Bisphenol A (BPA) in U.S. Food

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Bisphenol A (BPA) is a chemical used for lining metal cans and in polycarbonate plastics, such as baby bottles. In rodents, BPA is associated with early sexual maturation, altered behavior, and effects on prostate and mammary glands. In humans, BPA is associated with cardiovascular disease, diabetes, and male sexual dysfunction in exposed workers. Food is a major exposure source. We know of no studies reporting BPA in U.S. fresh food, canned food, and food in plastic packaging in peer reviewed journals. We measured BPA levels in 105 fresh and canned foods, foods sold in plastic packaging, and in cat and dog foods in cans and plastic packaging. We detected BPA in 63 of 105 samples, including fresh turkey, canned green beans, and canned infant formula. Ninety-three of these samples were triplicates which had similar detected levels. Detected levels ranged from 0.23 to 65.0 ng/g ww and were not associated with type of food or packaging but did vary with pH. BPA levels were higher for foods of pH 5 compared to more acidic and alkaline foods. Detected levels were comparable to those found by others. Further research is indicated to determine BPA levels in U.S. food in larger, representative sampling.

Introduction

Bisphenol A (BPA) is a monomer and found in epoxy resins commonly used in can linings and hard polycarbonate plastics, such as baby bottles, water bottles, food storage containers, power plugs, and automobile body primers. It is widely found in the environment because it provides a protective barrier between food and metal in cans, and also gives shape and durability (impact resistance) to plastics. BPA has been found in food, drinks, indoor and outdoor air, floor dust, and soil (*1*). BPA has also been found in thermal printer paper, such as receipt paper, and may also be transferred from thermal printer paper to hands (*2*). BPA has been identified in some dental composites and sealants (*3*) and in flame retardants (*4*). BPA has even been found in bathing and drinking water, and annually, billions of pounds of BPA are produced and over 100 tons are released into the atmosphere worldwide (*5, 6*). In the United States, there do not appear to be geographical differences in food BPA levels (*7*). BPA is thought to be present in 95% of the U.S. population (*8*), with higher levels in infants and children than in adults (*9*).

BPA is a chemical of concern because it is an endocrine disrupter (*1*) and has been associated with various adverse health effects. BPA exposure has been associated with heart disease in the adult U.S. population, including heart attacks, coronary heart disease, and angina (*10*). Increasing urinary BPA concentrations have been significantly associated with male sexual dysfunction as described by seven indices, including decreased sexual desire, erectile, and ejaculatory problems (*11, 12*). Prenatal exposure in rats is associated with increases in estrogen receptors α and β; increased aggressive behavior in males; obesity; early sexual maturation in females; changes in vaginal morphology; decreased serum testosterone; increases in adult prostate size (*13, 14*) increased incidence and susceptibility to neoplastic prostatic lesions when rats age (*15*); and alterations in brain sexual differentiation (*16*). Within mice, low dose exposure has been associated with early puberty (*17*), increased anxious behavior (*18*), and altered maternal behavior (*19*). Exposure to BPA during various life stages has also been associated with certain cancers, including mammary gland and prostate cancers; diabetes; and immune system alterations (*20, 21*).

Exposure to BPA is thought to occur primarily through ingestion, especially in children (*22*), though inhalation and dermal routes may also constitute significant sources of exposure, particularly in occupational settings (*1*). Migration and leaching of BPA from metal cans to food and drinks is possible (*5, 23, 24*), and evidence of BPA in canned food has been found around the world, including Japan, the United Kingdom, New Zealand, and the United States (*7, 25–29*). BPA has also been reported in fresh food in Italy, including cherries, eggplants, oranges, peaches, peppers, and tomatoes (*30*). Currently, there are no U.S. regulations or limitations pertaining to the amount of BPA in food or drink. The U.S. Environmental Protection Agency (EPA) and European Food Safety Authority (EFSA) have a BPA reference dose/tolerable daily intake (TDI) of 50 μg/kg/day (*5, 31*). However, many studies have shown adverse effects associated with exposure to BPA at lower doses, including early vaginal opening in female mice (*32*), decreased pituitary luteinizing hormone secretion and decreased Leydig cell testosterone production in male rats (*33*), decreased sperm motility and abnormalities in sperm morphology in male rats (*34*), reduction in tyrosine hydroxylase activity, resulting in hyperactivity in rats (*35*), altered immune system responses in mice (*36*), cytotoxicity in human placental cells, including apoptosis and necrosis (*37*), and promotion of testicular tumors in human males (*38*). BPA has also been found to cross the placenta in humans (*39*), as well as evidence of BPA in maternal circulation (*40*),which might lead to fetal exposure to unsafe BPA levels during this period of increased sensitivity during organogenesis (*38*). The European Commission Scientific Committee on Food proposed a temporary TDI of 10 μg/kg/day in 2002 based on the overall lowest observed adverse effect level of 50 mg/kg/day from previous studies (*41*). This study investigates BPA levels in fresh, canned, and plastic wrapped human foods, as well as in some cat and dog foods in the United States.

Materials and Methods

An assortment of 105 human, cat, and dog foods were collected from grocery stores in Dallas, Texas in March 2010.

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TABLE 1. BPA Levels [ng/g ww] in Canned and Plastic Wrapped U.S. Human Foods

food	pH	package	BPA level (ng/g ww)	food	pH	package	BPA level (ng/g ww)
			65.00				1.24
Del Monte Fresh			59.90	Enfamil Premium LIPIL			1.00
Cut Green Beans	6	can	26.60	Infant Formula Milk Based	7	can	0.97
			22.70				1.31
Progresso Light Homestyle			19.70	Beach Cliff Sardines			0.92
Vegetable and Rice Soup	6	can	15.60	in Water	7	can	0.81
			11.70				1.23
Progresso Classics Vegetable			10.80	Campbell's Chicken			0.77
Soup	5	can	7.28	Noodle Soup 3% Fat	6	can	0.76
			10.70				0.88
Progresso Classics Tomato			8.81	Swanson's White Premium			0.85
Basil Soup	4	can	8.17	Chunk Chicken Breast	7	can	0.82
			7.05				0.80
Campbell's Condensed			6.34				0.74
Chicken Noodle Soup	7	can	4.46	V8 100% Vegetable Juice	4	can	0.71
			5.59				0.49
Hormel Chili with			5.12	Tree Top 100% Apple Juice			0.47
Beans	6	can	3.47	From Concentrate	4	can	0.46
			5.04				0.78
Chef Boyardee Spaghetti			4.44	Summer Crisp Whole Kernel			0.54
and Meatballs	5	plastic	4.31	Golden Sweet Corn	7	can	0.37
			3.97				0.32
Kroger Sweet Peas Garden			2.74				0.25
Variety	6	can	2.65	Hormel SPAM	7	can	<0.20
				Campbell's Chicken Noodle			
			3.77	Soup 2.5%^{a}	6	can	<0.20
				Similac Advanced Infant			
			3.47	Formula^a	7	can	<0.20
Chicken of the Sea Chunk				Similac Isomil Advance			
Light Tuna in Water	6	can	1.66	Soy Infant Formula^a	7	can	<0.20
				Pineapple Chunks in			
			4.16	Pineapple Juice^a	4	can	<0.20
				Gerber Graduates Spaghetti			
			2.30	Rings in Meat Sauce^a	5	can	<0.20
				Chef Boyardee Mac and			
Kroger Mixed Vegetables	6	can	2.29	Cheese^a	6	can	<0.20
				Kroger SlimLite Ultimate			
			2.00	Creamy Chocolate Milk^a	8	can	<0.20
				Bumble Bee Chunk Light			
			1.50	Tuna in Water^a	6	can	<0.20
Campbell's Chunky				Sprouts Organic Cinnamon			
Savory Pot Roast	6	can	1.46	Apple Sauce^a	4	plastic	<0.20
				Carnation Evaporated Milk			
			1.71	Vitamin D Added^a	7	can	<0.20
				Hunts 100% Natural			
			0.81	Tomato Paste^a	5	can	<0.20
Kroger Canned Beef	6	can	0.80				

^{a} Foods with asterisks had three samples measured.

Although we cannot assert that what we found with regard to BPA in these samples is typical for the entire U.S., we do note that our previous monitoring of polybrominated diphenyl ethers (PBDEs) in food in this geographic region showed similar concentrations as found elsewhere in the U.S (*42*). Food samples consisted of three samples for each of 31 kinds of canned and plastic wrapped food for human consumption, four kinds of fresh meat and fish (one sample each), and eight individual samples of canned and plastic wrapped pet food. Fresh foods were frozen at −80 °C and shipped on dry ice, while canned and plastic wrapped foods were maintained and shipped at room temperature. Food samples were not opened or altered prior to shipment to avoid contamination with outside sources of BPA. Food samples were sent to Eurofins laboratory in Hamburg, Germany for individual chemical analysis. All appropriate steps were made during collection, shipping, and in the laboratory to avoid contamination.

Analytical. The method followed the isotope dilution procedure. The samples (approximately 10−200 g wet material/sample) were freeze-dried. After drying, internal standard (^{13}C-BPA, CIL, Andover, MA) was added, followed by homogenization. The extraction of the sample was performed by applying acetonitrile (from Merck Darmstadt, Germany) in an ultrasonic bath at 40 °C. Liquid/liquid extraction was then performed with hexane (Merck Darmstadt, Germany), as well as purification on ENVI- Carb (Sigma-Aldrich/Supelco, St. Louis) using hexane as solvent.

The purified extract containing the BPA was derivatized by means of BSTFA (Macherey-Nagel, Düren, Germany) forming the BPA-TMS-derivate. Further purification on silica column (Bakerbond SPE, Mallinckrodt Baker B.V., Deventer, Holland) was followed by a concentration step and the addition of a recovery standard (^{13}C-PCB no. 52; CIL, Andover, MA).

Measurements were performed by using HRGC/LRMS (GC 6890 Hewlett-Packard and MS 5973 Hewlett-Packard). The GC column applied was a DB5MS with a length of 30 m, an inner diameter of 0.25 mm, and a film thickness of 0.25

TABLE 2. BPA Levels [ng/g ww] in fFresh U.S. Human Foods

food	pH	package	BPA Level (ng/g ww)
sliced turkey	N/A	fresh	0.35
ham	N/A	fresh	<0.20
sliced chicken breast	N/A	fresh	<0.20
salmon	N/A	fresh	<0.20

TABLE 3. BPA Levels [ng/g ww] in U.S. Cat and Dog Foods

food	pH	package	BPA level (ng/g ww)
Friskies Classic Pate Salmon Dinner Cat Food	7	can	0.32
Alpo Prime Cuts Lamb and Rice in Gravy Dog Food	7	can	0.26
Friskies Classic Pate Turkey and Giblets Cat Foot	7	can	0.23
Friskies Classic Pate Whitefish and Tuna Cat Food	7	can	<0.20
Whiskas Rotisserie Chicken Flavor Cat Food	7	plastic	<0.20
Alpo Prime Cuts Beef and Liver in Beef Gravy Dog Food	7	can	<0.20
Alpo Prime Cuts London Grill in Beef Gravy Dog Food	7	can	<0.20
Cesar Chicken and Beef in Meaty Juices Puppy Food	7	plastic	<0.20

μm (J&W Scientific). A splitless injector was used at 280 °C. The oven was set at 120 °C for 1 min, 10 °C/minute to 240 °C, and 30 °C/minute to 300 °C and hold 10 min. The flow rate was 2.0 mL/min; interface was at 300 °C. GC/MS-SIM settings were 357.2 and 372.2 (BPA-TMS) (m/z) and 369.2 and 384.2 ($^{13}C_{12}$ BPA-TMS) (m/z). Recoveries ($^{13}C_{12}$ BPA-TMS) were between 65 and 112%.

QC/QA measures included a multi point calibration curve, recalibration within each sequence of analysis (with a minimum of one blank in each batch of a maximum of 10 samples), and duplicate analyses of >50% of positive samples. Nearly all positive samples were analyzed in replicate. The laboratory blank level for BPA is 0.43 ng abs. (mean; n: 15) with SD: 0.12 ng abs and BPA: 0.05 ng/g ww (LOD) with 0.11 ng/g ww (LOQ) based on 15 g ww (sample intake).The limits of detection were 0.20 ng/g wet weight (ww).

Results and Discussion

Of the 105 total samples analyzed for BPA, 63 had quantifiable levels. BPA levels were similar in each of the three samples analyzed. Table 1 shows BPA levels in human canned food and human food in plastic packaging. Table 2 shows BPA levels in fresh human food. Table 3 shows BPA levels in cat and dog foods in cans and plastic packaging. Del Monte Fresh Cut Green Beans (canned) had the highest level of BPA detected, with a range of 26.6−65.0 ng/g ww and a mean of 50.5 ng/g ww. One fresh food sample, sliced turkey, had a BPA level of 0.35 ng/g ww, which is lower than reported BPA levels in fresh food from Italy (*30*). Other examples of foods with quantifiable levels of BPA were Progresso Vegetable and Rice Soup (canned) with a range of 15.6−22.7 ng/g ww and a mean of 19.3 ng/g ww; Chef Boyardee Spaghetti and Meatballs (plastic container) with a range of 4.31−5.04 ng/g ww and a mean of 4.60 ng/g ww; Enfamil Infant Formula Milk Based (canned) with a range of 0.97−1.24 ng/g ww and a mean of 1.07 ng/g ww; and Alpo Lamb and Rice Dog Food (canned) with a BPA level of 0.26 ng/g ww. Several samples did not have detectable levels of BPA, such as Campbell's

TABLE 4. BPA Levels by pH

pH	number of Samples	BPA minimum	BPA median	BPA maximum
4	15	<0.20	0.47	10.70
5	12	<0.20	2.21	11.70
6	36	<0.20	1.86	22.70
7	35	<0.20	0.26	7.05
8	3	<0.20	<0.20	<0.20

Chicken Noodle Soup 2.5% Fat (canned), Similac Infant Formula Milk Based (canned), Sprouts Organic Apple Sauce (plastic container), fresh salmon, and Cesar Chicken and Beef puppy food (plastic container).

BPA levels detected in this study are comparable to others. BPA levels detected in Chicken of the Sea Chunk Light Tuna in Water ranged from 1.66 to 3.77 ng/g ww. No BPA was detected in Bumble Bee Chunk Light Tuna in Water. These values are lower than BPA detected in canned tuna samples from Mexico. Munguia-Lopez et al. (2005) measured BPA levels in seven different brands of canned tuna and detected levels ranging from 10.9 ± 2.3 to 57.3 ± 46.4 μg/kg (*43*). Brotons et al. (1995) detected BPA in canned peas (22.9 ± 8.8 μg/300 g), canned green beans (2.2 ± 0.2 μg/400 g), canned mixed vegetables (1.8 ± 0.2 μg/450 g), and canned corn (1.5 ± 0.1 μg/300 g) in Spain (*44*). While the detected BPA in canned green beans is comparable to values we detected (26.6 ng/g ww), the other detected levels exceeded ours. Neither Brotons et al. nor this study detected BPA in canned tomatoes and canned tomato paste, respectively. Yoshida et al. (2001) detected BPA in canned Japanese foods. BPA was detected in six canned corn samples with levels ranging from 18.4 to 95.3 ng/g (*45*), higher than our detected levels ranging from 0.37 to 0.78 ng/g ww. Neither we nor Yoshida et al. detected BPA in canned pineapple. Imanaka et al. (2001) detected BPA in Japanese canned corned beef and canned chicken with levels ranging from 17 to 602 ng/g and 212 ng/g, respectively. BPA levels in canned tuna, corn, and tomato paste were measured as 10, 2.3−79, and 86 ng/g, respectively (*46*), all of which are higher than BPA levels detected in this study. This suggests that BPA levels in food worldwide are comparable but can vary among similar food types.

Although BPA levels were somewhat higher for foods stored in cans than plastic containers, this difference was not statistically significant (Wilcoxon rank sum test $p = 0.45$). Given that only eight samples had plastic containers, a larger study may yield a statistically significant result. BPA concentrations were greater for foods with pH 5 than for lower (more acidic) or higher (more alkaline) levels (Table 4). The association of BPA level with pH was significant (one-way ANOVA with log transformed BPA, setting nondetected samples at half the detection limit, $F(4, 96) = 4.45$, $p < 0.01$). The difference in BPA for pH 6 vs pH 7 was significant ($p < 0.01$ using the Bonferroni method).

This relationship between BPA level and sample pH was unexpected and, we think, in need of further analysis. There was no significant *linear* relationship between pH and BPA, and the curvilinear relationship we found may be due to chance or artifact. For example, it may reflect the types of foods typically found at each pH or differences in types of cans or plastic containers, typically used with different food types.

A noteworthy finding in our study is that of the 105 food samples, 93 were triplicates of 31 different food types. Among these, BPA levels were detected at similar concentrations. For example, Del Monte Fresh Cut Green Beans had BPA levels of 65.00, 59.90, and 26.60 ng/g ww, Progresso Light

Homestyle Vegetable and Rice Soup had BPA levels of 22.70, 19.70, and 15.60 ng/g ww, and Swanson's White Premium Chunk Chicken Breast had BPA levels of 0.88, 0.85, and 0.82 ng/g ww. Others, such as Gerber Graduates Spaghetti Rings in Meat Sauce, Sprouts Organic Cinnamon Apple Sauce, and Hunt's 100% Natural Tomato Paste, had nondetectable levels of BPA in all three analyzed samples. We believe these results affirm our hypothesis that food packaging systematically causes the occurrence of BPA in food, as triplicate samples revealed extremely similar BPA levels. Detectable levels of BPA in only one sample of food may not necessarily be representative of food types and packaging in general and may be attributed to sample handling or preparation. However, our wide range of foods and high number of triplicate analyses provide evidence that food packaging can cause contamination of food with BPA.

The daily intake of BPA from certain food products from this study was calculated for a 70 kg adult and a 20 kg child. A child who weighs 20 kg falls at the 50% for 5−6 year olds (*47, 48*). Intake from Progresso Light Homestyle Vegetable and Rice Soup was calculated using the mean BPA concentration of 19.33 ng/g ww. A 70 kg adult eating 1 can of soup would have a BPA intake of 0.13 μg/kg/day from this source. A 20 kg child eating half a can of soup would consume 0.23 μg/kg/day of BPA. Intake from Del Monte Fresh Cut Green Beans was calculated using the mean BPA concentration of 50.5 ng/g ww. An adult eating one can of green beans per day would have a BPA intake of 0.35 μg/kg/day. A 20 kg child eating half a can of green beans per day would have a BPA intake of 0.61 μg/kg/day. Children ages 1.5−6 years have been reported to have BPA intake ranging from 0.043 to 14.7 μg/kg/day, whereas children ages 6−19 years have BPA intake ranging from 0.311 to 0.348 μg/kg/day (*21*). These levels exceed the temporary TDI proposed by the European Commission Scientific Committee on Food Safety of 10 μg/kg/day but are lower than the U.S. EPA and EFSA reference dose/TDI of 50 μg/kg/day. Volkel et al. (2008) estimated German BPA intake for adults as 30 ng/kg based on BPA urine concentrations (*49*). LaKind and Naiman (2010) estimated U.S. BPA intake for the overall population to be 34 ng/kg/day based on urinary BPA data (*50*). Both calculated daily intakes are lower than the U.S. EPA and EFSA reference dose/TDI but higher than the temporary TDI proposed by the European Commission Scientific Committee on Food Safety and are similar to our estimated daily intake levels. Miyamoto and Kotake (2006) estimated daily BPA intake from urinary excretion for the Japanese population and found intake to be 0.037−0.064 μg/kg/day for males and 0.043−0.075 μg/kg/day for females (*51*), both of which are lower than the temporary TDI proposed by the European Commission Scientific Committee on Food Safety and the U.S. EPA and EFSA reference dose/TDI.

BPA has also been detected in human breast milk, with levels as high as 6.3 ng/mL in U.S. women (*52*). Here, we detected BPA in only 3 of 12 samples of infant formula and evaporated milk. Three samples of Enfamil Infant Formula Milk Based had BPA levels ranging from 0.97 to 1.24 ng/g ww, each of which is significantly lower than levels observed in human breast milk. Similac Infant Formula, Similac Soy Infant Formula, and Carnation Evaporated Milk all had levels below the limit of detection. While the levels of BPA found in some of the infant formulas we tested are relatively low compared to those found in breast milk, these levels may be of concern as many infants consume formula in place of mothers' breast milk.

Of eight cat and dog food samples analyzed, three had detectable levels of BPA. These samples were canned, two of which were cat food and one which was dog food. The three values we detected in animal food ranged from 0.23 to 0.32 ng/g ww which is lower than detected levels found by Kang and Kondo (2002) (13−136 ng/g in Japanese canned cat food and 11−206 ng/g in Japanese dog food) (*53*). The pH value was neutral for all eight cat and dog food samples. The detected levels were lower than the majority of BPA levels measured in our human food samples. Further research investigating presence and association of cat and dog food brands, ingredients, and wrappings with BPA may illuminate possible oral BPA exposure for pets. Cats, and oftentimes dogs, are much smaller than humans. While low levels of BPA were measured, these levels may produce adverse health effects in cats and dogs as seen in rodent studies.

The presence of detectable levels of BPA in the majority of sampled U.S. food suggests a need for more research to determine not only to what extent BPA is present in U.S. food, but also what quantities average and special population adults, children, and animals consume. Larger and more representative sampling will help identify which types of foods or food packaging are typically associated with higher levels of BPA. The levels of BPA found in this study did not reach concentrations which to date have been associated with adverse health effects. However, given the possibility of ingesting multiple foods with elevated BPA levels and multiple sources of exposure to BPA, it is important to continue monitoring the U.S. food and water supply for BPA, and investigating other potential pathways of exposure to BPA.

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