]	1 (referent)	3.82 (0.61–23.8)	0.1	4.29 (0.55–33.4)	0.2	1.91 (0.21–17.3)	.5
Adjusted OR (95% CI)[c]	1 (referent)	4.85 (0.80–21.4)	0.08	5.36 (0.71–43.3)	0.09	2.10 (0.24–17.8)	.5

[a] Unweighted *n*.

[b] Adjusted for age, gender, race/ethnicity, urine creatinine, poverty-to-income ratio, and serum cotinine as a marker of smoking status.

[c] Adjusted for soda consumption in addition to above covariates.

TABLE 3 ORs for the Associations Between Urinary BPA Levels and Cardiovascular and Diabetic Risk Factors

Risk Factor	Q1 (<1.3 ng/mL)	Q2 (1.3–2.6 ng/mL)	*P* Value	Q3 (2.6–4.9 ng/mL)	*P* Value	Q4 (>4.9 ng/mL)	*P* Value
TC ≥200 mg/dL							
Sample size[a]	689	774		760		779	
Unadjusted OR (95% CI)	1 (referent)	0.85 (0.51–1.42)	.5	0.75 (0.48–1.17)	.2	1.36 (0.88–2.13)	.2
Adjusted OR (95% CI)[b]	1 (referent)	0.84 (0.51–1.38)	.5	0.75 (0.47–1.20)	.2	1.40 (0.86–2.27)	.2
Adjusted OR (95% CI)[c]	1 (referent)	0.86 (0.51–1.45)	.6	0.77 (0.49–1.23)	.3	1.42 (0.88–2.28)	.1
Adjusted OR (95% CI)[d]	1 (referent)	0.84 (0.51–1.39)	.5	0.74 (0.46–1.19)	.2	1.32 (0.81–2.17)	.3
HDL ≤35 mg/dL							
Sample size[a]	689	774		760		779	
Unadjusted OR (95% CI)	1 (referent)	0.90 (0.52–1.59)	.7	1.36 (0.69–2.69)	.4	1.26 (0.71–2.26)	.4
Adjusted OR (95% CI)[b]	1 (referent)	0.86 (0.45–1.66)	.6	1.30 (0.61–2.77)	.5	1.08 (0.51–2.30)	.8
Adjusted OR (95% CI)[c]	1 (referent)	0.91 (0.47–1.74)	.8	1.37 (0.64–2.91)	.4	1.15 (0.55–2.42)	.7
Adjusted OR (95% CI)[d]	1 (referent)	0.86 (0.45–1.67)	.7	1.31 (0.61–2.81)	.5	1.13 (0.52–2.44)	.8
Fasting LDL ≥130 mg/dL							
Sample size[a]	173	184		186		239	
Unadjusted OR (95% CI)	1 (referent)	0.75 (0.21–2.60)	.6	1.59 (0.54–4.64)	.4	1.85 (0.56–6.06)	.3
Adjusted OR (95% CI)[b]	1 (referent)	0.69 (0.19–2.56)	.6	1.38 (0.41–4.60)	.6	1.57 (0.44–5.68)	.5
Adjusted OR (95% CI)[c]	1 (referent)	0.68 (0.18–2.60)	.6	1.37 (0.42–4.49)	.6	1.56 (0.43–5.62)	.5
Adjusted OR (95% CI)[d]	1 (referent)	0.68 (0.18–2.57)	.6	1.37 (0.40–4.65)	.6	1.57 (0.43–5.75)	.5
Fasting TG ≥ 150 mg/dL							
Sample size[a]	173	184		186		240	
Unadjusted OR (95% CI)	1 (referent)	1.21 (0.48–3.07)	.7	1.80 (0.66–4.86)	.2	1.91 (0.82–4.47)	.1
Adjusted OR (95% CI)[b]	1 (referent)	1.11 (0.36–3.42)	.9	1.77 (0.67–4.71)	.2	2.28 (0.72–7.20)	.2
Adjusted OR (95% CI)[c]	1 (referent)	1.40 (0.49–4.00)	.5	2.03 (0.79–5.20)	.1	2.56 (0.74–8.78)	.1
Adjusted OR (95% CI)[d]	1 (referent)	1.11 (0.37–3.32)	.8	1.60 (0.61–4.18)	.3	2.08 (0.63–6.87)	.2
HOMA-IR[d] ≥4.39							
Sample size[a]	155	158		155		196	
Unadjusted OR (95% CI)	1 (referent)	1.66 (0.76–3.64)	.2	1.17 (0.56–2.44)	.7	1.35 (0.66–2.76)	.4
Adjusted OR (95% CI)[b]	1 (referent)	2.27 (0.79–6.48)	.1	1.27 (0.43–3.80)	.7	2.03 (0.75–5.50)	.2
Adjusted OR (95% CI)[c]	1 (referent)	2.30 (0.93–5.72)	.07	1.43 (0.54–3.83)	.5	2.13 (0.84–5.39)	.1
Adjusted OR (95% CI)[d]	1 (referent)	2.28 (0.77–6.72)	.1	1.27 (0.41–3.98)	.7	2.07 (0.72–5.94)	.2
Fasting glucose ≥100 mg/dL							
Sample size[a]	155	161		158		201	
Unadjusted OR (95% CI)	1 (referent)	0.83 (0.38–1.80)	.6	1.11 (0.54–2.28)	.8	0.56 (0.27–1.15)	.1
Adjusted OR (95% CI)[b]	1 (referent)	0.77 (0.33–1.79)	.5	1.23 (0.52–2.90)	.6	0.61 (0.21–1.73)	.3
Adjusted OR (95% CI)[c]	1 (referent)	0.80 (0.34–1.88)	.6	1.24 (0.52–2.96)	.6	0.60 (0.21–1.71)	.3
Adjusted OR (95% CI)[d]	1 (referent)	0.77 (0.33–1.78)	.5	1.32 (0.57–3.04)	.5	0.63 (0.22–1.82)	.4

[a] Unweighted *n*.

[b] Adjusted for BMI percentile, age, gender, race–ethnicity, urine creatinine, poverty-to-income ratio, and serum cotinine as a marker of smoking status.

[c] Adjusted for age, gender, race–ethnicity, urine creatinine, poverty to income ratio, and serum cotinine as a marker of smoking status.

[d] Adjusted for soda consumption, BMI percentile, age, gender, race–ethnicity, urine creatinine, poverty to income ratio, and serum cotinine as a marker of smoking status.

body fat as defined by DXA, although the smaller number of children for whom we had both DXA and BPA data ($n = 775$) may have limited our ability to find an association, compared with the other outcome measures measuring adiposity ($n = 3300$). We also did not find an association between BPA and increased WC but, again, this may be a reflection of an imperfect measure of adiposity in the face of a population encompassing different stages of puberty.

Surprisingly, there were no associations found between BPA and laboratory measures of cardiovascular and diabetes risk. This contrasts with adult studies that have linked BPA levels with cardiovascular disease and diabetes,[2] as well as mouse studies showing elevated cholesterol levels among mice with perinatal and postnatal exposure to BPA.[47] Based on these results, we consider the possibility that BPA may not have adverse effects on cardiovascular and diabetes risk. However, our cross-sectional study design may have also limited our findings, given that the adverse effects of BPA could compound over time, with health effects that manifest later in adulthood.

Our findings are similar to those of other cross-sectional studies in both the United States and China, which have shown that higher urinary BPA levels are associated with a higher odds of obesity among adults.[3,48,49] Trasande et al[8] also reported associations with obesity in the pediatric population using NHANES data, although they only examined data between 2003 and 2008 and did not evaluate additional measures of adiposity or cardiovascular and diabetes risk factors.

Although we did not find a significant gender interaction, we believe additional study of possible gender differences in the effects of BPA is warranted. For example, studies in mice have found

that estrogen may have a protective effect for females, possibly through its inhibitory effect of key adipogenic genes.[50] Alternatively, there could be gender differences in the way BPA alters eating patterns, as studies have found that male, but not female, rats exposed perinatally to BPA developed a preference for a sweet taste.[51]

Strengths of our study include using a large, nationally representative and diverse sample of US children and our ability to adjust for a number of covariates, including demographics, urinary creatinine, serum cotinine, and soda consumption. Furthermore, we evaluated several measures of adiposity and multiple outcomes related to diabetes and cardiovascular risk.

We also acknowledge limitations of our study. We used a cross-sectional study design; therefore, reverse causality cannot be excluded. Studies have demonstrated higher levels of BPA in adipose tissue versus liver and brain tissues in human samples.[52] It is possible obese individuals store BPA differently than nonobese individuals, thus leading to higher concentrations of BPA in the urine. It is unclear if a single measure of BPA would be indicative of long-term exposure to BPA, as humans metabolize and excrete BPA relatively rapidly (half-life of 6 hours with nearly complete urinary excretion by 24 hours).[53] However, in a study looking at the temporal variability of BPA, 1 measurement of BPA had moderate sensitivity (0.64) for predicting higher levels of BPA based on multiple measurements.[54] Moreover, similar assumptions have been made in previous studies.[2,8] We acknowledge caution must be used when drawing inferences from cross-sectional studies to imply a causal link between rapidly excreted toxicants like BPA and chronic disease,[55] thus emphasizing the need for additional longitudinal studies to explore these associations. Another limitation is the lack of dietary information included in the analyses. BPA exposure presumably can occur via oral ingestion[56]; thus, it is possible that those who are obese are merely eating more BPA-containing food. We were able to adjust our analyses for soda consumption; however, we acknowledge this is an imperfect measure of oral ingestion of BPA. Moreover, frequency of soda consumption was available for only 2 of the 4 survey waves. In addition, oral ingestion of BPA is not the only route of exposure; other routes of exposure include air, dust, and dermal exposure via thermal paper (ie, cash receipts).[57] Parental BMI is correlated to child BMI and could be considered as an important covariate in future studies; however, parental size data were not available for the NHANES waves in this analysis. Finally, we were unable to account for the effects of puberty due to the lack of Tanner staging data in NHANES.

CONCLUSIONS

Our findings suggest the need for longitudinal analyses to elucidate temporal relationships between BPA exposure and the development of obesity and chronic disease risk factors in children, to inform future policy regulating children's consumer products.

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(Continued from first page)

PEDIATRICS (ISSN Numbers: Print, 0031-4005; Online, 1098-4275).

FINANCIAL DISCLOSURE: The authors have indicated they have no financial relationships relevant to this article to disclose.

FUNDING: This work was supported by the Department of Pediatrics and the Office of the Vice President of Research, University of Michigan, by training grant support to Dr Eng (5T32 DK071212-07 National Institutes of Health/National Institute of Diabetes and Digestive and Kidney Diseases), and by grants from the National Institute of Environmental Health Sciences (P20ES018171) and US Environmental Protection Agency (RD834800). Funded by the National Institutes of Health (NIH).

POTENTIAL CONFLICT OF INTEREST: The authors have indicated they have no potential conflicts of interest to disclose.

COMPANION PAPERS: Companions to this article can be found on pages e646 and e747, online at www.pediatrics.org/cgi/doi/10.1542/peds.2012-4022 and www.pediatrics.org/cgi/doi/10.1542/peds.2013-2054.

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Pediatrics 2013;132;e637
DOI: 10.1542/peds.2013-0106 originally published online August 19, 2013;

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