Original Article

Gender differences in the associations between urinary bisphenol A and body composition among American children: The National Health and Nutrition Examination Survey, 2003–2006

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A B S T R A C T

Background: As an endocrine disruptor, bisphenol A (BPA) exposure has been implicated as a potential risk factor in childhood obesity, which is defined using percentiles of body mass index for age. We aimed to examine the associations between BPA exposure, reflected by urinary BPA concentration, and body composition in American children.

Methods: Data of 1860 children aged 8–19 years who participated in the 2003–2006 National Health and Nutrition Examination Survey (NHANES) were analyzed in this study. Urinary BPA concentration (ng/mL) was used to indicate BPA status in the body. Body composition was measured by dual-energy X-ray absorptiometry (DXA). Multivariate linear regression models were fitted using survey procedures to investigate the associations between urinary BPA level and body composition separately for boys and girls.

Results: After adjusting for demographic and lifestyle covariates, higher quartiled and log-transformed urinary BPA levels were significantly associated with elevated lean body mass index (LBMI) z-scores in boys (p < 0.05), and significantly associated with elevated fat mass index (BMI) z-scores in girls (p < 0.05). Lower urinary BPA concentration was associated with lower percentage of trunk fat in girls (compared to 1st quartile, 2nd-quartile: β = 2.85, 95% CI, 0.92–4.78; 3rd-quartile: β = 2.57, 95% CI, 0.28–4.85; 4th-quartile: β = 2.79, 95% CI, 0.44–5.14; all p < 0.05). Such patterns were not observed in boys.

Conclusions: Higher BPA levels may be associated with elevated LBMI in boys, but not in girls, while higher BPA levels may be associated with elevated FM in girls, but not in boys.

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Introduction

Cardiovascular diseases (CVDs) are the leading cause of death for men and women of most racial/ethnic groups in the United States.1 Obesity is a major risk factor for CVD.1 In addition to traditional risk factors that have been implicated in the development of obesity,2 emerging evidence has supported a link between obesity and exposure to chemical “obesogens”, such as bisphenol A (BPA).3

BPA is an endocrine-disrupting chemical produced in large quantities worldwide.4 It may alter adipocyte proliferation and differentiation by interfering with nuclear hormone receptor signaling pathways.5 Although cumulative evidence has demonstrated an association of higher BPA levels with higher risk of overweight and obesity in both children and adults6–9 existing epidemiological studies have reached inconclusive findings. For instance, Bhandari et al. examined 2664 children and adolescents of the 2003–2008 National Health and Nutrition Examination Surveys (NHANES) and found a significantly positive association between urinary BPA concentration and obesity in boys but not in girls.6 A study among 1326 Chinese school-age children reported that girls with urinary BPA level ≥2 µg/L had twice the risk of overweight than the low BPA group (<2 µg/L), while a similar association was not observed in boys.10 Furthermore, the InCHIANTI study on Italian adults showed that urinary BPA concentration was significantly associated with waist size but not with body mass index (BMI).8

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The discrepancies in the existing results may be partly explained by different study designs, study populations, or approaches used to evaluate BPA levels. However, a potential reason that cannot be ignored is BMI, rather than direct measurement of body composition, has been employed in most previous studies. In these studies, overweight and obesity was defined based on age-sex-specific BMI percentiles or z-scores in children and BMI in adults. Although BMI is the most commonly used indicator of overweight and obesity in epidemiological studies, it does not distinguish between fat mass (FM) and lean body mass (LBMI) and is only moderately or weakly correlated with body fat percentage (FP) measured using dual-energy X-ray absorptiometry (DXA), air-displacement plethysmography, or isotope dilution. Compared to body composition measurements, the use of BMI values alone may misclassify body weight status and possibly lead to the above-mentioned inconclusive findings.

In addition, BMI does not reflect fat distribution, which may be a more useful predictor of health outcomes, such as all-cause mortality. In adults, abdominal fat distribution has been consistently shown to be associated with increased risks of type 2 diabetes, arterial stiffness, and CVD, while leg fat appears to be protective. In children, higher trunk or lower leg adiposity was associated with greater risks for low high-density lipoprotein cholesterol (HDL-C), high triglycerides, insulin resistance, and high C-reactive protein, while arm adiposity was not associated with these cardiometabolic risk factors. Exploring associations between BPA exposure and regional adiposity may provide new information to help understand the underlying mechanisms of BPA exposure and obesity, examine potential effects of BPA exposure on obesity related diseases, and further identify at-risk populations in general settings.

Studies on exposure to BPA and body composition phenotypes are generally lacking. A recent study in 890 Swedish aging people did not find any significant relationships between serum BPA concentrations and adipose tissue measured by DXA and magnetic resonance imaging (MRI). To our knowledge, such relationships have not been thoroughly examined in children yet.

NHANES provide multi-year data on both urinary BPA concentration and body composition measurements for children. Compared to other population-based data sources, NHANES data have several advantages, such as large sample size, stable and robust sampling strategies, and standardized laboratory techniques. The objective of this study was to investigate the association of urinary BPA levels with body composition in children using multi-year (2003–2006) NHANES data. DXA was used in NHANES to non-invasively estimate lean mass (excluding bone mineral content) and FM of the total body, trunk, arms, and legs. Compared with other methods, such as anthropometric measurements, bioelectrical impedance analysis, computed tomography, and MRI, DXA is accessible, easy to use, carries a low radiation exposure, and has good accuracy and reproducibility even under disease states and growing conditions. Because alterations of body composition occur differently between boys and girls, the abovementioned associations were examined separately by gender.

Methods

Study population

NHANES is a continuous surveillance program administered by the National Center for Health Statistics (NCHS), which is part of Centers for Disease Control and Prevention (CDC). Participants in NHANES received cross-sectional surveys and were sampled from civilian, non-institutionalized Americans using a stratified multi-stage probability design. The aim of NHANES is to assess the health and nutritional status of the general United States population for both children and adults. The research protocols for NHANES were approved by NCHS Institutional Review Board (IRB). Detailed information on the study designs and data collection procedures has been published elsewhere.

Urinary concentrations of BPA have been measured among representative subsamples of participants aged 6 years and older since the 2003–2004 NHANES. Whole-body DXA scans were administered for participants aged 8 years and older during the 1999–2006 survey years. These yielded our final sample of 1860 children aged 8–19 years old who were enrolled in cross-sectional surveys of the 2003–2006 NHANES and had complete data on both urinary BPA concentration and body composition measurements using DXA.

Urinary BPA

Urinary concentrations of free and conjugated BPA were measured at the Division of Environmental Health Laboratory Sciences (National Center for Environmental Health, CDC, Atlanta, Georgia, USA) using on-line solid phase extraction coupled to high-performance liquid chromatography and tandem mass spectrometry. Coefficients of variation for quality control urine samples at low and high concentrations were 19% and 15% in the 2003–2004 cycle and 16% and 15% in the 2005–2006 cycle. The lower limit of detection was 0.36 ng/mL in 2003–2004 and 0.4 ng/mL in 2005–2006. NHANES has assigned BPA concentrations below the level of detection with a value of 0.3 ng/mL. Due to a right-skewed distribution, urinary BPA concentrations were log-transformed, as well as being categorized into quartiles (Q1: 0.30 ng/mL to <1.50 ng/mL, Q2: 1.50 ng/mL to <3.17 ng/mL, Q3: 3.17 ng/mL to <6.06 ng/mL, and Q4: ≥6.06 ng/mL) to examine dose–response relationships.

Measurements of body composition by DXA

After urine specimen collection, DXA scans were conducted during the examination sessions on the same day. Participants aged 6 years or older at examination were eligible for DXA scans. Whole-body DXA scans were undertaken in the NHANES mobile examination centers using the Hologic QDR-4500A fan-beam densitometer (Hologic, Inc., Bedford, MA, USA) with Hologic software version 8.26.3a till mid-2005. The acquisition software was upgraded to Hologic Discovery v12.4 in 2005. Participants were excluded from DXA exams if they: 1) had a positive pregnancy test at the time of the examination; 2) stated that they were pregnant; 3) weighed over 300 lbs (136 kg); or 4) were taller than 6’5” (195 cm).

The QDR-4500A densitometers overestimated lean mass and underestimated FM by 5%. Therefore, NHANES decreased DXA lean mass by 5% and an equivalent weight (in kilograms) was added to the FM so that the total mass remained the same. To account for nonrandom missing DXA data, multiple imputation was performed by the National Center for Health Statistics (NCHS) to create five imputed data sets using a sequential regression multivariate imputation method. Detailed information on the rationale and methods for multiple imputation has been described in the NHANES DXA data file documents.

The percentage of body fat of each region and the total body was estimated using DXA scans. Fat mass index (FMI) and lean body mass index (LBMI) were calculated as FM (kg) or LBMI (kg), respectively, divided by the square of height (m). LBMI did not include bone mineral content. To facilitate comparisons of FMI and LBMI across age, gender, and race/ethnicity, FMI and LBMI z-scores were calculated based on a newly published fat and lean BMI distribution of the general United States population for both children and adults. The research protocols for NHANES were approved by NCHS Institutional Review Board (IRB). Detailed information on the study designs and data collection procedures has been published elsewhere.
reference curve for American children. Peripheral fat mass (kg) or lean body mass (kg) was estimated by summing up FM or LBMI from arms and legs. Trunk:peripheral fat ratio was calculated by dividing trunk fat mass (kg) by peripheral fat mass (kg).

Statistical methods

All analyses were weighted for the complex cluster sample design and conducted using Proc Survey in SAS Version 9.3 (SAS Institute, Cary, NC, USA). Distributions of selected demographic and lifestyle characteristics were described using unweighted frequencies and weighted proportions. Weighted means and standard errors of urinary BPA concentrations were calculated and compared across those demographic and lifestyle covariates.

Weighted means and standard errors of body composition measurements were calculated for the whole sample and compared by age and gender (i.e., 8–11 years old vs. 12–19 years old and boys vs. girls). The associations of urinary BPA concentration with body composition measurements were examined using multivariate linear regression models. Urinary BPA was categorized using weighted quartiles. Urinary BPA was also analyzed as a continuous variable using log-transformation. Body composition measurements were treated as continuous outcome variables.

Measurement of potential confounders that were adjusted for in linear regression models is described in supplementary material (Appendix 1). Linear regression models were fitted using 4-year waves of NHANES from 2003 to 2006. In order to investigate whether the associations of urinary BPA concentration and body composition measurements differed by gender, linear regression models were fitted separately for boys and girls.

All regression analyses were repeatedly performed for each of the five imputed data sets. Final results were generated by combining five sets of regression coefficients using Rubin's combining rules (SAS procedure: PROC MIANALYZE). p < 0.05 was considered to be statistically significant in all analyses.

Results

Urinary BPA concentration by selected demographic variables

A total of 1860 children participated in the 2003–2006 NHANES, donated urine samples, and completed DXA exams (Table 1). Approximately 67.5% of the participants were older than 12 years. Slightly more than half (51.5%) were boys. The weighted mean urinary BPA level was 5.61 ng/mL (standard error: 0.25 ng/mL). Although urinary BPA concentration did not significantly differ by age, gender, body weight status, caregiver’s education, family income:poverty ratio, or sedentary behaviors, BPA concentration varied statistically significantly by race/ethnicity, serum cotinine, and survey year (p < 0.05).

Comparisons of body composition measurements by age and gender

Body composition measurements are presented for all subjects and by age-sex subgroups in Table 2. Compared to the participants aged 8–11 years old, children 12–19 years of age had statistically significantly greater FM, LBMI, and trunk:peripheral fat ratio (p < 0.05). Younger children had statistically significantly greater FP of the arms, legs, and total body (p < 0.05).

Among 8–11 year olds, girls had significantly lower arm LBMI, but significantly greater trunk:peripheral fat ratio, and significantly greater total and regional FPs than boys (p < 0.05). Within the group of 12–19 year olds, girls had significantly lower LBMI, but significantly higher FM, and significantly greater total and regional FPs compared to their same-aged male counterparts (p < 0.05). FMI z-scores and LBMI z-scores did not significantly differ by age and gender (p > 0.05).

The associations between urinary BPA concentration and body composition measurements in boys

Body composition measurements are presented by quartiles of urinary BPA concentration for boys in Table 3. Using multiple linear regression analysis after controlling for demographic and lifestyle covariates, the trunk FM of boys in the second (β = 1.38, 95% CI, 0.32–2.43) and third (β = 1.03, 95% CI, 0.16–1.89) quartiles, but not in the highest quartile, were statistically significantly higher than that in the lowest quartile of urinary BPA concentration (p < 0.05). LBMI of all regions (arms, legs, and trunk) were ubiquitously significantly higher in the second and fourth quartiles compared to the lowest quartile of urinary BPA level (p < 0.05). Correspondingly, trunk:peripheral fat ratio was significantly greater in the second (β = 0.064, 95% CI, 0.025–0.103), third (β = 0.061, 95% CI, 0.027–0.094), and fourth (β = 0.041, 95% CI, 0.007–0.075) quartiles compared to the lowest quartile of urinary BPA concentration (p < 0.05). Neither FPs nor FMI z-scores were significantly associated with BPA concentration. However, LBMI z-scores were significantly higher in the second (β = 0.436, 95% CI, 0.137–0.735) and fourth (β = 0.406, 95% CI, 0.200–0.611) quartiles. Using log-transformed urinary BPA to substitute BPA quartiles, significantly positive associations were found between log-transformed urinary BPA levels and LBMI (β = 0.10, 95% CI, 0.02–0.17 for arms and β = 0.24, 95% CI, 0.02–0.45 for legs), and between LBMI z-score (β = 0.109, 95% CI, 0.030–0.188).

The associations between urinary BPA concentration and body composition measurements in girls

Table 4 shows changes in body composition measurements by quartiles of urinary BPA concentration in girls. After adjusting for demographic and lifestyle covariates, arm FM was significantly higher in the second (β = 0.24, 95% CI, 0.02–0.46) quartile than in the lowest quartile of urinary BPA concentration, and trunk FM was significantly greater in the second (β = 1.12, 95% CI, 0.15–2.09) and fourth (β = 1.32, 95% CI, 0.24–2.40) quartiles (p < 0.05). Trunk:peripheral fat ratio was significantly greater in the third (β = 0.049, 95% CI, 0.003–0.096) and fourth (β = 0.056, 95% CI, 0.011–0.102) quartiles compared to the lowest quartile of urinary BPA concentration (p < 0.05). FP of the arms, trunk, and total body was ubiquitously statistically significantly increased in the second and third quartiles (p < 0.05). Neither LBMI nor LBMI z-scores had statistically significant changes with elevated BPA concentration. However, FMI z-scores were significantly increased in the second (β = 0.294, 95% CI, 0.064–0.524), third (β = 0.295, 95% CI, 0.022–0.567), and fourth (β = 0.293, 95% CI, 0.037–0.549) quartiles. Similarly, log-transformed urinary BPA levels were positively associated with trunk FP (β = 0.81, 95% CI, 0.02–1.61) and FMI z-score (β = 0.090, 95% CI, 0.003–0.177).

Discussion

This study used a multi-year nationally representative sample of American children to examine the associations of urinary BPA concentration with body composition measurements, such as FM, LBMI, and body FP. To our knowledge, this may be the first study to investigate the associations in a large-scale population-based sample of young people. Moderate associations between high urinary BPA concentration (both quartiled and log-transformed) and body mass accumulation were identified using regression models, even after controlling for traditional demographic and lifestyle covariates. However, the contribution of urinary BPA concentration
to body weight was undertaken through different pathways between boys and girls. Specifically, high levels of urinary BPA concentration were statistically significantly associated with an increase in LBM among boys but an increase in FM among girls.

The “environmental obese gen hypothesis” proposes that exposure to environmental obesogenic chemicals may predispose some individuals to the development of obesity and associated health conditions, such as type 2 diabetes, CVDs, hypertension, and dyslipidemia. BPA is one of the most common obesogens, with the majority of daily exposure to BPA coming from our diet. As a synthetic estrogen, BPA could imitate the actions of estradiol and disrupt nuclear hormone receptor signaling pathways involved in adipogenesis, lipid metabolism, and energy balance.

No randomized controlled trials have been conducted to examine the associations between BPA exposure and obesity because of ethical concerns, while cross-sectional, case-control, and prospective epidemiological studies have provided mixed findings. Non-significant associations were found between birth weight of offspring and BPA concentration of mothers. A prospective cohort study of 297 mother-child pairs from the HOME Study found that prenatal and early-life exposure to BPA was not associated with an increase in BMI at 2–5 years of age. However, a number of other studies have reported significant associations between BPA levels and body weight (or BMI) in children, adults, and polycystic ovary syndrome patients.

BPA has been widely used in previous studies to measure adiposity of their subjects, which may partly explain such discrepancies. Trasande et al. analyzed the data of 2838 children aged 6–19 years from the 2003–2008 NHANES and observed positive associations between urinary BPA and BMI z-scores in both boys and girls. A study in eastern China found no difference in urinary BPA concentrations between normal weight and overweight/obese school children. Eng et al. examined children aged 6–18 years from the 2003–2010 NHANES and found that urinary BPA was significantly associated with obesity and waist circumference:height ratio but not associated with other chronic disease risk factors, including body FP. Although BMI is commonly used as a proxy for obesity, it has been noted that BMI does not distinguish between adipose tissue and lean mass and gives an imperfect estimate of body FP. Factors such as age, race/ethnicity, and physical activity may confound the relationship between BMI and adiposity status.

The major finding of this study is that we observed urinary BPA concentration differentially associated with body composition measurements between boys and girls aged 8–19 years old. Boys at higher levels of urinary BPA concentration had significantly greater LBM, reflected by LBM z-scores, while girls with higher BPA concentration had significantly greater FM, reflected by FM z-scores, as well as FP of the arms, trunk, and total body. It is unclear why BPA may “target” body compartments (i.e., fat and lean mass) differently in boys and girls. We speculate that the underlying mechanism may be related to different sex hormonal reactions to BPA exposure by gender. LBM growth is promoted by testosterone in boys. The data on the BPA association with testosterone concentration are scarce in boys. However, Galloway et al. examined the relationship between BPA excretion and sex hormone levels in Italian men. They found no association between urinary BPA concentration and 17β-estradiol but a highly significant association between BPA and total testosterone concentration, even after adjusting for covariates ($\beta = 0.046, 95\% CI, 0.015–0.076$). Increased FM in girls may be due to the estrogen-like effects of BPA. Girls with higher BPA concentration are more likely to develop early onset of puberty, which is usually concurrent with childhood obesity. Future research is needed to confirm this postulation and further examine the relationships between BPA exposure, sex hormone levels, and body composition changes.

Our results did not show an obvious dose–response relationship between urinary BPA concentration and body composition measurements in boys and girls. A large body of cell culture, animal, and epidemiological studies support this observation, and demonstrate low-dose effects and nonmonotonic dose–response curves of endocrine-disrupting chemicals (e.g., BPA) on adipose tissue. For instance, BPA suppressed adiponectin release from mature adipocytes of human tissue and showed a U-shaped relationship. In female mice, low-dose but not high-dose exposure to BPA increased adipose tissue weight and serum leptin concentrations, while low-dose but not high-dose BPA exposure increased serum triacylglycerol and glucose in male mice. Both children and adult epidemiological studies reported nonmonotonic associations between urinary BPA and obesity. The effects at low doses of BPA cannot be predicted by the effects at high doses. This may be explained by different endocrine-disrupting pathways that low-dose BPA activates via interfering with estrogen receptors, other nuclear and nonnuclear receptors, hormone metabolism, and epigenetic regulation.

Our data suggested a variation in locations of body composition changes that were related to BPA exposure. BPA-related LBM

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**Table 1**

| Characters                      | All $^a$ | Urinary bisphenol A level (ng/mL)$^b$ | $p$ value$^c$ | Mean (SE) |
|--------------------------------|---------|--------------------------------------|--------------|-----------|
| N                              | 1860    | 5.61 (0.25)                          | 0.116        |           |
| Age, years, n (%)              |         |                                      |              |           |
| 8–11                           | 448     | 6.43 (0.70)                          |              |           |
| 12–19                          | 1412    | 5.22 (0.20)                          |              |           |
| Sex, n (%)                     |         |                                      |              |           |
| Male                           | 950     | 6.04 (0.52)                          | 0.221        |           |
| Female                         | 910     | 5.16 (0.33)                          |              |           |
| Race/ethnicity, n (%)          |         |                                      | 0.001        |           |
| Non-Hispanic white             | 495     | 5.40 (0.33)                          |              |           |
| Non-Hispanic black             | 631     | 6.23 (0.42)                          |              |           |
| Mexican American               | 592     | 4.09 (0.33)                          |              |           |
| Other Hispanic                 | 50      | 7.11 (2.09)                          |              |           |
| Other                          | 92      | 8.00 (2.19)                          |              |           |
| Body weight status             |         |                                      | 0.445        |           |
| Underweight                    | 70      | 6.39 (1.00)                          |              |           |
| Normal weight                  | 1096    | 5.67 (0.39)                          |              |           |
| Overweight                     | 314     | 5.07 (0.41)                          |              |           |
| Obesity                        | 380     | 5.78 (0.44)                          |              |           |
| Caregiver education, n (%)     |         |                                      | 0.487        |           |
| Less than high school          | 572     | 5.21 (0.48)                          |              |           |
| High school, GED or equivalent | 418     | 5.97 (0.39)                          |              |           |
| More than high school          | 782     | 5.59 (0.39)                          |              |           |
| Family income:poverty ratio, n (%) |       |                                      | 0.419        |           |
| <1                             | 550     | 6.11 (0.36)                          |              |           |
| 1–4                            | 1065    | 5.59 (0.33)                          |              |           |
| ≥5                             | 171     | 4.96 (0.83)                          |              |           |
| Serum cotinine, ng/mL, n (%)   |         |                                      | 0.010        |           |
| Low to moderate (<2 ng/mL)     | 1433    | 5.02 (0.27)                          |              |           |
| High (≥2 ng/mL)                | 263     | 6.86 (0.53)                          |              |           |
| Television/video watching,     |         |                                      | 0.489        |           |
| hours/day, n (%)               |         |                                      |              |           |
| <2 h/day                       | 573     | 5.93 (0.53)                          |              |           |
| ≥2 h/day                       | 1242    | 5.48 (0.30)                          |              |           |
| Computer use, n (%)            |         |                                      | 0.270        |           |
| Non-use                        | 434     | 6.23 (0.51)                          |              |           |
| Use                            | 1380    | 5.50 (0.31)                          |              |           |
| Survey year, n (%)             |         |                                      | 0.037        |           |
| 2003–2004                      | 918     | 6.17 (0.18)                          |              |           |
| 2005–2006                      | 942     | 5.07 (0.47)                          |              |           |

GED, general equivalency diploma; SE, standard error.

$^a$ Unweighted frequencies and weighted proportions are presented.

$^b$ Weighted means and SE are presented.

$^c$ Survey linear regression models were used to compare urinary bisphenol A concentration for each of the selected demographic characteristics.

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and prospective epidemiological studies have provided mixed associations. Trasande et al. analyzed the data of 2838 children aged 6–19 years from the 2003–2008 NHANES and observed positive associations between urinary BPA and BMI z-scores in both boys and girls. A study in eastern China found no difference in urinary BPA concentrations between normal weight and overweight/obese school children. Eng et al. examined children aged 6–18 years from the 2003–2010 NHANES and found that urinary BPA was significantly associated with obesity and waist circumference: height ratio but not associated with other chronic disease risk factors, including body FP. Although BMI is commonly used as a proxy for obesity, it has been noted that BMI does not distinguish between adipose tissue and lean mass and gives an imperfect estimate of body FP. Factors such as age, race/ethnicity, and physical activity may confound the relationship between BMI and adiposity status.
Table 2
Body composition measurements of the study participants (8–19 years old), National Health and Nutrition Examination Survey (NHANES) 2003–2006.

|                  | All          | 8–11 years | 12–19 years | p value | 8–11 years | 12–19 years | p value |
|------------------|--------------|------------|-------------|---------|------------|-------------|---------|
| Lean body mass, kg |              |            |             |         |            |             |         |
| Arm              | 417.0 (0.07) | 2.68 (0.05)| 4.88 (0.07)| <0.001  | 2.77 (0.07)| 2.58 (0.05)| 0.030   |
| Leg              | 12.54 (0.17) | 8.29 (0.16)| 14.56 (0.17)| <0.001 | 8.41 (0.24)| 8.17 (0.17)| 0.382   |
| Trunk            | 18.01 (0.23) | 11.89 (0.22)| 20.92 (0.19)| <0.001 | 12.08 (0.33)| 11.70 (0.22)| 0.324   |
| Lean body mass, kg |              |            |             |         |            |             |         |
| Arm              | 2.01 (0.05)  | 1.51 (0.05)| 2.25 (0.06)| <0.001  | 1.44 (0.10)| 1.59 (0.06)| 0.207   |
| Leg              | 7.07 (0.15)  | 5.31 (0.16)| 7.91 (0.17)| <0.001  | 5.03 (0.27)| 5.61 (0.20)| 0.112   |
| Trunk            | 6.94 (0.19)  | 4.76 (0.19)| 7.98 (0.22)| <0.001  | 4.40 (0.32)| 5.15 (0.21)| 0.065   |

FBM, fat mass index; LBMI, lean body mass index; SE, standard error.
* Survey linear regression models were used to compare body composition measurements by age and gender.

Table 3
Associations between urinary bisphenol A concentration and body composition measurements among boys (8–19 years old), National Health and Nutrition Examination Survey (NHANES) 2003–2006.

| Concentration quartiles | Q1 (0.30 ng/mL to <1.50 ng/mL) | Q2 (1.50 ng/mL to <3.17 ng/mL) | Q3 (3.17 ng/mL to <6.06 ng/mL) | Q4 (>6.06 ng/mL) |
|-------------------------|---------------------------------|---------------------------------|---------------------------------|------------------|
|                         | Beta estimate | 95% CI             | Beta estimate | 95% CI             | Beta estimate | 95% CI             | Beta estimate | 95% CI             |
| Fat mass, kg            | Reference       |                   | Reference       |                   | Reference       |                   |
| Arm                     | 0.24             | -0.05 0.53        | 0.19             | -0.03 0.42        | 0.27             | -0.07 0.61        |
| Leg                     | 0.43             | -0.34 1.20        | 0.16             | -0.51 0.84        | 0.45             | -0.53 1.43        |
| Trunk                   | 1.38             | 0.32 2.43         | 1.03             | 0.16 1.89         | 1.21             | -0.07 2.50        |
| Lean body mass, kg      | Reference       |                   | Reference       |                   | Reference       |                   |
| Arm                     | 0.33             | 0.08 0.58        | 0.21             | 0.01 0.41        | 0.28             | 0.05 0.50        |
| Leg                     | 0.67             | 0.04 1.31        | 0.51             | -0.06 1.08        | 0.75             | 0.14 1.38        |
| Trunk                   | 1.23             | 0.22 2.24        | 0.65             | -0.13 1.43        | 0.95             | 0.11 1.78        |
| Lean body mass, kg      | Reference       |                   | Reference       |                   | Reference       |                   |
| Arm                     | 0.27             | -2.16 2.69       | -0.06             | -2.13 2.00        | 0.14             | -2.58 2.86        |
| Leg                     | 0.16             | -1.75 2.08       | -0.62             | -2.51 1.27        | -0.40            | -2.73 1.52        |
| Trunk                   | 1.61             | -0.42 3.64       | 1.12             | -0.63 2.88        | 1.04             | -1.42 3.49        |
| Total body fat percentage | Reference     |                   | Reference       |                   | Reference       |                   |
| FMI z-score             | 0.155            | -0.095 0.405  | 0.013            | -0.218 0.245  | 0.072            | -0.200 0.344  |
| LBMI z-score            | 0.436            | 0.157 0.735   | 0.213            | -0.039 0.464  | 0.406            | 0.200 0.611  |

The significance level is p < 0.05.
* Survey linear regression models were adjusted for age (months), ethnicity/race, height, caregiver’s education, family income:poverty ratio, serum cotinine level, daily calorie intake, television/video watching, computer use, survey year, and urinary creatinine (log-transformed).
Table 4
Associations between urinary bisphenol A concentration and body composition measurements among girls (8–19 years old), National Health and Nutrition Examination Survey (NHANES) 2003–2006.

| Concentration quartiles | Beta estimate | 95% CI |
|-------------------------|---------------|--------|
| Q1 (0.30 ng/mL to <1.50 ng/mL) | 0.24 | 0.02 0.46 |
| Q2 (1.50 ng/mL to <3.17 ng/mL) | 0.21 | -0.05 0.47 |
| Q3 (3.17 ng/mL to <6.06 ng/mL) | 0.27 | -0.01 0.55 |
| Q4 (> 6.06 ng/mL) | 0.09 | -0.02 0.19 |

Fat mass, kg

| Component | Beta estimate | 95% CI |
|-----------|---------------|--------|
| Arm | Reference | 0.02 0.19 |
| Leg | Reference | 0.02 0.19 |
| Trunk | Reference | 0.02 0.19 |

Lean body mass, kg

| Component | Beta estimate | 95% CI |
|-----------|---------------|--------|
| Arm | Reference | 0.02 0.19 |
| Leg | Reference | 0.02 0.19 |
| Trunk | Reference | 0.02 0.19 |

Trunk:peripheral fat ratio

| Component | Beta estimate | 95% CI |
|-----------|---------------|--------|
| Arm | Reference | 0.02 0.19 |
| Leg | Reference | 0.02 0.19 |
| Trunk | Reference | 0.02 0.19 |

Fat percentage

| Component | Beta estimate | 95% CI |
|-----------|---------------|--------|
| Arm | Reference | 0.02 0.19 |
| Leg | Reference | 0.02 0.19 |
| Trunk | Reference | 0.02 0.19 |

Total body fat percentage

| Component | Beta estimate | 95% CI |
|-----------|---------------|--------|
| Arm | Reference | 0.02 0.19 |
| Leg | Reference | 0.02 0.19 |
| Trunk | Reference | 0.02 0.19 |

BMI z-score

| Component | Beta estimate | 95% CI |
|-----------|---------------|--------|
| Arm | Reference | 0.02 0.19 |
| Leg | Reference | 0.02 0.19 |
| Trunk | Reference | 0.02 0.19 |

The significance level is p < 0.05.

BPA, bisphenol A; CI, confidence interval; FMI, fat mass index; LBMI, lean body mass index.

Survey linear regression models were adjusted for age (months), ethnicity/race, height, caregiver’s education, family income:poverty ratio, serum cotinine level, daily calorie intake, television/video watching, computer use, survey year, and urinary creatinine (log-transformed).

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Appendix A. Supplementary data

Non-circulating data related to this article can be found at http://dx.doi.org/10.1016/j.je.2016.12.001.

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Conflicts of interest

None declared.

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