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Urinary Levels of BPA in Pregnant African American Women in Atlanta

By

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Master in Public Health

Environmental Health

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B.S., Emory University, 2018

Thesis Committee Chair: P. Barry Ryan, PhD
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An abstract of
A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
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Abstract

Urinary Levels of BPA in Pregnant African American Women in Atlanta

By Anisha Verma

BPA is an organic synthetic compound that is commonly found in many household products such as plastic bottles, personal care products, the inner lining of food and beverage cans, dental sealants, and cigarette filters. Due to the widespread number of plastics containing BPA, exposure to BPA is ubiquitous. Ninety-five percent of tested individuals in the United States have detectable levels of BPA in their urine. Despite ongoing and published research regarding the endocrine-disrupting properties of BPA, more research is needed to evaluate the effects BPA can have on pregnant women. Exposure to BPA has the potential to cause morphologic and functional alternations by influencing growth, reproduction, and development. Objectives of this study were to characterize urinary BPA levels in pregnant Atlanta-area African American women and compare to the population averages using data from the National Health and Nutrition Examination Survey (NHANES) cycle 2013-2014 and to evaluate predictors of urinary BPA levels in pregnant African American women in Atlanta. These data are part of a larger analysis to determine the role of BPA in preterm birth. Urine samples were collected on three occasions from 175 pregnant women at two hospitals in Atlanta. During the second home visit, study participants provided information on their diets and lifestyles. Tobacco, hair product and relaxer use, and bottled beverage consumption were indicators of higher BPA levels. Consumption of canned food showed no clear association with BPA levels. Higher BPA levels in the non-Hispanic black population can be attributed to cosmetic product use or to easy access of canned food in primarily black neighborhoods. This study has many implications for future research, such as evaluating other potential sources of BPA exposure, including exposure from occupation, the environment, and consumer products.

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I would also like to thank my advisors, Dana Boyd Barr and P. Barry Ryan, for allowing me an opportunity to learn more about the many health impacts environmental exposures can have on various populations. I could not have picked a more perfect culminating experience to conclude my time in the Environmental Health department. My sincerest gratitude is owed to Mitch Klein, who helped me tremendously with data analysis.

Finally, I want to express my greatest gratitude to my family, my sister, Ankita, and specifically, to my parents. I owe all of my success to the constant support, uplifting, and laughs you all provide to me each day.

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Background

Humans are constantly exposed to a variety of chemicals and products that can have negative impacts on their health. Of these, bisphenol A (BPA) is of special concern due to its widespread presence in consumer products. BPA is an organic synthetic compound that is commonly found in many household products such as plastic bottles, personal care products, the inner lining of food and beverage cans, dental sealants, and cigarette filters (Le et al., 2008; vom Saal and Hughes, 2005; Shankar and Teppala, 2011). Due to the widespread number of plastics containing BPA, exposure to BPA is ubiquitous. Ninety-five percent of tested individuals in the United States have detectable levels of BPA in their urine (Calafat et al., 2008). BPA in polycarbonate drinking bottles can migrate from the bottles into the liquids it contains and can subsequently be a contributing source to the total burden of endocrine disruptor chemicals (EDC) to which individuals are exposed. Moreover, elevated temperatures can increase BPA migration (Le et al., 2008). Migrating from items made from synthetic polymers, BPA is also found in dust. Therefore, individuals can also be exposed to BPA through dust inhalation. However, exposure to BPA from ingestion of canned food and bottled water is far greater than exposure to BPA through dust inhalation (Braun et al., 2011). In addition, building workers or workers employed at factories of BPA and epoxy resins synthesis may also be exposed to BPA through inhalation and dermal contact (Michalowicz 2014).

The main route of human exposure to BPA is through dietary ingestion. BPA is rapidly metabolized via hydrolysis and oxidation/elimination followed by glucuronidation and is subsequently excreted in urine (Stahlhut 2009; Nelson et al., 2012). Due to the quick metabolism of BPA, its pharmacokinetic properties, and individual lifestyles and behaviors, BPA concentrations do not show strong correlations over 1-6 months (Braun et al., 2011). Formerly

considered to have a short biological half-life of 5.4 hours, recent research suggests the half-life of BPA is longer than expected (Stahlhut 2009; Rubin 2011). In analyses that consider fasting times in relation to BPA levels as measured in urine, an inverse correlation was expected but not shown. This evidence suggests long-term storage of BPA in adipose while implying ingestion may not be the sole route of exposure. Other than ingestion, it is possible that humans are exposed to BPA through dermal contact and inhalation (Rubin 2011).

BPA metabolites are completely recovered in urine 24 hours after oral exposure. However, metabolism of orally ingested BPA provides no insight on long-term intake (Dekant and Volkel, 2007). Additionally, BPA levels as measured in urine do not yield information of BPA that is potentially stored in the body (Rubin 2011). With new data exemplifying other sources and routes of exposure, it is important to consider the implications of non-dietary sources. First-pass metabolism is lacking through inhalation and dermal contact, therefore implying that these routes of exposure may be of greater toxicological relevance due to the absence of toxicological reduction before entering systemic circulation (Martinez et al., 2018).

As an endocrine disrupting chemical, BPA mimics the body's hormones and can have other adverse effects on human health. There are many health effects that have been linked to BPA exposure. BPA interrupts normal cell function, serves as an estrogen agonist and androgen antagonist, can be toxic to the liver, decreases sperm count and sperm activity, and can be carcinogenic as a precursor to breast cancer (Huang et al., 2011). Moreover, BPA exposure can contribute to obesity development and hypertension (Michalowicz 2014; Shankar and Teppala 2011). The ubiquitous nature of BPA not only calls for researchers to discover the negative health impacts it can have on vulnerable populations, but also implicates BPA as a public health concern (Huang 2011).

BPA is ubiquitous throughout populations. Yet, more research is needed to evaluate the effect BPA can have on pregnant women (Pergialiotis et al., 2018). It is important to evaluate predictors of BPA exposure as well as behaviors and lifestyles that could result in higher levels of BPA exposure as measured in urine. A study conducted by Braun et al. (2011) measured predictors of BPA levels of pregnant women over three visits during pregnancy. BPA concentrations were nearly identical among women who attended all three visits. Additionally, demographic factors did not affect BPA concentrations, with the exception of higher BPA levels in women with lower education. Moreover, prenatal BPA concentrations were higher among women who were cashiers and lowest among women who worked in teaching and industrial occupations. Canned vegetable consumption was positively associated with urinary BPA concentrations. Adjusting all values for socioeconomic status did not cause a significant change in the values between environmental factors and BPA levels. This study shows that it is necessary to conduct more research into the predictors of BPA exposure in pregnant women and that the collection times of urine samples must be considered during data analysis due to rapid metabolism and excretion of BPA.

Another study conducted by Gerona et al. (2016) showed near universal BPA exposure in a study of women in their second trimester of pregnancy. Although this study showed highest levels of BPA in the highest income bracket, the study involved predominantly low-income women. Additionally, in contrast to previous studies, Gerona et al. found the lowest levels of BPA in African American women as compared to Hispanic women. This could be attributed to the lack of ethnic and racial variability in the study sample. Both studies found that women in occupations handling thermal paper had higher BPA levels (Gerona et al., 2016; Braun et al., 2011). In addition to these findings, the National Toxicology Program 2017 Annual Report states

that workers who handle raw BPA are exposed to BPA by inhalation and absorption through the skin. In fact, BPA levels in these workers were about seventy times higher than the general US population (Braun et al., 2011).

Introduction

Worldwide exposure to BPA in pregnant women has led scientists to research BPA and its potential for disrupting endocrine systems. Epidemiological studies have shown that these endocrine disruptors, along with other environmental chemicals, may have the potential to negatively modify sex and thyroid hormone levels in pregnant women (Huang 2011). Moreover, exposure to BPA has the potential to alter circulating vitamin D levels. This is of concern because vitamin D regulates functions in female reproductive and pregnancy outcomes (Johns et al., 2017).

Exposure to BPA *in utero* has the potential to cause morphologic and functional alterations in humans. Endocrine disruptors can cause abnormalities by influencing growth, reproduction, and development. The human placenta does not serve as an effective barrier to BPA. (Schonfelder et al., 2002). Therefore, BPA can easily migrate from maternal blood to the fetus (Pergialiotis et al., 2018). This is concerning because interactions between BPA and the embryo during pregnancy can exert noxious effects on the fetus. Moreover, fetuses are more susceptible to the harmful effects of BPA than adults, and potential for harm to fetuses are considered more likely than harm to adults (Michalowicz 2014; Stahlhut et al., 2009). It is certain that BPA migrates from maternal blood to the fetus, as detectable levels have been measured in placental and amniotic fluids, proving that exposure to BPA begins *in utero* (Valvi, 2013).

In one study, Cantonwine et al. (2010) reported an association between higher levels of BPA, premature delivery, and shorter gestation time. This study included a population of twelve Mexican women in their third trimester of pregnancy. A significant association was found between elevated total BPA and premature delivery (<37 weeks). To increase sample size, researchers found a trend toward significance ($p<0.08$) when including women who delivered at 37 weeks (Rochester 2013).

Moreover, a study conducted by Shankar and Teppala (2012) analyzed a large, multiethnic, and representative sample of US adults. They found that individuals with high BPA levels were more likely to have high blood pressure. These results were independent of related confounding factors such as smoking, BMI, alcohol intake, diabetes, and serum cholesterol. Hypertension due to elevated urinary BPA levels could cause and result in preterm birth, as well (Shankar and Teppala, 2012). Exposure to BPA can also cause dose-dependent cell death of human primary cytotrophoblasts (CTB) after 24 hours of exposure. Trophoblast proliferation is essential to placental development. Therefore, failure or deficiencies in trophoblast proliferation may lead to preterm birth (Benachour and Aris, 2009).

Exposure to BPA during pregnancy requires more research to truly understand the effects on fetal development. The hormone-like actions of BPA pose a greater threat and concern to exposure during pregnancy. In fact, animal studies have repeatedly shown that exposure to BPA *in utero* has the potential to modify a variety of organ systems (Gerona 2016).

Data evaluating the impact of BPA during pregnancy is scarce and conflicting. For example, research analyzing impacts of BPA on neonatal birthweight are not clearly understood and have reported controversial findings. However, some studies suggest that high urinary BPA levels tend to increase incidence of preterm birth in women (Pergialiotis et al., 2018). Despite the

research that has already been conducted regarding associations between urinary BPA levels and pregnancy, specifically preterm birth, it is difficult to find consistent significant associations between urinary BPA concentrations and premature birth in the literature. Therefore, more research is needed to establish the relationship between elevated urinary BPA levels and preterm birth (Cantonwine et al., 2015).

To learn which behaviors and lifestyles contributed to elevated BPA levels, we measured urinary BPA levels in a socio-economically diverse cohort of pregnant African American women in Atlanta over three visits. The aims of this study were to characterize urinary BPA levels in pregnant Atlanta-area African American women and compare to the population averages using data from the National Health and Nutrition Examination Survey (NHANES) cycle 2013-2014 and to evaluate predictors of urinary BPA levels in pregnant African American women in Atlanta.

Methods

Urine samples were collected from 175 pregnant African American women who planned to deliver at Grady Hospital (N=103) and Emory University Hospital – Midtown (N=66) in Atlanta, Georgia. Urine samples were collected at three different time points throughout pregnancy; at 8-14 weeks, 20-24 weeks, and 24-30 weeks. The second visit was conducted at the participant's home, while the first and third biological samples were collected at their respective delivery hospitals. During the home visit, trained individuals administered a survey in which researchers were able to obtain data about dietary lifestyles and behaviors of study participants. Study participants were able to provide information about frequency of canned food, canned

meat, fresh food, and bottled beverages consumption. Study participants also provided information on hair product and relaxer use.

Associations between urinary BPA concentrations and demographic, education, income, age, and dietary data were evaluated. Information on lifestyle and behavior data were taken from the survey during the second home visit, while urine samples were used to measure BPA concentrations. Demographic factors included were maternal age, marital status, maternal education, and household income. Marital status was designated as either married or unmarried and income was hierarchically classified as percentages of the Georgia poverty level. These data were collected as a part of the Center for Children's Health, the Environment, the Microbiome and Metabolomics (C-CHEM^2) as part of a larger research project determining whether elevated levels of BPA lead to preterm birth in African American women. Across the data, demographic and lifestyle characteristics of all study participants with creatinine-corrected BPA measurements were assessed to determine differences of urinary BPA levels between women using intraclass correlation coefficients and generalized linear models suitable for repeated subjects with exchangeable working correlation structure. BPA measurements were log-transformed to assume normal distribution and values below the limit of detection were not considered in analysis. Data were analyzed using SAS 9.4.

Results

Analysis was performed on individuals who had at least one BPA measurement corrected by creatinine in combination with available survey data, as well. In total, 150 individuals had creatinine-corrected BPA measurements. Only 5 individuals had measurements for all three visits, 22 had measurements for two visits, and 123 had a corrected BPA measurement from one

visit. Creatinine-corrected BPA values had similar values between women who only had one measurement (Mean=1.27E-04; STD = 2.26E-04), two measurements (Mean=1.11E-04; STD = 9.04E-05), and three measurements (Mean = 1.75E-04; STD = 2.10E-04).

Prenatal urine samples were collected at two hospital visits and one home visit. The first hospital visit occurred at 8-14 weeks of pregnancy, the home visit occurred at 20-24 weeks of pregnancy, and the second hospital visit occurred at 28-30 weeks of pregnancy. There was no significant difference between the corrected BPA measurements between Grady Hospital and Emory University Hospital - Midtown (p=0.9306). Therefore, measurements from both hospitals were not distinguished during analysis. Detectable levels of BPA were found in 94% of individuals from the first hospital visit, in 88% from the second hospital visit, and in 90% of the home visit (Figure 1).

Intraclass correlation coefficients (ICC) for creatinine, corrected BPA measurements, and serial BPA measurements did not show consistent reproducibility across the three measurements (Table 3). However, the ICC of creatinine-corrected BPA values was 0.7974 (p<0.0001), representing high reproducibility within the population of women who had creatinine-corrected BPA measurements. The ICC of serial urinary concentrations was 0.1392 (p=0.0407) and the ICC of creatinine concentrations was 0.2927 (p=0.0172).

All analysis was conducted on BPA measurements corrected by creatinine across demographic factors and information provided by at-home surveys. BPA did not significantly vary between various education levels, although those who completed some graduate work or degree had lower levels of BPA than those who completed less schooling. Marital status, either married or unmarried, did not affect corrected urinary BPA measurements. Income was measured as percentages below and above the poverty level. Overall, higher incomes were

associated with higher levels of BPA. Lastly, levels of creatinine-corrected BPA did not vary by age. Younger (age 18-25) and older (age 31-40) women had similar levels of BPA as women between the ages of 26 and 30 (Table 1).

Hair product use was positively associated with higher levels of BPA. Women who used hair products daily had BPA levels 92% higher than women who never used hair products. A similar trend was seen with hair relaxer use, although the association is less clear with hair relaxer than hair products. Women who use hair relaxer daily and weekly had 19% and 8% higher levels of BPA, respectively, than those who never utilized hair relaxers. Tobacco use was also an indicator of higher BPA levels, as corrected BPA levels were 19% higher in women who used tobacco than those who did not (Table 2).

Similar to hair product use and tobacco, food and beverage consumption impacted levels of BPA, as well. Women who consumed more than sixteen cups of bottled water in the past 48 hours had BPA levels 68% higher than women who consumed no bottled water in the past 48 hours. These results do not show a consistent association between BPA levels and bottled water. However, women consuming 1-5 cups or 6-10 cups of bottled beverages had BPA levels 24% and 40% higher, respectively, than women who consumed no bottled beverages in the past 48 hours (Table 2).

Food consumption, whether fresh or canned, showed mild associations with corrected BPA levels. Women who consumed 6-10 servings of fresh fruit and vegetable servings in the past 48 hours had lower levels of BPA than women who had no fruit and vegetable servings. Frequency of canned food consumption and canned food consumption in the past 48 hours showed no variance. In fact, those who rarely consumed canned food had similar urinary BPA levels as those who ate canned food 2-3 times per week or every day. Similar results were seen

with canned meat consumption in the past 48 hours. Women who did not consume any canned meat in the past 48 hours had urinary BPA levels 6% higher than those who had 1-5 servings (Table 2).

Discussion

Survey data allowed women to provide information on behaviors and lifestyles that may be predictors of high urinary BPA levels. Moreover, creatinine-corrected BPA levels combined with surveys were analyzed to determine whether patterns are distinguishable among different behaviors and lifestyles. Serial urinary BPA levels and corrected BPA levels had low reproducibility and high variability. Therefore, clear correlations between BPA levels and demographic data were not observed in many cases. However, tobacco, hair product and relaxer use, and bottled beverage consumption were indicators of higher BPA levels. Consumption of canned food showed no clear association with BPA levels.

The differences of ICCs between serial BPA measurements, creatinine, and corrected BPA measurements could be attributed to the time of urine collection, diet, and other lifestyles and behaviors influencing BPA levels. It is not uncommon for ICCs of BPA to be low, and varying reproducibility has been calculated in other studies, as well. However, the calculated ICCs for uncorrected BPA levels differ from results of previous studies. In one study, Braun et al. (2013) reported an ICC of BPA as 0.12 among pregnant women. In another study, the reported ICC of BPA was 0.11. Serial urinary concentrations for this study were also taken during pregnancy. (Braun, 2011). Another study showed the ICC of BPA as 0.31 after correcting by creatinine (Jusko et al., 2014). Due to the rapid metabolism and excretion of BPA, the time of the urine sample in relation to previously consumed meals may be of importance and provide

useful information on long-term storage of BPA. Closely monitoring these data can also be used to determine BPA variability within women, among women, and between visits. If significant within-person variability exists, it may be indicative of physiological changes that are impacting absorption, distribution, metabolism, or concentration of BPA during pregnancy (Braun et al., 2012).

Many other studies have reported a positive correlation between tobacco use and BPA levels. These findings are not surprising, as up to 25 percent of cigarette filters are made from products containing BPA (Jackson and Darnell, 1985). Among the assessed demographic factors, only education and income seemed to have any association with BPA level. There was no direct linear relationship between BPA level and education. A study conducted by Braun et al. (2011) measured predictors of subsequent BPA levels of pregnant women over three visits during pregnancy. Similar to our study, demographic factors did not affect BPA concentrations, with the exception of higher BPA levels in women with lower education than higher. Although corrected BPA levels did not steadily increase as years of education increased, those who completed less schooling than some graduate work or degree had higher levels of urinary BPA. Marital status did not affect levels of BPA. Women who were married had very similar levels of BPA as those who were not. However, 92% of study participants were unmarried.

Studies examining the relationship between income and BPA levels have shown varying results. One study in San Francisco, California showed highest levels of BPA in the highest income bracket. However, this study involved predominantly low-income women; 50% of study participants had a total household income below $40,000/year. Therefore, this study may not have been indicative of a true comparison between BPA levels across various incomes. Another study in China showed that higher BPA levels were found in individuals with higher levels of

education. Although this study did not specifically use income as a demographic factor, researchers assumed that household income was directly and positively correlated with education level. Results showed higher non-creatinine-adjusted BPA levels in study participants with the highest education level, and therefore, the highest income, as well (He et al., 2009). A study in the Netherlands found similar results. Women in a higher income bracket had elevated levels of urinary BPA and phthalate metabolites. This was attributed to a greater use of personal care products within high-income individuals, as these products may contain BPA and phthalates (Ye et al., 2008).

Concentrations of BPA can change based on socioeconomic position (SEP), as SEP can serve as a mechanism of many activities, behaviors, or circumstances that may underlie differences (Nelson et al., 2012). Nelson et al. (2012) found that urinary BPA concentrations were inversely related to income, with the lowest quartile of adjusted family income having BPA concentrations 27% higher than the highest income quartile. The National Health and Examination Survey showed that least square geometric means of those in the low household income category were higher than individuals in the high household income category. (Calafat et al., 2008). It is clear that BPA levels vary by income. However, there are many factors and habits that are influenced by income that may contribute to higher or lower levels of BPA.

Forty-three percent of study participants with creatinine-corrected data had a total household income below the poverty level. Financial constraints can also affect the type of food individuals consume. Affordable foods for low-income individuals primarily include canned foods, which can offer high nutrient density at low cost (Drewnowski and Eichelsdoerfer, 2010). Therefore, both income and food consumption can impact urinary BPA levels in women.

Our study found no significant association with urinary BPA levels and canned food. Women who consumed more fresh fruit and vegetables in the last 48 hours had lower levels of urinary BPA than those who did not consume any servings. Lower levels of BPA in these individuals may be attributed to an absence of canned food consumption. BPA is present in the inner lining of canned foods and can migrate into the food. A study in Canada has shown that canned tuna had the highest level of BPA, followed by canned soups (Cao et al., 2010). This association might explain higher levels of BPA in study participants who consumed more canned meats in our study population.

There was a positive association between urinary BPA levels and bottled beverages. Women who consumed 1-5 cups, 11-16 cups, and more than 16 cups of bottled water had higher levels of BPA than those who consumed no bottled water. This is supported by recent literature claiming the primary route of exposure to BPA is through ingestion of contaminated foods and beverages (Le et al., 2008; Braun et al., 2011). Moreover, BPA can migrate from consumer plastics under conditions of normal use, thus implying individuals consuming more bottled and canned foods will have higher levels of BPA (Vandenberg et al., 2007; Le at al., 2008).

Levels of BPA as measured in urine are also different when measured across race. According to the 2013-2014 National Health and Nutrition Examination Survey, concentrations of BPA are significantly lower in Mexican Americans (2.3 μg/L) than in non-Hispanic blacks (3.0 μg/L) and non-Hispanic whites (2.7 μg/L) (Calafat et al., 2008). Urinary BPA levels in pregnant African American women in Atlanta are higher than those of the US non-Hispanic white populations and lower than the non-Hispanic black populations as presented in the Fourth National Report on Human Exposure to Environmental Chemicals from the survey years of 2013-2014. The population averages for the US non-Hispanic white population and the US non-

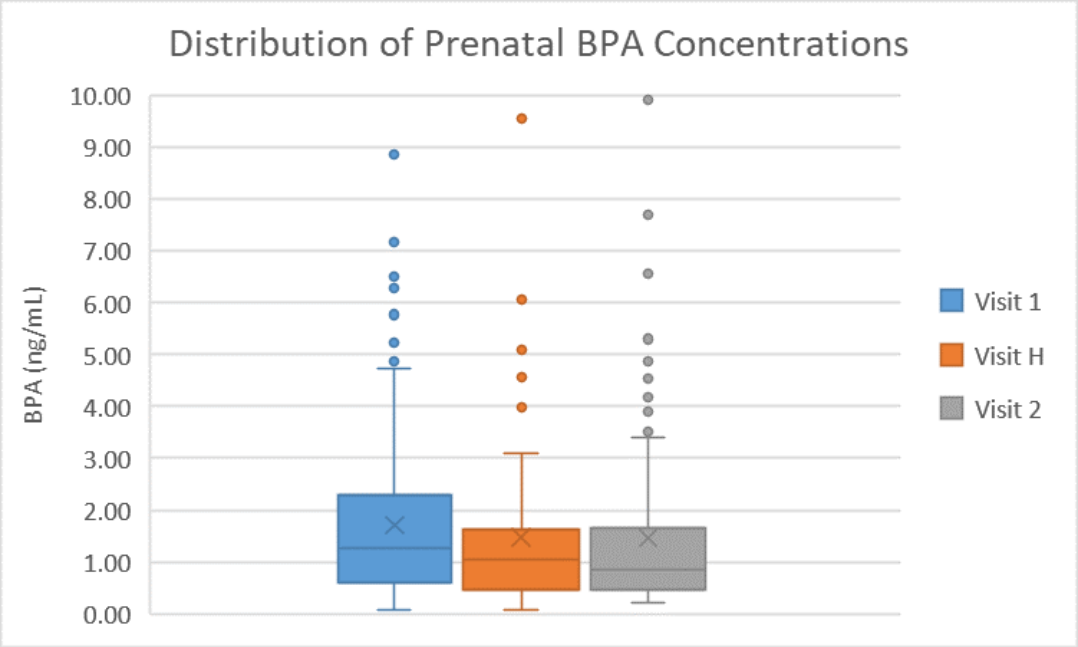
Hispanic black population are 1.22 μg/L and 1.83 μg/L, respectively. The population average from our study is 1.31 μg/L (Figure 2). Higher levels in the non-Hispanic black population can be attributed to many factors, such as cosmetic products. BPA is present in cosmetic products that are specifically tailored for African American women. Beltifa et al. (2018) tested cosmetic products for a variety of plasticizers and BPA. Researchers reported that BPA was found in all samples of face and body moisturizers, and banned BPA residues were detected in 66 percent of skin moisturizer samples. In another study, researchers tested eighteen hair products for endocrine disrupting chemicals. The hair products tested positive for 45 endocrine disrupting chemicals (EDC), including BPA. Use of these hair products differ by race and ethnicity which may contribute to disparities of BPA exposure. EDCs, such as BPA, within personal care products used primarily by black women may be a contributing factor to elevated BPA levels within the black population (Helm 2018). Our findings showed similar results. Women who used hair products daily had higher level of creatinine-corrected BPA than those with sparser usage. The association between BPA levels and hair relaxer use was less direct. Women who used hair relaxer daily and weekly had higher BPA levels than those who never use it. However, 74% of individuals with creatinine-corrected BPA values never or only occasionally used hair relaxers.

Consumption of canned food was prevalent among 64 percent of women in this study with corrected-BPA values. Morland and Filomena (2007) reported that availability of fresh produce is reliant on the racial composition of neighborhoods. Neighborhoods with predominantly white populations have a wider selection of fresh produce, as well as greater availability. Moreover, canned produce and foods are available in a larger proportion in black areas than other neighborhoods. Abundance and selection of fresh produce can be determined by neighborhood racial composition, which may contribute to higher BPA levels found within black

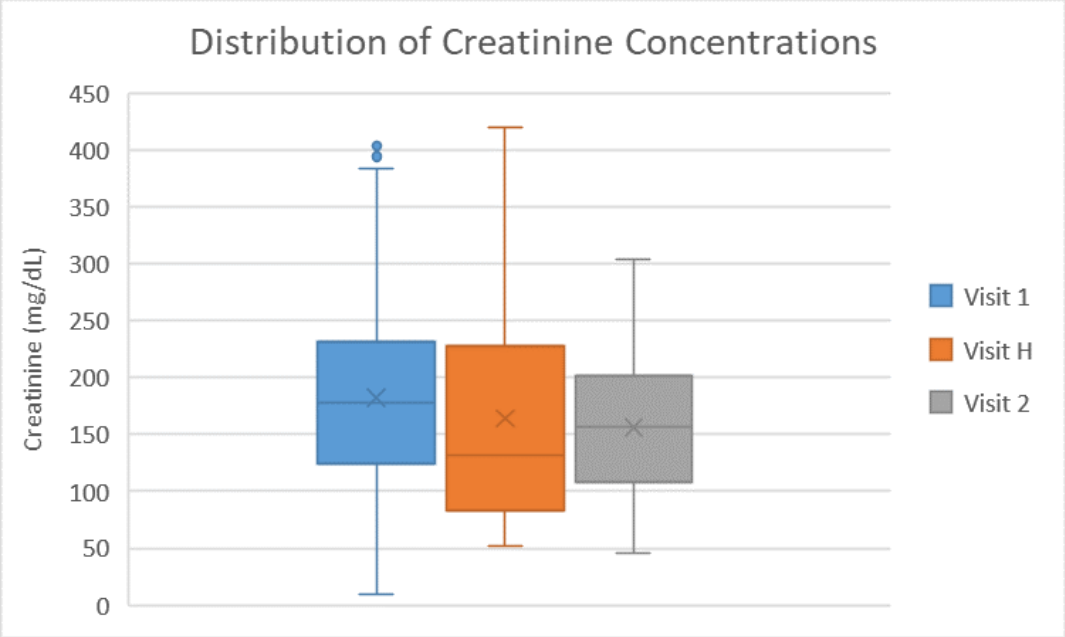
women in the United States (Morland and Filomena, 2007). This demonstrates that access to fresh food may be determined by neighborhood and race.

The results in this study have many implications for future research. Averages of BPA levels in this cohort study were higher than the average of US non-Hispanic whites, but lower than the NHANES population of non-Hispanic blacks (Figure 2). Additional research is required to assess the impact EDCs can have on pregnancy and fetuses *in utero.* Future studies should also record time of urine collection and the effects fasting can have on BPA levels due to rapid metabolization and excretion (Braun et al., 2011). Therefore, time of urine collection should be standardized to reduce variability of BPA levels. Lastly, future research should evaluate various potential sources of EPA exposure, including exposure from occupation, the environment, and consumer products.

a.


Distribution of Prenatal BPA Concentrations
BPA (ng/mL)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Visit 1
Visit H
Visit 2

b.


Distribution of Creatinine Concentrations
Creatinine (mg/dL)
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400
350
300
250
200
150
100
50
0
Visit 1
Visit H
Visit 2

c.

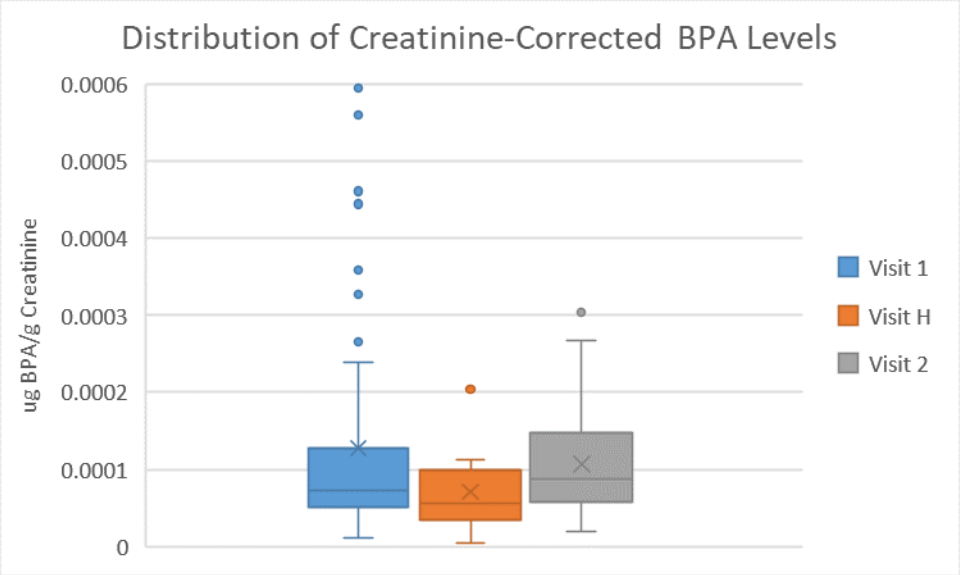

Figure 1. Distribution of prenatal BPA (a), creatinine concentrations (b), and creatinine-corrected BPA (c). The box represents the interquartile range and the middle line represents the median value. Xs within plots represent mean values. Black tick marks represent minimum and maximum values and circles above and below tick marks represent outliers.

Table 1. Urinary BPA concentrations (μg BPA/g creatinine) according to demographic and maternal factors.

Variable	n (%)	Mean (SD)	Ratio (95% CI)	P-value
Education				
Some high school	47 (27)	7.61E-5 (6.76E-5)	1.3327 (0.94-1.88)	0.1032
Graduated high school or GED	69 (40)	1.38E-4 (2.31E-4)	1.2104 (0.86-1.70)	0.2731
Some college or technical school	39 (22)	1.05E-4 (1.17E-4)	1.3395 (0.86-2.08)	0.1935
Graduated college	10 (6)	9.92E-5 (8.17E-5)	1.3988 (0.78-2.49)	0.2551
Some graduate work or degree	9 (5)	0.00014 (1.82E-4)	Reference	Reference
Marital Status				
Married	12 (8)	1.24E-4 (1.55E-4)	1.0059 (0.60-1.67)	0.9819
Unmarried	137 (92)	1.27E-4 (2.14E-4)	Reference	Reference
Income (per year)				
<100%	64 (43)	1.17E-4(1.79E-4)	0.9088 (0.44-1.86)	0.7934
100-132%	29 (20)	1.15E-4(1.32E-4)	0.9077 (0.43-1.92)	0.7993
133-149%	13 (9)	7.78E-5(3.48E-5)	0.7388 (0.35-1.55)	0.4219
150-199%	24 (16)	8.57E-5(5.30E-5)	0.8186 (0.40-1.69)	0.5876
200-299%	3 (2)	4.55E-4(6.58E-4)	2.14 (0.38-12.13)	0.3906
300-399%	8 (5)	8.05E-5(4.28E-5)	0.7743 (0.35-1.71)	0.5268
400 or greater	8 (5)	1.70E-4 (1.99E-4)	Reference	Reference
Age				
18-25	97	1.26E-04(2.36E-04)	1.0500 (0.72-1.53)	0.8007
26-30	25	1.10E-04(1.19E-04)	Reference	Reference
31-40	27	1.45E-04(1.75E-04)	1.2222 (0.79-1.89)	0.3692

Table 2. Creatinine-corrected BPA levels according to lifestyles and behaviors.

Variable	n (%)	Mean (SE)	Ratio (95% CI)	P-value
Hair Relax Use				
Never	22 (30)	8.91E-5 (6.49E-5)	Reference	Reference
Occasionally	33 (44)	9.79E-5 (1.09E-4)	0.9271 (0.61-1.42)	0.7258
Weekly	11 (15)	1.02E-4 (5.19E-5)	1.1926 (0.74-1.91)	0.4634
Monthly	6 (8)	6.26E-5 (1.93E-5)	0.8001 (0.52-1.23)	0.3115
Daily	2 (3)	8.72E-5 (3.51E-5)	1.0808 (0.68-1.17)	0.74
Hair Product Use				
Never	8 (11)	7.14E-5 (6.97E-5)	Reference	Reference
Occasionally	18 (25)	6.20E-5 (5.22E-5)	0.9171 (0.50-1.68)	0.78
Weekly	12 (16)	9.75E-4 (7.42E-5)	1.45 (0.79-2.68)	0.2311
Monthly	18 (25)	9.43E-5 (5.37E-5)	1.56 (0.86-2.80)	0.1402
Daily	17 (23)	1.31E-4 (1.30E-4)	1.92 (1.04-3.53)*	0.0373*
Tobacco use				
Yes	28 (12)	1.17E-4(9.93E-5)	1.1899 (0.74-1.92)	0.4785
No	198 (88)	1.23E-4(2.12E-4)	Reference	Reference
Bottles water in past 48 hrs				
None	15 (21)	8.38E-5(6.21E-5)	Reference	Reference
1-5 cups	39 (53)	1.05E-4(1.00E-4)	1.1319 (0.7401-1.7312)	0.5676
6-10 cups	15 (21)	5.84E-5(3.48-5)	0.7688 (0.4757-1.2424)	0.283
11-16 cups	2 (3)	1.94E-4(6.44E-5)	2.3579 (1.23-4.53)*	0.0101*
>16 cups	2 (3)	1.037E-4(5.83E-5)	1.6804 (1.04-2.71)*	0.0326*
Bottled beverages in past 48 hours				
None	33 (45)	8.01E-5 (6.13E-5)	Reference	Reference
1-5 cups	34 (45)	1.01E-4 (1.03E-4)	1.2397(0.86-1.78)	0.2457
6-10 cups	7 (10)	1.13E-4 (6.52E-5)	1.3931(0.86-2.26)	0.1788
Fruit/veg servings in past 48 hours				
None	13 (18)	1.13E-4 (7.15E-5)	Reference	Reference
1-5 servings	52 (71)	9.22E-5 (9.06E-5)	0.8323 (0.50-1.39)	0.4805
6-10 servings	8 (11)	7.00E-5 (4.38E-5)	0.7903 (0.41-1.52)	0.4799
Frequency of canned food consumption				
Every day	5 (7)	1.07E-4(1.02E-4)	1.002 (0.42-2.40)	0.9964
2-3 times per week	26 (35)	9.11E-5(5.66E-5)	0.9828 (0.65-1.48)	0.93431
Once a week	16 (22)	7.28E-5(3.89E-5)	0.8986 (0.59-1.36)	0.6127
Rarely	27 (36)	1.04E-4(1.16E-4)	Reference	Reference
Canned food consumption in past 48 hours				
None	54 (73)	9.39E-5(8.92E-5)	Reference	Reference
1-5	18 (24)	9.47E-5(6.75E-5)	1.0855 (0.7246-1.6261)	0.6909
6-10	2 (3)	4.25E-5(3.18E-5)	0.5057 (0.2186-1.1715)	0.1117
Canned meat consumption in past 48 hours				
None	67 (91)	9.49E-5 (8.70E-5)	1.0620 (0.83-1.37)	0.6394
1-5	7 (9)	7.24E-5 (2.14E-5)	Reference	Reference

Table 3. Intraclass correlation coefficients across different outcomes.

Outcome	**ICC**	**P-value**
BPA levels	0.1392	0.0407
Creatinine	0.2927	0.0172
Creatinine-Corrected BPA	0.7974	P<0.0001

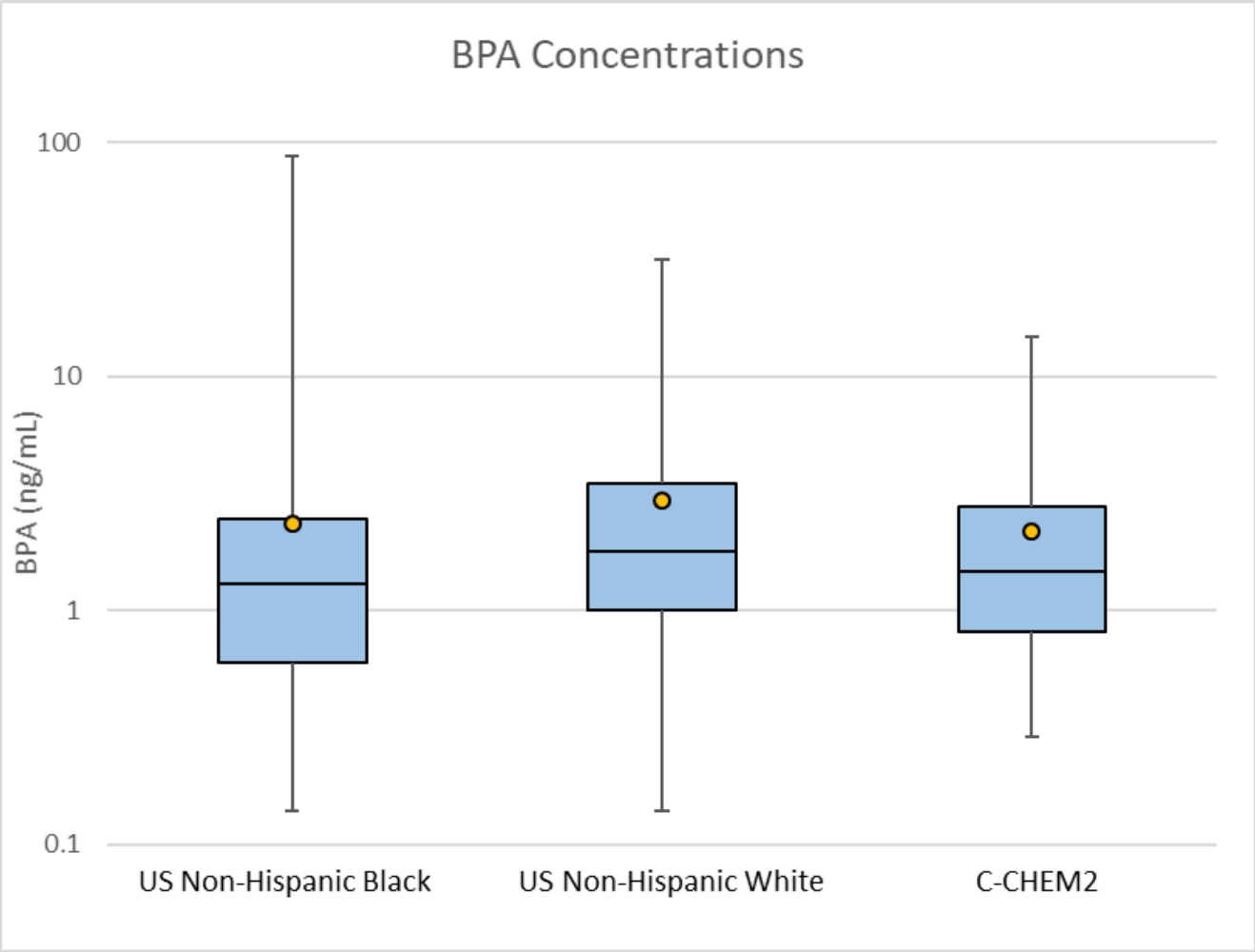

Figure 2. Distribution of BPA from NHANES data from 2013-2014 for US Non-Hispanic Black population and Non-Hispanic White population and distribution of C-CHEM[2] BPA values. The box represents the interquartile range and the middle line represents the median value. The yellow circle represents the mean value. Black tick marks represent minimum and maximum values.

References

Behnia, F., Peltier, M., Getahun, D., Watson, C., Saade, G., & Menon, R. (2016). High bisphenol A (BPA) concentration in the maternal, but not fetal, compartment increases the risk of spontaneous preterm delivery. J Matern Fetal Neonatal Med, 29(22), 3583-3589.

Beltifa, A., Belaid, A., Lo Turco, V., Machreki, M., Ben Mansour, H., & Di Bella, G. (2018). Preliminary evaluation of plasticizer and BPA in Tunisian cosmetics and investigation of hazards on human skin cells. International Journal of Environmental Health Research, 28(5), 491–501.

Benachour, N., & Aris, A. (2009). Toxic effects of low doses of Bisphenol-A on human placental cells. Toxicol Appl Pharmacol, 241(3), 322-328.

Braun, J. M., Kalkbrenner, A. E., Calafat, A. M., Bernert, J. T., Xiaoyun Ye, Silva, M. J., … Lanphear, B. P. (2011). Variability and Predictors of Urinary Bisphenol A Concentrations during Pregnancy. Environmental Health Perspectives, 119(1), 131–137.

Calafat, A. M., Xiaoyun Ye, Lee-Yang Wong, Reidy, J. A., & Needham, L. L. (2008). Exposure of the U.S. Population to Bisphenol A and 4- tertiary-Octylphenol: 2003-2004. Environmental Health Perspectives, 116(1), 39–44.

Cantonwine, D. E., Ferguson, K. K., Mukherjee, B., McElrath, T. F., & Meeker, J. D. (2015). Urinary Bisphenol A Levels during Pregnancy and Risk of Preterm Birth. Environmental Health Perspectives, 123(9), 895–901.

Cao XL, Corriveau J, Popovic S. 2010. Bisphenol A in canned food products from Canadian markets. J Food Prot 73(6):1085–1089.

Dekant, W., & Völkel, W. (2008). Human exposure to bisphenol A by biomonitoring: Methods, results and assessment of environmental exposures. Toxicology & Applied Pharmacology, 228(1), 114–134.

Drewnowski A., Eichelsdoerfer P. Can low-income Americans afford a healthy diet? Nutr. Today. 2010;44:246–249. doi: 10.1097/NT.0b013e3181c29f79.

Gerona, R. R., Pan, J., Zota, A. R., Schwartz, J. M., Friesen, M., Taylor, J. A., … Woodruff, T. J. (2016). Direct measurement of Bisphenol A (BPA), BPA glucuronide and BPA sulfate in a diverse and low-income population of pregnant women reveals high exposure, with potential implications for previous exposure estimates: a cross-sectional study. Environmental Health: A Global Access Science Source, 15, 1–14.

He, Y., Miao, M., Herrinton, L. J., Wu, C., Yuan, W., Zhou, Z., & Li, D.-K. (2009). Bisphenol A levels in blood and urine in a Chinese population and the personal factors affecting the levels. *Environmental Research*, *109*(5), 629–633.

Huang, Y. Q., Wong, C. K., Zheng, J. S., Bouwman, H., Barra, R., Wahlstrom, B., . . . Wong, M. H. (2012). Bisphenol A (BPA) in China: a review of sources, environmental levels, and potential human health impacts. *Environ Int*, *42*, 91-99.

Jackson WJ, Darnell WR. 1985. Process for foaming cellulose acetate rod. US Patent 4,507,256, filed 26 May 1983, and issued 26 March 1985.

Johns, L. E., Ferguson, K. K., Cantonwine, D. E., McElrath, T. F., Mukherjee, B., & Meeker, J. D. (2017). Urinary BPA and Phthalate Metabolite Concentrations and Plasma Vitamin D

Levels in Pregnant Women: A Repeated Measures Analysis. Environmental Health Perspectives, 125(8), 1–9.

Le, H. H., Carlson, E. M., Chua, J. P., & Belcher, S. M. (2008). Bisphenol A is released from polycarbonate drinking bottles and mimics the neurotoxic actions of estrogen in developing cerebellar neurons. Toxicology Letters, 176(2), 149–156.

Martínez, M. A., Rovira, J., Prasad Sharma, R., Nadal, M., Schuhmacher, M., & Kumar, V. (2018). Comparing dietary and non-dietary source contribution of BPA and DEHP to prenatal exposure: A Catalonia (Spain) case study. Environmental Research, 166, 25–34.

Michałowicz, J. (2014). Bisphenol A – Sources, toxicity and biotransformation. Environmental Toxicology & Pharmacology, 37(2), 738–758.

Morland, K., & Filomena, S. (2007). Disparities in the availability of fruits and vegetables between racially segregated urban neighbourhoods. Public Health Nutrition, 10(12).

Nelson, J. W., Scammell, M. K., Hatch, E. E., & Webster, T. F. (2012). Social disparities in exposures to bisphenol A and polyfluoroalkyl chemicals: a cross-sectional study within NHANES 2003-2006. Environmental Health: A Global Access Science Source, 11(1), 1–15.

Pergialiotis, V., Kotrogianni, P., Christopoulos-Timogiannakis, E., Koutaki, D., Daskalakis, G., & Papantoniou, N. (2018). Bisphenol A and adverse pregnancy outcomes: a systematic review of the literature. Journal of Maternal-Fetal & Neonatal Medicine, 31(24), 3320–3327.

Rochester, J. R. (2013). Bisphenol A and human health: a review of the literature. Reprod Toxicol, 42, 132-155.

Rubin, B. S. (2011). Bisphenol A: An endocrine disruptor with widespread exposure and multiple effects. Journal of Steroid Biochemistry & Molecular Biology, 127(1/2), 27–34.

Schonfelder, G., Wittfoht, W., Hopp, H., Talsness, C. E., Paul, M., & Chahoud, I. (2002). Parent Bisphenol A Accumulation in the Human Maternal-Fetal-Placental Unit. Environmental Health Perspectives, 110(11), A703.

Shankar, A., & Teppala, S. (2012). Urinary Bisphenol A and Hypertension in a Multiethnic Sample of US Adults. Journal of Environmental & Public Health, 1–5.

Stahlhut RW, Welshons WV, Swan SH. Bisphenol A data in NHANES suggest longer than expected half-life, substantial nonfood exposure, or both. Environ Health Perspect. (2009) 117:784–9.

Townsend, J., Roderick, P., & Cooper, J. (1994). Cigarette smoking by socioeconomic group, sex, and age: effects of price, income and health publicity. BMJ: British Medical Journal (International Edition), 309(6959), 923.

Valvi D, Casas M, Mendez MA, Ballesteros-Gómez A, Luque N, Rubio S, Sunyer J, Vrijheid M.Prenatal bisphenol a urine concentrations and early rapid growth and overweight risk in the offspring. Epidemiology. 2013;24(6):791–799.

Vandenberg LN , Hauser R , Marcus M , Olea N , Welshons WV 2007 Human exposure to bisphenol A (BPA). Reprod Toxicol 24:139–177.

vom Saal, F. S., & Hughes, C. (2005). An Extensive New Literature Concerning Low-Dose Effects of Bisphenol A Shows the Need for a New Risk Assessment. Environmental Health Perspectives, 113(8), 926–933.

Ye X, Pierik FH, Hauser R, Duty S, Angerer J, Park MM, et al. 2008. Urinary metabolite concentrations of organophosphorous pesticides, bisphenol A, and phthalates among pregnant women in Rotterdam, the Netherlands: The Generation R study. Environ Res 108(2):260–267.