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4-Nonylphenol and bisphenol A in Swedish food and exposure in Swedish nursing women

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ABSTRACT

4-Nonylphenol (NP) and bisphenol A (BPA) are phenolic substances used in high volumes by the industry. Studies on cells and in experimental animals have shown that both these compounds can be classified as estrogenic hormone disrupters. Information about the exposure of humans to NP and BPA is still scarce, especially regarding levels in human blood. The first aim of this study was to investigate possible sources of NP and BPA exposure from food, by analyzing the levels of NP and BPA from a Swedish food market basket, based on the Swedish per capita food consumption. A second aim was to investigate blood serum levels of NP and BPA, as well as NP-ethoxylates, among young women in Sweden (n = 100). Moreover, associations between food consumption and blood NP and BPA levels were studied. In food, NP was to some extent found at levels above limit of quantification (LOQ 20 ng/g fresh weight) in fruits, cereal products, vegetables, and potatoes. BPA levels above LOQ (2 ng/g fresh weight) were found in fish, meats, potatoes, and dairy products. The estimated mean intakes per capita were (medium bound) 27 μg NP/day and 3.9 μg BPA/day, showing that food is a source of BPA and NP in the general Swedish population. In blood serum, free NP above limit of detection (LOD 0.5 ng/g) was detected in 46% of the study participants while detectable levels of total NP (LOD 0.8 ng/g) were observed in 43%. The corresponding percentages for BPA were 25% and 22%, respectively. The results indicate that there is a continuous source of exposure to NP and BPA that is high enough for free NP and BPA to be detected in some consumers. Among the participants with quantifiable levels of free and total NP (n = 38), 85% (median, range: 38–112%) of the NP was present as free NP. For BPA 76% (49–109%) was detected as free BPA (n = 15). All women had levels of ethoxylates of NP below LOD (0.1–0.7 ng/g). A significantly higher total consumption of fruits and vegetables was reported in questionnaires by participants with NP levels at or above LOD than among women with levels below LOD. This result is supporting the market basket results of relatively high NP levels in these types of food.

1. Introduction

4-Nonylphenol (NP) and bisphenol A (BPA) are phenolic substances used in high volumes by the industry. NP is mainly used as a raw material for the production of plastics and of surface-active substances, so called nonylphenol-ethoxylates. The NP-ethoxylates can relatively easily degrade back to NP (Soares et al., 2008). BPA is used mainly in the production of polycarbonate plastics, epoxy resins and thermo plastics, and is found in for example food and beverage containers, glues, materials for floor covering, varnishes and paints. BPA has been shown to leach from these materials due to incomplete polymerization and to degradation of the polymers by exposure to high temperatures, occurring under normal conditions of use (Biles et al., 1997). A certain type of BPA-containing epoxy resin is used as a protective barrier on the inside of food cans (Chapin et al., 2008). Toxicological studies on cells and in experimental animals have shown that NP and BPA act as hormone disrupters. Both chemicals are estrogenic and affect the reproductive system in animals after exposure to high doses (ECB, 2002; Maffini et al., 2006). Some animal studies of BPA indicate that negative health effects occur even at very low doses (vom Saal and Hughes, 2005). These low doses effects of BPA have however been questioned (Chapin et al., 2008; Hengstler et al., 2011).

Possible exposure sources for NP are application of paint, and the use of pesticides and cosmetics (ECB, 2002; Ying et al., 2002). Exposure to NP can also occur by consumption of food and drinking water (Guenther et al., 2002; Shao et al., 2005). Possible sources of human exposure to BPA are packaged food that have been in contact with BPA material, inhalation of household air and dust and dental fillings containing BPA (Vandenberg et al., 2007; Von Goetz et al., 2010). An increase in urinary BPA was found in students in the USA after one week of exposure to beverages from polycarbonate bottles (Carwile et al., 2009). The European Food Safety Authority (EFSA) has established a tolerable daily intake (TDI) of BPA at 50 μg/kg

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body weight (bw) (EFSA, 2006). The World Health Organization (WHO) has estimated the mean dietary daily intake of BPA for adults to be 0.4–1.4 μg/kg bw, with a worst case scenario of 4.2 μg/kg bw (FAO/WHO, 2011). The European Union has estimated the worst case scenario intake to be 1.5 μg BPA/kg bw for adults (EFSA, 2006). No European TDI for NP has been established but Danish researchers have proposed a TDI of 5 μg/kg bw (Nielsen et al., 2000). The daily intake of NP from food for adults has been estimated to be 7.50 μg/day in a study from Germany (Guenther et al., 2002) and around 30 μg/day in a study from Taiwan (Lu et al., 2007). For adults, this is comparable to 0.1 and 0.4 μg/kg bw per day, respectively. The estimated intakes of NP and BPA from food are well below the TDI but other sources may also be important for the total exposure (ECB, 2002; Vandenberg et al., 2007).

Information about the exposure of humans to NP and BPA is still scarce. NP was found in 51% of urine samples from 394 adult Americans, with the limit of detection (LOD) 0.1 ng/ml (Calafat et al., 2005). BPA has been detected in blood serum and urine in populations from around the world in the nanograms per milliliter range (Dekant and Völkel, 2008; Mielke and Gundert-Remy, 2009; Vandenberg et al., 2010a). In a study from the County of Uppsala, Sweden, serum BPA levels were analyzed in serum from 1016 individuals at the age of 70, showing a median concentration of total BPA of 3.76 ng/ml (interquartile range: 2.02–6.52) (Lind and Lind, 2011). These exposure studies indicate that humans are constantly exposed to these compounds as the half life of NP and BPA in humans is very short, just a few hours in blood (Müller et al., 1998; Volkel et al., 2002). However, for BPA the toxicokinetic studies have been criticized and the major exposure sources and the total daily exposure of BPA is debated (Taylor et al., 2011; Vandenberg et al., 2010a, 2010b).

The body burdens of NP and BPA among Swedish consumers and the levels in food on the Swedish market are to a large extent unknown. The aim of this study was first to determine if food may be a source of BPA and NP exposure in Sweden, by analyzing the levels of NP and BPA in food, based on the Swedish per capita food consumption. Secondly we investigated the serum levels of NP and BPA as well as NP-ethoxylates among young women in Sweden. BPA, NP, and NP-ethoxylates were analyzed in blood serum samples from 100 nursing primiparous women from Uppsala County. Associations between contaminant levels in blood and food consumption patterns were also studied. The population of young Uppsala women has been part of a long-term and well-investigated study (POPUP) of body burdens of environmental pollutants (Lignell et al., 2009). A study of regional differences in body burdens of PCB, chlorinated pesticides and brominated flame retardants revealed that the Uppsala population did not differ significantly from other populations from other regions in Sweden (Malmö, Lund, Gothenburg, Lycksele) (Lignell et al., 2005). Exposure estimates during the pregnancy and nursing periods are relevant because humans may be most sensitive to NP and BPA early in life (Chapin et al., 2008; ECB, 2002).

2. Methods

2.1. Swedish food market basket study

Food items consumed at a minimum of 0.5 kg per person and year, based on per capita-consumption data derived from Swedish producers and trade statistics (SBA, 2005), were purchased in 2005. The foods were divided into 12 different food groups (see Table 1). The food was purchased from the two largest food store chains in Sweden in four major Swedish cities, Malmö, Gothenburg, Uppsala, and Sundsvall (except for fats/oils which were only bought in Uppsala). The chosen cities represent major population areas and are geographically well separated in different regions of Sweden. All purchases were made during spring/summer 2005 and locally produced products were chosen when available. In Table 1 the percentage of each type of products in each food group is shown, and also the percentage of canned products (if purchased) for each food group.

2.1.1. Sample preparation and chemical analysis

From each food unit/package, a defined amount (1%) of the yearly per capita consumption was taken out for sample preparation. In the case of food items where wastage could be expected, inedible parts such as bone, skin etc. were removed prior to homogenization. One homogenate sample was prepared for each food group and stored in −20 °C, for less than a year. NP and BPA were analyzed by the Swedish Environmental Research Institute, IVL, Stockholm, Sweden. The samples were extracted with organic solvents. The extracts were cleaned through distribution extraction with acetonitrile. Extract from samples with high lipid content was further cleaned with

Table 1
Description of food groups sampled in the Swedish market basket. The food items were purchased from the two largest food store chains in four different cities in Sweden 2005.

Food group	1% of annual average consumption (g)	No. of food items	Main items (%, shown only for the food groups where results are presented)	Results presented
Cereal products	911	11	Bread (64), flour (12), pasta (9), rice (6), corn flakes (5), grain (4)	Yes
Pastries	191	5	Cakes, biscuits including pizza	No
Meat/meat products	744	16	Beef (24), pork (23), lamb (1), chicken (12), game (2), processed meats except pizza (38). Canned product of total (3)	Yes
Fish/fish products	167	13	Fresh and frozen lean fish (26), fresh and frozen fatty fish (15), processed products (47), prawns (12). Canned products of total (22)	Yes
Dairy products	1758	16	Milk (61), sour milk (16), yogurt (8), cream and sour cream (5), cheese (8), cottage cheese (2)	Yes
Egg	81	1		Yes
Fats (only purchased in Uppsala)	140	7	Butter (9), margarine (46), low fat margarine (29), oil (9), mayonnaise (6)	Yes
Vegetables, including root vegetables	636	19	Fresh and frozen vegetables (78), canned vegetables (21), dried vegetables (1)	Yes
Fruit	683	15	Fresh and frozen fruit (64), canned fruit (6), Nuts and raisins (2), Jam, juice and syrup (28)	Yes
Potatoes	443	4	Potatoes (74), French fries (20), chips (5), powder (1)	Yes
Sugar and sweets	318	7	Sugar, chocolate, sugar sweets, ketchup	No
Soft drinks, lemonade, beer (≤3.5% alcohol)	1267	4	Soft drinks, mineral water, beer	No
Ice cream	60	2		No