Brominated Flame Retardants in Serum from General Population in North China

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Abstract

One hundred and twenty-eight serum samples were collected in 2006 from three populations in Tianjin, China: office cleaners, university students, and policemen. These samples were all analyzed for polybrominated diphenyl ethers (PBDEs) and for other brominated flame retardants (BFRs). The median concentration of total PBDEs was 7.1 ng/g lipid weight, ranging from 0.48 to 1980 ng/g lipid. Among these PBDE congeners, the median sum of the tri- to hepta-PBDEs ($\Sigma PBDE_{3\text{-}7}$) congener concentrations was 2.9 ng/g lipid, ranging from 0.48 to 20 ng/g lipid. The most common tri- to heptabrominated congeners were BDE-47 (30%), BDE-99 (24%), BDE-183 (15%), BDE-153 (12%), BDE-28 (9.5%) and BDE-100 (6.2%). Compared to other countries, these levels of $\Sigma PBDE_{3\text{-}7}$ were similar to those observed in Europe and Asia but were much lower than those observed in North America. Highly brominated BDEs congeners were detected in some serum samples. In particular, BDE-209 was detected in 28 samples, and the median BDE-209 concentration in these samples was 42 ng/g lipid, ranging from 8.8 to 1770 ng/g lipid. The total PBDE levels in office cleaners were significantly higher than in university students and policemen. In addition, we also measured several other BFRs. Hexabromobenzene (HBB) was identified in 26 samples with a median concentration in these samples of 0.27 ng/g lipid, ranging from 0.11 to 1.50 ng/g lipid. Pentabromoethylbenzene (PBEB), hexabromocyclododecane (HBCD), 1,2-*bis*(2,4,6-tribromophenoxy)ethane (BTBPE), and decabromodiphenylethane (DBDPE) were not detected in any of these samples.

Key Words: Brominated flame retardants (BFRs); polybrominated diphenyl ethers (PBDEs); human serum; general population; North China

Introduction

Polybrominated diphenyl ethers (PBDEs) are a group of commonly used brominated flame retardants; in 2001, their annual world market demand was over 67,000 metric tons according to a report published by the Bromine Science and Environmental Forum. There are three kinds of PBDE commercial products: Penta-BDE, Octa-BDE, and Deca-BDE. Toxicological studies in animal models suggest that the effects of PBDEs are similar to those of PCBs with an increased risk of neurodevelopmental deficits, immunotoxicity, reproductive effects, teratogenicity, and endocrine disruption (1, 2). The majority of studies on human exposure are from North America, Europe, Japan, and Korea, and little is known about PBDE levels in the Chinese population, especially in northern China. There have been only three reports on PBDE levels in Chinese human serum (3-5), and all of them have focused on occupational exposures in the e-waste industry in Guangdong province, which is located in southern China.

The present study investigated the levels of BFRs in three populations from Tianjin, a typical industrial metropolis in North China. The three populations were office cleaners, university students, and policemen; 128 samples were collected in 2006. The PBDE concentrations and congener patterns were analyzed as a function of occupation category, age, and gender.

Materials and Methods

Chemicals. All standard solutions were purchased from Wellington Laboratories (Ontario, Canada). Standard mixture "BFR-PAR" contained 41 PBDE congeners at different concentrations and pentabromoethylbenzene (PBEB), hexabromobenzene (HBB), 1,2-*bis*(2,4,6-tri- bromophenoxy)ethane

(BTBPE), decabromodiphenylethane (DBDPE), and hexabromocyclododecane (HBCD) at concentrations of 50 µg/mL each. Surrogate standards, BDE-77 and $^{13}C_{12}$-BDE-209, were used to monitor the method recovery of PBDEs. The internal standard, BDE-118, was used for the quantitation of the tri- to hepta- BDEs, and $^{13}C_{12}$-BDE-206 was used for the quantitation of the octa- to deca-BDEs.

Serum Sampling and Preparation. One hundred and twenty-eight serum samples were collected from non-occupationally exposed people at a hospital in Tianjin, China in 2006. They were 30 office cleaners (17 males and 13 females, 21-51 years old), 69 university students (25 males and 44 females, 21-24 years old) and 29 policemen (all males, 23-52 years old). All subjects were given information about PBDEs, and they voluntarily agreed to participate in the investigation. Serum samples were thawed before analysis. Each serum sample was transferred into a clean centrifuge tube. BDE-77 (1 ng/sample) and $^{13}C_{12}$-BDE-209 (2.5 ng/sample) were added as surrogate standards. Hydrochloric acid (6 M, 0.5 mL) was added, and the sample was rigorous blended on a vortex mixer. Three mL of 2-propanol was then added, and the sample was mixed again. The samples were subsequently extracted twice with a 1:1 hexane/MTBE mixture (5 mL each). The organic fractions were combined and evaporated under a gentle stream of nitrogen. After measuring the lipid content gravimetrically, the lipids were removed by adding 4 mL of concentrated sulfuric acid, and this mixture was washed with 3 mL hexane twice. The combined hexane fraction was blown down to 0.5 mL with nitrogen and loaded on a 6.5 cm × 1.9 cm (i.d.) alumina column. Two fractions of 8 mL each were collected using hexane and 40% dichloromethane in hexane. The second fraction was reduced to ~0.1 mL, and internal standards (0.5 ng of BDE-118 and 1 ng of $^{13}C_{12}$-BDE-206) were added.

Instrumental Parameters. The samples were analyzed on a Hewlett-Packard 6890 gas chromatograph coupled to an Agilent 5973 mass spectrometer (Agilent Technologies, Santa Clara, CA) with helium as the carrier gas. The mass spectrometer was operated in the electron capture negative ionization (ECNI) mode using methane as the reagent gas. Selected ion monitoring (SIM) used both bromine isotopes at *m/z* 79 and 81 for the BFRs; *m/z* 719.5 and 721.5 for BDE-201; *m/z* 408.8 and 410.8 for BDE-197; *m/z* 561.7 and 563.7 for BDE-203; *m/z* 486.8 and 488.8 for BDE-204 and BDE-206 to BDE-209; and *m/z* 494.6 and 496.6 for $^{13}C_{12}$-BDE-206 and $^{13}C_{12}$-BDE-209.

Results and Discussion

Concentrations of PBDEs. BDE-47 and 99 were present in all of the serum samples, and BDE-28, 100, 139, 153, 154, 183, 197, 207, and 208 were detected in more than 50% of samples, BDE-209 was detected in 22% of samples, indicating widespread PBDE contamination in northern Chinese people. The total PBDE concentration (ΣPBDE), which includes all of the congeners analyzed, varied from 0.48 to 1,980 ng/g lipid with a median of 7.1 ng/g lipid and a mean of 46 ng/g lipid.

To compare the levels of PBDE in serum from this study to the data reported in literature, the concentrations of only the most commonly reported congeners (BDE-28, 47, 99, 100, 153, 154, and 183) have been summed, and this sum is defined here as $\Sigma PBDE_{3\text{-}7}$. Figure 1 illustrates the median levels of $\Sigma PBDE_{3\text{-}7}$ in human serum from different countries; the red bar represents the data reported here. Clearly $\Sigma PBDE_{3\text{-}7}$ levels in this study are similar to levels in people from southern China, implying that this level is representative of the median PBDE concentration in the general Chinese population. $\Sigma PBDE_{3\text{-}7}$ levels in China are similar to levels reported in European countries, such as Belgium (3.6 ng/g lipid), Sweden (2.1 ng/g lipid) and Germany (4.5 ng/g lipid) (6-9), New Zealand (5.6 ng/g lipid) (10), and in some regions of Asia such as Japan and Singapore (3, 8, 11). The levels in China are lower than those reported in Korea (14.3 ng/g lipid) (12) and Canada (13.4 ng/g lipid), and much lower than those in Central and North America (13, 14). This geographical distribution of PBDE concentrations was similar to that reported in our previous study of PBDE levels in human milk (15).

For BDE-209, the median and mean values in this study were non-detected and 36.4 ng/g lipid, respectively, varying in the range of non-detected to 1770 ng/g lipid. The highest level of BDE-209 was found in a 39 year old male cleaner. This level was higher than the highest level in rubber workers at 270 ng/g lipid (16). The average concentration of BDE-209 (36 ng/g lipid) was lower than that reported in southern China (130 ng/g lipid), but higher than those reported in other countries, such as Nicaragua and Belgium. This suggests that deca-BDE is widely present in the Chinese environment and can accumulate in

people. Since BDE-209 has a short half-life in human serum (6.8 days), the relatively high concentration of BDE-209 in some serum samples suggests that these people are continuously exposed to BDE-209.

The subjects were divided into three groups according to their occupations: cleaners, university students, and policemen. The median and mean ΣPBDE concentrations and ranges in each group were 11 and 140 ng/g lipid (1.7 to 1980), 6.2 and 15 ng/g lipid (2.1 to 210), and 5.1 and 18 ng/g lipid (0.48 to 150), respectively. Figure 2 illustrates the differences in total PBDE concentrations among the three groups. An analysis of variance (ANOVA) showed that the average logarithmically-transformed concentration in cleaners was significantly higher than those in the university students and policemen ($F = 8.04$, $P < 0.001$). Cleaners in China seldom use vacuum cleaners or wear filter masks; thus, they continuously breathe indoor dust, which could be an important PBDE exposure pathway.

All data were grouped together to investigate the relationships of PBDE concentration in human serum with gender, age, and body mass index (BMI). Persistent lipophilic compounds tend to accumulate in people, and the levels of these compounds tend to increase with age and body fat content and tend to be lower in women. In this study, no correlation was found between the total PBDE concentration and gender, age, or BMI. This result is similar to results reported by others (4, 10, 17). Because PBDEs are relatively new compounds (they started to enter the environment in ~1980), age may not yet be an important factor in explaining their levels in people. On the contrary, PCBs and many chlorinated pesticides started entering the environment in the 1940s, and most people alive today have continuously accumulated these compounds over their entire lifetimes.

Congener profile of PBDEs. The average PBDE congener distribution in these serum samples is shown in Figure 3 as the black bars. The most abundant congener is BDE-209 followed by BDE-197 and 207. The $\Sigma PBDE_{3\text{-}7}$ congeners made up only about 10% of the total PBDE concentration. There are several reports on the detection of BDE-209 in occupationally exposed people (4, 16), but reports on the presence of the BDE-209 in non-occupationally exposed people are rare. The congener pattern reported here are similar to those in e-waste dismantling workers and in referent people in Guangzhou, which is in southern China, (4), but much different than those in people from other countries, in which the nona and deca-BDE congeners were not detected or were not abundant in the general population (8, 18).

In order to compare the congener patterns observed here with those from other countries, the sum of the concentrations of the seven most prevalent PBDE congeners (BDE-28, 47, 99, 100, 153, 154, and 183) was normalized to 100%. The resulting PBDE congener patterns are shown in Figure 4. The predominant congeners in Chinese people were BDE-47 (30%) and BDE-99 (24%), followed by BDE-183 (15%), BDE-153 (12%), BDE-28 (9.5%), BDE-100 (6.2%), and BDE-154 (3.7%). These data show that BDE-47 was relatively low in China (< 30%) compared to other countries (33%-51%). BDE-47 is the predominant congener in human milk, human blood, and adipose in North America and in some European countries (Thomsen 2001, Meironyte 1999, Schecter 2003). In Asian countries, such as Korea and China, the contribution of BDE-183 (~15%) was much higher compared to other countries (0-5%). Since BDE-183 is the major component in the octa-BDE commercial product, this finding may suggest that relatively large amounts of Octa-BDE have been used in China. We also noted that the contribution of BDE-28 (~10%) was relatively higher in the serum of Chinese people compared to other countries, with the exception of Norway. The reason for this observation is not yet clear.

The congener pattern in human serum is consistent to what we found in human milk in the same area of China (15). In both cases, the more highly brominated PBDEs are the most significant contributor contaminating the general population in China. This result may reflect the market demand of PBDEs in China. By comparing each congener among the three population groups using an ANOVA, it was found that the more highly brominated congeners, such as BDE-153, 154, 183, 207, 208, and 209, were significantly more concentrated in the cleaners than in the students ($P < 0.02$), but there were fewer distinct differences for the levels of BDE-28, 47, 99 and 100 among the three population groups. This suggests that cleaners might be preferentially accumulating the more brominated congeners through inhalation or ingestion of dust particles.

We also measured several non-PBDE flame retardants in these samples. HBB was detected in 26 (20%) of the serum samples; the median and mean concentrations in these 26 samples were 0.27 and 0.46 ng/g lipid, respectively. HBCD was only found in one male cleaner at 133 ng/g lipid. PBEB, BTBPE and

DBDPE were not detected in any of these samples. The absence of these compounds is a bit surprising given that the estimated domestic production volumes in 2006 were 20,000, 12,000 and 4,500 metric tons for deca-BDE, DBDPE and HBCD, respectively (Xiao, 2006) and given that both BTBPE and DBDPE were found in tree bark samples from Tianjin at levels of 0.5 and 2.9 ng/g bark, respectively (19), suggesting that these chemicals are widely present in the environment of China. Perhaps, HBCD, BTBPE, and DBDPE do not readily bioaccumulate or are metabolized in people.

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References

1. Hallgren, S.; Darnerud, P. O., Polybrominated diphenyl ethers (PBDEs), polychlorinated biphenyls (PCBs) and chlorinated paraffins (CPs) in rats--testing interactions and mechanisms for thyroid hormone effects. *Toxicology* **2002,** *177*, 227-243.

2. Branchi, I.; Capone, F.; Alleva, E.; Costa, L. G., Polybrominated Diphenyl Ethers: Neurobehavioral Effects Following Developmental Exposure. *NeuroToxicology* **2003,** *24*, 449-462.

3. Bi, X.; Qu, W.; Sheng, G.; Zhang, W.; Mai, B.; Chen, D.; Yu, L.; Fu, J., Polybrominated diphenyl ethers in South China maternal and fetal blood and breast milk. *Environmental Pollution* **2006,** *144*, 1024-1030.

4. Bi, X.; Thomas, G. O.; Jones, K. C.; Qu, W.; Sheng, G.; Martin, F. L.; Fu, J., Exposure of Electronics Dismantling Workers to Polybrominated Diphenyl Ethers, Polychlorinated Biphenyls, and Organochlorine Pesticides in South China. In *Environmental Science & Technology*, 2007; Vol. 41, pp 5647-5653.

5. Qu, W.; Bi, X.; Sheng, G.; Lu, S.; Fu, J.; Yuan, J.; Li, L., Exposure to polybrominated diphenyl ethers among workers at an electronic waste dismantling region in Guangdong, China. *Environment International* **2007,** *33*, 1029-1034.

6. Thomsen, C.; Lundanes, E.; Becher, G., Brominated Flame Retardants in Archived Serum Samples from Norway:A Study on Temporal Trends and the Role of Age. In *Environmental Science & Technology*, 2002; Vol. 36, pp 1414-1418.

7. Guvenius, D. M.; Aronsson, A.; Ekman-Ordeberg, G.; Bergman, Å.; Norén, K., Human Prenatal and Postnatal Exposure to Polybrominated Diphenyl Ethers, Polychlorinated Biphenyls, Polychlorobiphenylols, and Pentachlorophenol. *Environmental Health Perspectives* **2003,** *111*, 1235-1241.

8. Hites, R. A., Polybrominated Diphenyl Ethers in the Environment and in People: A Meta-Analysis of Concentrations. In *Environmental Science & Technology*, 2004; Vol. 38, pp 945-956.

9. Thomas, G. O.; Wilkinson, M.; Hodson, S.; Jones, K. C., Organohalogen chemicals in human blood from the United Kingdom. *Environmental Pollution* **2006,** *141*, 30-41.

10. Harrad, S.; Porter, L., Concentrations of polybrominated diphenyl ethers in blood serum from New Zealand. *Chemosphere* **2007,** *66*, 2019-2023.

11. Tan, J.; Loganath, A.; Seng Chong, Y.; Philip Obbard, J., Persistent organic pollutants in human blood: A review of global data with a comparison to the Singapore population. In *Toxicological & Environmental Chemistry*, Taylor & Francis: 2008; Vol. 90, pp 837 - 859.

12. Lee, S.-J.; Ikonomou, M. G.; Park, H.; Baek, S.-Y.; Chang, Y.-S., Polybrominated diphenyl ethers in blood from Korean incinerator workers and general population. *Chemosphere* **2007,** *67*, 489-497.

13. Sjödin, A.; Jones, R. S.; Focant, J.-F.; Lapeza, C.; Wang, R. Y.; McGahee III, E. E.; Yalin, Z.; Turner, W. E.; Slazyk, B.; Needham, L. L.; Patterson Jr, D. G., Retrospective Time-Trend Study of Polybrominated Diphenyl Ether and Polybrominated and Polychlorinated Biphenyl Levels in Human Serum from the United States. . *Environ Health*

Perspect **2004,** *112*, 655-658.

14. Sandanger, T. M.; Sinotte, M.; Dumas, P.; Marchand, M.; Sandau, C. D.; Pereg, D.; Bérubé, S.; Brisson, J.; Ayotte, P., Plasma Concentrations of Selected Organobromine Compounds and Polychlorinated Biphenyls in Postmenopausal Women of Québec, Canada. *Environmental Health Perspectives Volume* **2007,** *115*, 1429–1434.

15. Zhu, L.; Ma, B.; Li, J.; Wu, Y.; Gong, J., Distribution of Polybrominated Diphenyl Ethers in Breast Milk from North China: Implication of Exposure Pathways. *Chemosphere* **2009,** *impress*, Distribution of Polybrominated Diphenyl Ethers in Breast Milk from North China: Implication of Exposure Pathways.

16. Thuresson, K.; Bergman, A.; Jakobsson, K., Occupational Exposure to Commercial Decabromodiphenyl Ether in Workers Manufacturing or Handling Flame-Retarded Rubber. In *Environmental Science & Technology*, 2005; Vol. 39, pp 1980-1986.

17. Thomsen, C.; Liane, V. H.; Becher, G., Automated solid-phase extraction for the determination of polybrominated diphenyl ethers and polychlorinated biphenyls in serum : application on archived Norwegian samples from 1977 to 2003. *Journal of Chromatography B* **2007,** *846*, 252-263.

18. Sjödin, A.; Patterson, D. G.; Bergman, Å., A review on human exposure to brominated flame retardants--particularly polybrominated diphenyl ethers. *Environment International* **2003,** *29*, 829-839.

19. Qiu, X.; Hites, R. A., Dechlorane Plus and Other Flame Retardants in Tree Bark from the Northeastern United States. *Environmental Science & Technology* **2008,** *42*, 31-36.

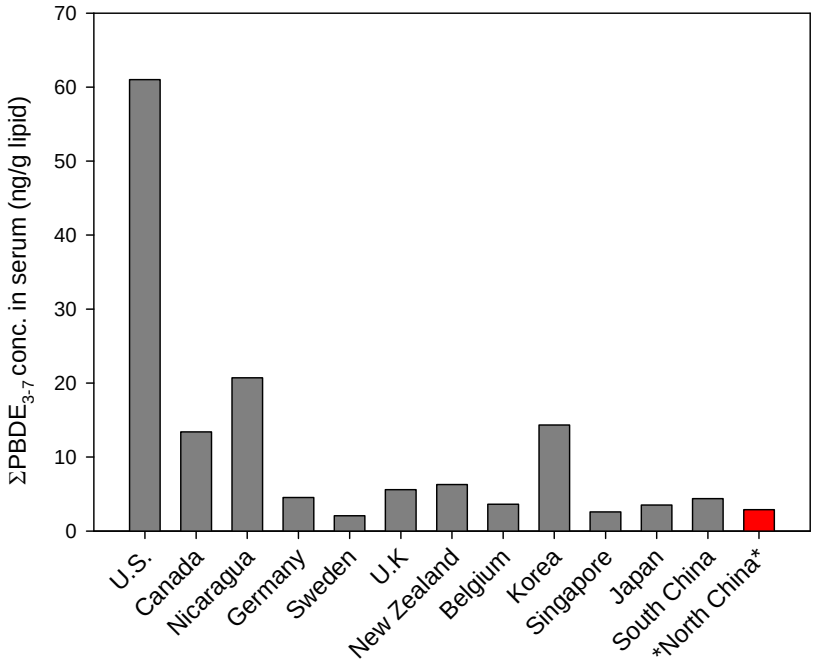

Figure 1. Median $\Sigma PBDE_{3\text{-}7}$ concentrations (ng/g lipid) in human serum from different countries.

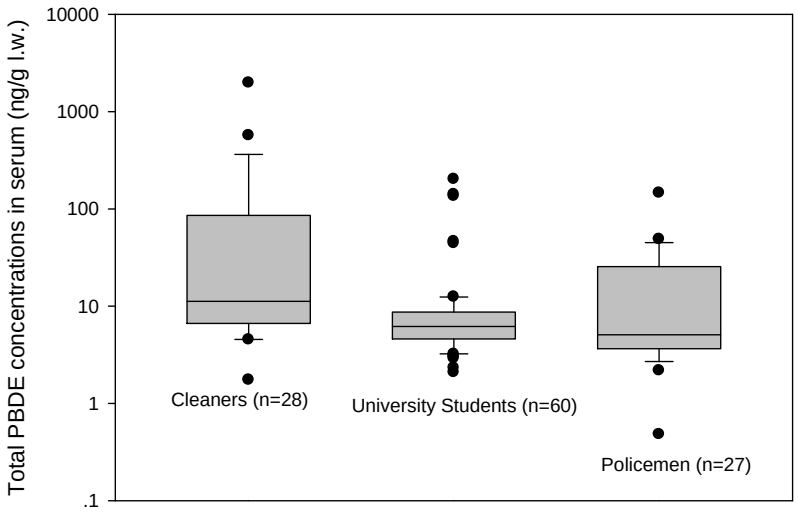

Figure 2. Comparison of total PBDE concentrations in the three groups of participants.

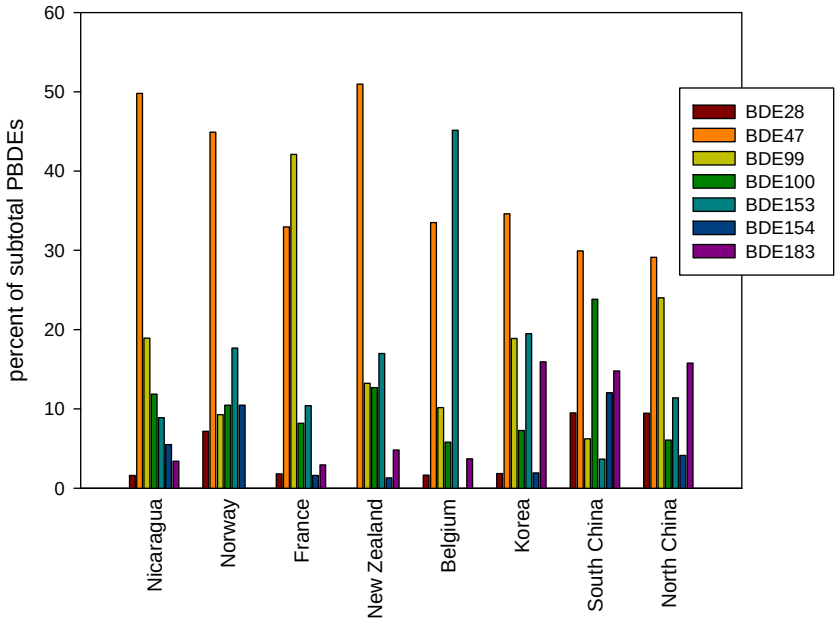

Figure 3. Comparison of PBDE congener profiles in serum from different regions in the world. The data was normalized to the sum of BDE-28, 47, 99, 100, 153, 154, and 183.