Preplanned Studies

Exposure to Bisphenolic Analologues in the Sixth Total Diet Study — China, 2016–2019

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Summary

What is already known about this topic?
Bisphenol A (BPA) and other bisphenolic compounds (BPs) are proved to pose potential endocrine disrupting properties. The primary source of BP exposure is the diet. European Food Safety Authority (EFSA) established a temporary tolerable daily intake (t-TDI) of BPA 4 μg/kg body weight per day.

What is added by this report?
BPs were detected in composite food samples from the Sixth China Total Diet Study (TDS) at percentages of 27.1%–78.5%. The estimated dietary exposure of BPA and bisphenol S (BPS) for an average adult were 18.1 ng/kg body weight per day and 22.2 ng/kg body weight per day, respectively. The main dietary contributors for BPs were cereals, water and beverage, meat as well as vegetables.

What are the implications for public health practices?
BP dietary intake poses low risks on the Chinese general population based on the t-TDI set by EFSA. BPS presented a higher exposure level than BPA, which highlights the need to strengthen the surveillance of BP alternatives in foodstuffs.

Bisphenol A (BPA) is used in the synthesis of commercial plastics, including polycarbonates and epoxy resins, which are incorporated into a wide variety of consumer goods. Exposure to BPA was suspected to result in a variety of toxicities in the neurological, reproductive, metabolic, and immune system (1). Considering these potential undesirable effects, European Food Safety Authority (EFSA) established a temporary tolerable daily intake (t-TDI) of 4 μg/kg body weight per day (2).

Abiding by the regulations on the production and restricted use of BPA in European Union, United States, China, and other countries, BPA in commercial products was gradually replaced by its analogues, such as bisphenol S (BPS), bisphenol F (BPF), bisphenol B (BPB), and bisphenol AF (BPAF). After being put into use, these bisphenolic compounds (BPs) were released into the environment and entered the food chain. A variety of foods (cereals, fruits, meats etc.) were found to contain BPS and other analogues. Studies have shown that the genotoxicity and estrogenic activity of these alternatives are like that of BPA (3–4).

The primary source of exposure to BPA for most people is through the diet from contaminated foodstuffs (5). Dietary exposure of BPA from the Canadian Total Diet Study (TDS) was evaluated in view of BPs in composite food samples (6). In China, BPA from the Fourth China TDS (2007) samples as well as BPA and several analogues from the Fifth China TDS (2010–2012) were analyzed and the estimated daily intakes (EDI) of these BPs were safe for general people (7–8). However, in past decades, China’s sustained development and progress have affected the lives of every resident. Under this circumstance, food consumption and contamination levels might have changed remarkably since China’s restriction of BPA in baby products and food contact materials implemented since 2011. The purpose of this study was to evaluate the Chinese daily exposure to BPs from the Sixth TDS (2016–2019) (9).

Levels of BPs in the Sixth China TDS were provided in Supplementary Tables S1–S4 (available in https://weekly.chinacdc.cn/) and summarized in Table 1, where BPA was detected in 216 out of total 288 samples, with a concentration range of non-detected value (ND) to 20.0 μg/kg, among which the highest level occurred in cereals from Jiangsu Province. The mean concentrations of BPA from food categories ranged from 0.129 μg/kg (milk)–1.02 μg/kg (meat). BPS presented a rate of detection of 78.5%, accounting for 226 samples. The maximum level 67.1 μg/kg was attributed to a sample of meats from Fujian Province. While the second largest value is 16.6 μg/kg from a meat sample in Henan Province. BPF and BPAF were found in 8.33% and 27.1% of samples, with the maximum concentrations of 1.06 μg/kg and 1.75 μg/kg, respectively.

The EDIs of BPA, BPS, BPF, and BPAF for an
TABLE 1. Occurrence of BPA and its analogues in different composite Total Diet Study samples.

| Category        | Parameter          | BPA (μg/kg) | BPS (μg/kg) | BPF (μg/kg) | BPAF (μg/kg) |
|-----------------|--------------------|-------------|-------------|-------------|--------------|
| Cereals         | Mean (μg/kg)       | 0.466       | 0.545       | 0.007       | 0.012        |
|                 | Medium (μg/kg)     | 0.256       | 0.128       | ND          | ND           |
|                 | Range (μg/kg)      | ND to 1.44  | ND to 6.40  | ND to 0.169 | ND to 0.129  |
|                 | Detective rate (%) | 91.7        | 83.3        | 4.2         | 29.2         |
| Legumes and nuts| Mean (μg/kg)       | 0.484       | 0.984       | 0.146       | ND           |
|                 | Medium (μg/kg)     | 0.255       | 0.707       | ND          | ND           |
|                 | Range (μg/kg)      | ND to 3.39  | ND to 4.23  | ND to 1.06  | ND           |
|                 | Detective rate (%) | 87.5        | 91.7        | 37.5        | 0            |
| Potatoes        | Mean (μg/kg)       | 0.340       | 0.163       | 0.008       | 0.006        |
|                 | Medium (μg/kg)     | 0.271       | 0.147       | ND          | ND           |
|                 | Range (μg/kg)      | ND to 1.35  | ND to 0.648 | ND to 0.186 | ND to 0.029  |
|                 | Detective rate (%) | 95.8        | 91.7        | 4.2         | 29.2         |
| Meats           | Mean (μg/kg)       | 1.024       | 5.827       | 0.106       | 0.026        |
|                 | Medium (μg/kg)     | 0.476       | 2.010       | ND          | ND           |
|                 | Range (μg/kg)      | ND to 5.82  | ND to 67.1  | ND to 0.279 | ND to 0.530  |
|                 | Detective rate (%) | 95.8        | 91.7        | 20.8        | 25           |
| Eggs            | Mean (μg/kg)       | 0.180       | 0.130       | ND          | 0.021        |
|                 | Medium (μg/kg)     | 0.169       | 0.042       | ND          | 0.013        |
|                 | Range (μg/kg)      | ND to 0.544 | ND to 0.636 | ND          | ND to 0.061  |
|                 | Detective rate (%) | 54.2        | 87.5        | 0           | 50           |
| Aquatic foods   | Mean (μg/kg)       | 0.927       | 1.25        | 0.015       | 0.125        |
|                 | Medium (μg/kg)     | 0.689       | 0.621       | ND          | 0.024        |
|                 | Range (μg/kg)      | 0.199 to 3.31 | ND to 6.34  | ND to 0.192 | ND to 1.75   |
|                 | Detective rate (%) | 100         | 95.8        | 8.3         | 79.2         |
| Milk            | Mean (μg/kg)       | 0.129       | 0.022       | ND          | 0.002        |
|                 | Medium (μg/kg)     | ND          | 0.008       | ND          | ND           |
|                 | Range (μg/kg)      | ND to <0.385 | ND to 0.148 | ND          | ND to 0.026  |
|                 | Detective rate (%) | 41.7        | 29.2        | 0           | 12.5         |
| Vegetables      | Mean (μg/kg)       | 0.347       | 0.343       | 0.015       | 0.010        |
|                 | Medium (μg/kg)     | 0.293       | 0.127       | ND          | ND           |
|                 | Range (μg/kg)      | ND to 1.09  | 0.020 to 1.81 | ND to 0.190 | ND to 0.041  |
|                 | Detective rate (%) | 95.8        | 100         | 8.3         | 37.5         |
| Fruits          | Mean (μg/kg)       | 1.68        | 0.315       | 0.032       | 0.023        |
|                 | Medium (μg/kg)     | 0.418       | 0.111       | ND          | ND           |
|                 | Range (μg/kg)      | ND to 20.0  | 0.026 to 1.71 | ND to 0.449 | ND to 0.175  |
|                 | Detective rate (%) | 91.7        | 100         | 12.5        | 41.7         |
| Sugar           | Mean (μg/kg)       | 0.909       | 0.034       | 0.011       | 0.006        |
|                 | Medium (μg/kg)     | 0.602       | 0.021       | ND          | ND           |
|                 | Range (μg/kg)      | 0.197 to 3.26 | ND to 0.114 | ND to 0.260 | ND to 0.043  |
|                 | Detective rate (%) | 91.7        | 70.8        | 4.2         | 20.8         |
| Beverages and water | Mean (μg/kg)   | 0.234       | 0.058       | ND          | ND           |
|                 | Medium (μg/kg)     | ND          | 0.013       | ND          | ND           |
|                 | Range (μg/kg)      | ND to 1.57  | ND to 0.612 | ND          | ND           |
|                 | Detective rate (%) | 20.8        | 50.0        | 0           | 0            |
| Alcoholic beverages | Mean (μg/kg) | 0.161       | 0.081       | ND          | ND           |
|                 | Medium (μg/kg)     | ND          | 0.012       | ND          | ND           |
|                 | Range (μg/kg)      | ND to 0.610 | ND to 1.54  | ND          | ND           |
|                 | Detective rate (%) | 37.5        | 50          | 0           | 0            |
| Total           | Mean (μg/kg)       | 0.546       | 1.17        | 0.023       | 0.019        |
|                 | Medium (μg/kg)     | 0.251       | 0.055       | ND          | ND           |
|                 | Detective rate (%) | 75.3        | 78.5        | 8.33        | 27.1         |

Abbreviations: BPA=bisphenol A; BPS=bisphenol S; BPF=bisphenol F; BPAF=bisphenol AF; LOD=limits of detection; ND=non-detected value.
average male adult are given in Figure 1. For BPA, the highest exposure was found in Henan (56.9 ng/kg body weight per day), while the lowest was found in Jilin (5.74 ng/kg body weight per day). Mean exposure to BPA was estimated to be 18.1 ng/kg body weight per day, significantly below the t-TDI (4 μg/kg body weight per day) recommended by the EFSA (2). The EDI of BPS in the Sixth TDS for an average Chinese male adult was 22.2 ng/kg body weight per day. Jiangsu (120 ng/kg body weight per day) and Fujian (114 ng/kg body weight per day) posed the two highest exposures in this TDS; while the exposure in Jilin residents (0.559 ng/kg body weight per day) was the lowest. BPF and BPAF presented dietary exposures of 0.485 ng/kg body weight per day and 0.384 ng/kg body weight per day, respectively.

The contributions of different food categories to total EDI of BPs are shown in Figure 2. The main dietary contributors for BPA were cereals (40.3%), water and beverage (17.4%) as well as vegetables (13.7%). As for BPS, the dominant contribution food groups were cereals (31.4%), followed by meats (25.4%), legumes (11.7%), vegetables (11.7%) and water and beverages (8.76%). Legumes (41.2%), meats (20.7%), and fruits (11.7%) were the top three contributors of BPF. Exposure to BPAF was mainly from cereals (22.6%), aquatic foods (21.5%) and vegetables (21.2%).

**DISCUSSION**

In the Sixth China TDS, BPS posed a comparable rate of detection as BPA, demonstrating the wide use of BPs. Compared to BPA and BPS, BPF and BPAF appeared to possess evidently lower rates of detection and detection levels. Similar trends were found in the Fifth China TDS (8) and several other reports (10–11).

Considering the similar endocrine disrupting properties and other toxicological effects of BPs, the exposure levels of BPA, BPS, BPF, and BPAF were summed up to assess the risks through dietary intake. The combined exposure levels (6.45–139 ng/kg body
weight per day, Figure 1) were far below the t-TDI of BPA set by EFSA, which implied that the exposure to BPs for Chinese adults was safe.

BPs were concerning in the past three China TDSs (Supplementary Table S5, available in https://weekly.chinacdc.cn/). The BPA exposures in the Fourth and Fifth TDS were 43.0 ng/kg body weight per day (7 and 217 ng/kg body weight per day (8), respectively. The increase of BPA exposure might be attributed to the feverish growth of China’s BPA consumption from 2000 to 2014. The exposure to BPA in this study was significantly less than that in the Fifth TDS, which may be related to the measures and restrictions of BPA use in China. The exposures to BPS, BPF, and BPAF in the Sixth TDS were also lower than that in the Fifth one.

The most remarkable change was that the exposure to BPS exceeded BPA and became the most dominant BP in the Sixth TDS. In Fujian and Jiangsu, the only two provincial-level administrative divisions (PLADs) where BPs intakes were higher than 100 ng/kg body weight per day, BPS contributed more than 80% of the total BP exposure due to the high levels of BPS in meat from Fujian and cereals from Jiangsu.

It is noteworthy that Jilin implemented the “Restriction on Plastic Bags” from January 1, 2015, stipulating that the production and sale of non-degradable plastic shopping bags and plastic tableware were prohibited throughout the province. It has become China’s first PLAD to fully ban “plastics”. The EDIs of BPA and BPS in Jilin in this study were 5.74 ng/kg body weight per day and 0.559 ng/kg body weight per day, respectively, ranking lowest among the 24 PLADs. These values were lower by more than an order of magnitude than the results in the Fifth TDS (300 ng/kg body weight per day for BPA and 11.7 ng/kg body weight per day for BPS, respectively), indicating that the implementation of the restrictions affected the reduction of BPs contaminants.

The total dietary exposure to BPA in the Sixth China TDS (18.13 ng/kg body weight per day) was lower than that in France (42.4 ng/kg body weight per day) (12), Canada (52–81 ng/kg body weight per day) (6), the United States (44.6 ng/kg body weight per day) (11), and the EFSA (116–159 ng/kg body weight per day).

FIGURE 2. Contribution (% of daily intake) of the food categories to dietary BP intakes for the general Chinese population.

Abbreviation: BP=bisphenolic compound; BPA=bisphenol A; BPS=bisphenol S; BPF=bisphenol F; BPAF=bisphenol AF.

![Diagram of dietary BP intakes for the general Chinese population](image-url)
per day) (2). However, it was higher than that of a recent survey in United States (6.0 ng/kg body weight per day) (13). The diversity in food consumption habits may be a potential reason for the relatively high BPA exposure to these Western countries.

This study has several limitations. Only composite samples were analyzed for the dietary intake assessment of population in a given region, which could reveal realistic information by virtue of appropriate selection of the composite sample size and retesting of select individual samples. As for the samples with extremely high levels of contamination, the original individual samples can be assessed instead. The estimated BPs intake was based on a standard Chinese male adult (18–45 years). There was a lack of the dietary exposure data of 0–18 years-old people in this study. Furthermore, young-aged people and pregnant women are prone to be vulnerable to the endocrine disrupting compounds. The chlorinated derivatives of BPA and BPS reported higher estrogenic activity and other potential toxicities. It is necessary to continuously monitor the dietary exposure of the various BPs, including the chlorinated derivatives.

This study investigated the contamination of BPs in composite food samples from the Sixth China TDS during 2016–2019. BPA and BPS were detected in more than 75% of the food samples. Dietary intakes of BPs for Chinese adults were below the t-TDI, and the major contribution was from cereals, water and beverages, meat, and vegetables. The exposure of BPs in the Sixth TDS exceeded that of BPA. This implies the need to strengthen the monitoring of BPs in foodstuffs.

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### SUPPLEMENTARY TABLE S1. Levels of BPA in composites food samples from the Sixth China Total Diet Study (μg/kg).

| Food category | Cereals | Legumes | Potatoes | Meat | Eggs | Aquatic birds | Vegetables | Fruits | Water and beverages | Alcoholic beverages | Alcohol (LN) | China CDC Weekly (ND) | LN | HE | BJ | JX | JS | ZJ | SD | HB | SC | GX | QX | GD | GZ |
|---------------|---------|---------|----------|------|------|--------------|------------|--------|---------------------|---------------------|-------------|---------------------|-----|----|----|----|----|----|----|----|----|----|----|----|----|
|               | ND      | ND      | ND       | ND   | ND   | 0.016        | 0.073      | ND     | ND                  | ND                  | ND          | ND                  | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Vegetables    | ND      | ND      | ND       | ND   | ND   | 0.029        | 0.203      | ND     | ND                  | ND                  | ND          | ND                  | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Fruits        | ND      | ND      | ND       | ND   | ND   | 0.021        | 0.154      | ND     | ND                  | ND                  | ND          | ND                  | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Water and beverages | ND | ND | ND | ND | ND | 0.028 | 0.129 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Alcoholic beverages | ND | ND | ND | ND | ND | 0.028 | 0.129 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |

Note: ND: non-detectable value. Presented as 1/2 LOD in calculations.
### SUPPLEMENTARY TABLE S3. Levels of BPF in composites food samples from the Sixth China Total Diet Study (μg/kg).

| Food categories      | HL | LN | HE | BJ | JL | SX | SN | HA | NX | NM | QH | GS | SH | FJ | JX | JS | ZJ | SD | HB | SC | GX | HN | GD | GZ |
|-----------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Cereals               | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.169 |
| Legumes               | ND | 0.184 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Potatoes              | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Meat                  | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Eggs                  | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Aquatic foods         | 0.169 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Milk                  | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Vegetables            | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Fruits                | 0.169 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Sugars                | 0.26 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Water and beverages   | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Alcoholic beverages   | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |

Note: ND: non-detected value, assigned 0 in calculations.

### SUPPLEMENTARY TABLE S4. Levels of BPAF in composites food samples from the Sixth China Total Diet Study (μg/kg).

| Food categories      | HL | LN | HE | BJ | JL | SX | SN | HA | NX | NM | QH | GS | SH | FJ | JX | JS | ZJ | SD | HB | SC | GX | HN | GD | GZ |
|-----------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Cereals               | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.015 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Legumes               | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Potatoes              | ND | 0.024 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Meat                  | ND | 0.530 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Eggs                  | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Aquatic foods         | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Milk                  | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Vegetables            | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Fruits                | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Sugars                | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Water and beverages   | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Alcoholic beverages   | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |

Note: ND: non-detected value, assigned 0 in calculations.
SUPPLEMENTARY TABLE S5. Estimated BPA and its analogues exposures in three Total Diet Studys (ng/kg body weight per day).

| Compound | The Fourth TDS 2007 | The Fifth TDS 2010–2012 | The Sixth TDS (this study) 2016–2019 |
|----------|---------------------|--------------------------|--------------------------------------|
| BPA      | 43                  | 217                      | 18.1                                 |
| BPS      | –                   | 25.6                     | 22.2                                 |
| BPF      | –                   | 25.1                     | 0.485                                |
| BPAF     | –                   | 0.499                    | 0.384                                |

Note: “−” means not detected.

Abbreviations: BPA=bisphenol A; BPS=bisphenol S; BPF=bisphenol F; BPAF=bisphenol AF; TDS=Total Diet Studys.