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Does flying present a threat of PBDE exposure?

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Abstract

Objective—To investigate possible exposure to polybrominated diphenyl ethers (PBDEs) in US professional airline workers.

Methods—We recruited 30 healthy US professional airline workers who lived in the Dallas, TX area to test their blood PBDE levels. We examined the relationship between hours worked in an airplane to total PBDE blood levels.

Results—Total PBDE blood levels from the 30 volunteers were unremarkable despite minor elevations of certain congeners in a few volunteers. No statistically significant correlations were noted between hours in airplanes in the past one or five years and levels of individual BDE congeners or total PBDEs.

Conclusions—We hypothesized that elevated PBDE levels in commercial aviation workers could be found associated with time spent in airliners. Our findings do not support such an association.

Introduction

Polybrominated diphenyl ethers (PBDEs) are brominated flame retardants (BFRs) widely used in the United States since the 1970's [1]. They are persistent organic pollutants (POPs) used in a variety of applications, such as in the manufacture of foam used in sofas, chairs, and mattresses; and in electronics and plastic casings, such as television sets, computers, and computer monitors 2. Because they are additive compounds and not covalently bound, they can dissociate from products and accumulate at low levels in air and at much higher levels in dust 3–4. They are found in food, such as fruits and vegetables, and in much higher levels in meat, fish, and dairy products 5[–12]. Human intake is primarily from food and dust [6, 13–14]. PBDEs have similar chemical structure and toxic profiles as PCBs, [1]and have been associated with cancer [15], reproductive and developmental pathology [16–17], decreased

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thyroid function [17], endocrine disruption [17–19], and neurotoxicological effects [20–24]. Recently, prenatal exposure to PBDEs has been associated with effects on neurodevelopment, including reduced scores on mental development, psychomotor development, and IQ tests [25]. Serum PBDE concentrations have also been associated with a decrease in fecundity as measured by time to pregnancy [26]. PBDEs have been increasing in blood and milk in the general population worldwide in industrial countries during the past few decades [27–28]. Body burden of PBDEs is orders of magnitude higher in the U.S. population than in Europe because of greater use in the US [6, 28–29]. Certain exposed workers, especially in less developed countries, have marked elevation of PBDEs 30; other workers have less striking PBDE elevations [31]. In the US and European Union (EU) countries, PBDEs are being phased out either by regulations or consent decrees [32–33].; however, PBDEs will remain in the environment for a considerable amount of time because of their persistence and resistance to degradation 1. POPs exist in landfills where products containing PBDEs are dumped without specific disposal strategies, and it is expected that there will be low level contamination in humans for decades to come [1, 13, 34–35].

PBDE exposure can lead to increased body burden of this class of brominated flame retardant, especially in highly exposed workers [30, 36–40]. One recent article suggests that passengers flying in airplanes may have increased exposure to PBDEs reflected by elevated blood levels following flight as compared to levels prior to their flight or flights [41]. Possible PBDE exposure in airplane cabins could originate from PBDEs in carpet liners, seat cushions, and plastics used for luggage storage or in electronics, each of which is sometimes manufactured using PBDEs [36, 42]. To expand on the Christiansson et al study, we organized a study of potentially highly exposed airline workers, either flight attendants or pilots. In a brief letter following a preliminary study, we reported no increase in total PBDE blood levels in 9 US flight attendants and 1 U.S. pilot with thousands of hours spent working in aircraft [43]. This article extends our previous study with measurement of PBDE blood levels in 30 U.S. professional airline workers, which includes the initial 10 study participants.

The half-lives of PBDEs, although not yet well characterized, vary depending upon the level of bromination. Thuresson et al estimated the half life of the deca congener, BDE 209, to be 15 days based on human data, whereas the hepta congener, BDE 183, has a half life of 94 days [44]. Geyer et al estimated human PBDE congener half-lives based on rodent data and estimated values ranging from 1.8 to 11.7 years for some tetra (BDE 47), penta (BDE 99), and hexabrominated (BDE 153) congeners [45]. Therefore, the airline workers' PBDE blood levels, with sampling several days after their most recent flight, should represent recent and previous exposures 46–47.

Materials and Methods

Volunteer Recruitment

The Institutional Review Committees of the University of Texas Health Science Center at Houston and the University of Texas Southwestern Medical Center in Dallas approved the research protocol. Informed consent was obtained from each volunteer prior to enrollment in the study. Recruitment was initially by word of mouth from members of the research team and subsequently by the airline workers themselves. Most volunteers lived in or around Dallas, Texas, usually for many years prior to entry in the study. Volunteers had to be in good health and between the ages of 18 and 70 years; there were no gender, ethnic, or religious exclusions. All participants worked for at least the previous 5 consecutive years in their positions as pilots or flight attendants. All had blood obtained a short time after their last flight. Blood was collected at a research clinic at the University of Texas Southwestern Medical Center by a trained phlebotomist. Each volunteer completed a questionnaire that included number of hours worked in commercial airplanes in the past year and five years,

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age, residence, present and past occupational status, health conditions, and known exposure to toxic chemicals. Approximately 50 mL of whole blood was collected; serum was extracted by centrifugation and used for analysis. Blood was stored at −80 degrees C, sent by express delivery to Eurofins laboratory on dry ice, and kept in a deep freezer until analyzed.

Analytic Methods

All analyses were performed following the isotope dilution method. Thirty native standards (BDE 17, 25, 28, 35, 37, 47, 49, 66, 77, 85, 99, 100, 119, 126, 138, 140, 153, 154, 155, 181, 183, 190, 203, and 207) were obtained from Cambridge Isotope Laboratories, Andover, Massachusetts, USA. Other native standards (BDE 71, 156, 197, and 209) were either from Wellington Laboratories, Guelph, Canada, or from Accu Standards (BDE 75 and 116). Six internal C^{13} labelled standards (BDE 28, 47, 99, 153, 154, 183 and 209) were from Wellington, Canada; one (BDE 100) was from Cambridge Isotope Laboratories. For quality control, each block of samples (6 – 10 samples) had a QC pool (U.S. human serum) and a laboratory blank analyzed in parallel. Blank concentrations for BDEs 28, 47, 99, 100, 153, 154, 183, 197, and 207 ranged from 0.01 – 0.06 ng/g lipid. The blank concentration for BDE 209 is 1.2 ng/g lipid. The internal standards, 20 g water and 5 mL ethanol, were added to 20 g whole blood. Twenty mL hexane was then added, mixed, centrifuged, and cooled overnight. After solvent evaporation, gravimetric lipid determination was performed.

Acid treatment, activated silica gel, and alumina oxide column clean up was employed. The final extract was reduced in volume by a stream of nitrogen. The measurements were performed using high-resolution gas chromatography /high resolution mass spectrometry (HRGC /HRMS, Thermo Trace Ultra GC coupled with Thermo Fisher DFS) at RP = 10,000 using a DB 1 (15 m, 0.18 mm ID, 0.18 μm film) column for gas chromatographic separation. The two most abundant masses were used for measurement (M+ for Tri- and Tetra-BDE, and M−2BR+ for Penta- to Deca-BDE). The identification of BDEs was based on retention time and isotope ratio. The quantification was performed using a five point calibration curve.

Reduction of solvents and control of blank data is important in quality control when analyzing PBDEs at ultra trace levels. Solvents and reagents were tested for contamination prior to analytic procedures. All glassware was rinsed with solvents prior to use. Silica gel and sodium sulphate were pre-washed. Rotary evaporators were not used to reduce the risk of contamination. No plastic equipment was used. Quantification was only done if sample data was at least twice the blank value.

Detailed methods used by Eurofins laboratory for analysis of PBDEs in blood have been described elsewhere [48]. PBDE congeners BDE 17, 28, 47, 66, 77, 85, 99, 100, 138, 153, 154, 183, 203, 207, and 209 were measured.

Statistical Analyses

Individual congener levels were log transformed and Spearman rank correlation coefficients were calculated between PBDE congener levels and hours flown in the last year or last five years, age, and years served. The Bonferonni correction was used to adjust for multiple comparisons. Factor analysis was conducted to detect patterns in PBDE congener distribution as described previously [49]. Factor selection was based on eigen values, screen plots, as well as a requirement that at least 80% of the variation was explained by the factors. Varimax (orthogonal) pattern rotation was utilized. A three dimensional scatterplot was constructed with rotated factor loadings. Descriptive statistics, correlations, factor

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analysis and three-dimensional scatterplots were performed using R 2.10.1 (R Foundation for Statistical Computing, 2010).

Results and Discussion

The volunteers' occupational and demographic characteristics are summarized in Table 1. The 7 male and 23 female volunteers varied in age, from 32–61 years. Each had 480 to 3,000 hours of time working in airliners over the past year and 2,500 to 15,000 hours over the previous five years. Table 2 presents the individual and total blood levels of PBDEs in each volunteer by subject number. Figure 1 provides levels of highest detected individual BDE congeners by volunteer number.

Total PBDE blood levels, determined as the sum of all detected congeners from the 30 volunteers, was not elevated compared to other recent reports of PBDEs in blood in the general US population. [50–51]. This holds true when comparing PBDE levels from our study population to the 2003–2004 NHANES population as reported by Sjodin et al. The total PBDE blood level concentration measured in our study is, in fact, lower than the levels found in the NHANES population. NHANES totals are reported as sums of PBDE congeners BDE 28, 47, 99, 100, and 153. For the 20–39 year old age group, the geometric mean for total PBDE levels was 30.8 ng/g lipid. For 40–59 year olds, the geometric mean was 26.7 ng/g lipid, and for 60+ year olds, 65.6 ng/g lipid [50]. Within our study, the total PBDE levels for these specific 5 congeners ranged from 3.2 to 143.5 ng/g lipid with a geometric mean of 21.16 ng/g lipid.

Within our analysis, we also calculated total PBDE levels using all thirteen PBDE congeners that were measured. In order to make better comparisons to previous studies that did not measure BDE-209, we include totals both with and without BDE 209. Excluding BDE 209, the total PBDE blood level median was 27 ng/g lipid and the range was 9–149 ng/g. Including BDE 209, the PBDE blood level median was 31 ng/g and the range was 11–149 ng/g. BDE 209 itself had a median of 2 ng/g with a range of 0–41 ng/g. While a few of the airline workers in this study had elevated levels of BDE 47, 99, and 209, there do not appear to be uniform elevations in our study population.

In order to better explain the patterns of specific PBDE congeners, a factor analysis was performed in which a three factor solution was found to explain 83% of the variation in the data. To determine relationships between congeners, the individual congeners were plotted on the loading scores of the first three factors. To aid in visualizing the relationship, we grouped congeners by numbers of bromines present on the molecule. The one hexa-brominated congener we measured, BDE 153, is found in both the pentaBDE and octaBDE commercial mixtures [52]. Therefore, we labeled this congener separately on the figure. Clear clustering by molecular weight was observed, particularly for tri, tetra, and pentabrominated congeners. In factor analysis, a clear separation was noted between tri-, tetra-, and pentabrominated congeners and hepta-, octa-, nona-, and decabrominated congeners, suggesting that individuals were exposed to either lower brominated or higher brominated congeners, but not both. Interestingly, BDE 153 clustered with the highly brominated congeners on the first factor, but with the lower brominated congeners on the second factor. This can likely be explained by BDE 153's presence in both the pentaBDE and octaBDE commercial mixture. Unfortunately, due to lack of information regarding non-occupational exposures, we are unable to differentiate routes of exposure to the various commercial mixtures.

No statistically significant correlations were noted between hours in airplanes in the past one or past five years and levels for individual BDE congeners or total PBDEs. Therefore, it

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seems reasonable to conclude that time spent in aircraft cabins does not constitute a substantial enough PBDE exposure to increase PBDE body burden above the day to day exposure of the general public. Total PBDE levels were also not correlated with age of the airline worker. The few elevated PBDE congeners measured in several commercial aviation workers are most likely due to non-occupational exposures.

Other occupational exposure to PBDEs and corresponding elevated blood levels of PBDEs has been documented previously. A study of Nicaraguan children working and/or living in municipal waste disposal sites compared to nonworking children living in nearby urban areas found relatively high levels of BDE 28, 27, 66, 100, 99, 85, 154, and 153, with minimal differences found in BDE 183 and 209 levels [30]. In a study by Stapleton et. al., foam workers and carpet layers were found to have elevated levels of PBDE congeners associated with exposure to the penta-BDE commercial mixture compared to the general population [53]. However, octa-, nona-, and decabrominated congeners were not measured in the study to compare between occupationally exposed cases and controls. Within our occupational cohort, the results are not consistent with the hypothesis that flying in commercial aircrafts leads to elevated PBDE exposure and body burden. The disparity between our results and those presented in the prior study by Christiansson et al. 2008 may be explained in several ways. PBDE concentrations of different congeners may very well be different between manufacturer, country of origin, model type, and year produced. This variability has been shown in automobiles [54]. The participants in the European study are likely to have flown different airlines and different planes than those within our study. While all of the flight attendants and pilot in this study flew with the same airline, they flew a wide variety of airplane models. Of the 22 out of 30 responses on airplane model that were given, each of the 22 participants predominantly flew more than one airplane model, with some flying on up to 4 different airplanes regularly. Aircraft may have been international and included European, Canadian, or other airlines. Different airlines produce planes to different specifications, and third party companies often provide interior renovations with materials that may possibly contain PBDEs as flame retardants. This variability makes it difficult to pinpoint PBDE exposure to a specific airplane type.

Additionally, differences in overall PBDE levels between European and the American populations may account for the disparate results between our study and the European study. The relatively high levels of PBDEs in Americans may have obscured small increases in PBDEs from exposure on aircraft. The lower PBDE levels found in Europeans may not have hidden these increases in the Christiansson study. Lastly, chance may have played a role in the elevation of five (BDE 28, BDE 99, BDE 100, BDE 153, and BDE 154) of the thirteen measured PBDE congeners in the post-travel blood levels compared to pre-travel blood levels in the relatively small European study, although this is simply a possibility. The median values of these congeners, however, are similar to the levels found in a Swedish group [41]. Despite the large number of hours flown by the U.S. volunteers, it seems likely that there is little risk of elevated PBDE exposure and hence elevated body burden in U.S. commercial aviation workers or passengers flying in commercial airlines. A limitation shared by both our study and the Christiansson study is the relatively small sample size. Our findings do not support the hypothesis that time spent in US commercial airliners is associated with increased PBDE blood levels. Further research with larger and more representative samples is indicated.

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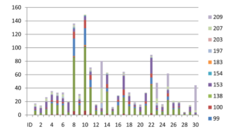

Figure 1.
Levels of PBDEs in Serum in U.S. Airline Workers (ng/g) lipid

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Table 1

Occupational Characteristics of the Volunteers

Volunteer	Gender	Hours Flown in Past Year	Hours Flown in Past Five Years	Profession*	Age	Years of Service
1	M	733	3000	P	54	20
2	F	700	3500	FA	36	15
3	F	1080	5400	FA	45	22
4	F	720	3600	FA	50	22
5	F	480	4200	FA	44	21
6	F	1500	6000	FA	46	19.5
7	F	1104	5520	FA	54	30
8	F	900	4500	FA	52	30
9	M	1200	5000	FA	61	Unknown
10	F	1200	7000	FA	59	25
11	F	1450	7250	FA	55	34
12	F	1350	7500	FA	60	34
13	F	800	4200	FA	60	33
14	F	750	3250	FA	54	31
15	F	750	3250	FA	53	31.5
16	F	500	2500	FA	55	33
17	F	1000	5000	FA	56	31
18	M	1000	5000	FA	35	12
19	F	1000	5000	FA	52	28
20	F	1000	5000	FA	57	33.5
21	F	1000	5000	FA	55	30
22	M	900	4500	FA	45	23
23	M	1400	7000	FA	58	18.5
24	F	3000	15000	FA	53	28
25	F	960	4500	FA	49	22

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Volunteer	**Gender**	**Hours Flown in Past Year**	**Hours Flown in Past Five Years**	**Profession***	**Age**	**Years of Service**
26	M	1200	6000	FA	49	21
27	M	1320	5300	FA	32	12
28	F	1200	6000	FA	61	41
29	F	1200	6000	FA	61	41
30	F	1200	6000	FA	39	39

* P stands indicates Pilot, FA indicates Flight Attendant

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Table 2

Levels of PBDE congeners in Serum of Airline Workers (ng/g (lipid)

ID	*17*	*28*	*47*	*66*	*77*	*85*	*99*	*100*	*138*	*153*	*154*	*183*	*197*	*203*	*207*	*209*	Total
1	(0.03)	0.52	5.80	0.06	(0.01)	0.12	1.30	1.10	(0.03)	3.20	0.13	0.15	0.69	NA	2.30	1.80	**14.00**
2	(0.03)	0.29	2.50	0.05	(0.02)	0.01	0.64	0.37	(0.05)	6.30	0.07	0.19	1.00	(0.40)	1.50	1.20	**12.10**
3	(0.03)	0.67	7.30	0.07	(0.01)	0.13	1.10	1.40	(0.05)	8.80	0.10	0.21	0.97	0.47	3.30	1.90	**22.00**
4	(0.02)	1.00	16.00	0.15	(0.01)	0.17	2.40	2.20	(0.04)	7.90	0.21	0.10	0.78	0.25	2.50	1.90	**32.00**
5	0.15	1.20	13.00	0.13	(0.01)	0.30	2.50	4.70	0.06	6.00	0.32	0.25	1.40	NA	1.20	2.00	**31.00**
6	0.14	0.96	13.00	0.14	(0.01)	0.24	2.60	2.10	0.04	5.20	0.18	0.31	2.10	NA	3.50	3.00	**28.00**
7	0.07	0.25	3.50	0.05	(0.01)	0.09	0.93	0.84	(0.04)	13.00	0.08	0.21	0.34	0.03	0.72	(2.00)	**20.00**
8	0.65	5.00	80.00	0.68	(0.01)	1.50	26.00	10.00	0.16	4.60	1.30	0.40	1.50	NA	1.90	2.40	**133.00**
9	0.13	0.80	13.00	0.12	(0.02)	0.36	2.90	2.50	(0.06)	2.70	0.29	0.26	1.50	0.28	3.60	2.80	**26.00**
10	0.33	5.90	95.00	0.93	(0.01)	2.00	25.00	12.00	0.16	5.60	1.10	0.22	(1.00)	NA	1.10	(1.00)	**149.50**
11	(0.01)	1.60	38.00	0.30	(0.01)	1.50	11.00	7.00	0.17	4.50	0.66	0.37	1.50	0.23	1.40	2.50	**67.10**
12	(0.01)	0.55	5.80	0.03	(0.01)	0.18	1.40	1.60	0.04	4.50	0.16	0.19	0.65	0.23	0.60	(1.00)	**14.50**
13	(0.01)	0.36	4.20	0.03	(0.01)	0.14	0.98	1.00	0.02	3.00	0.14	0.39	7.30	0.89	21.00	41.00	**51.10**
14	0.01	1.70	32.00	0.19	0.01	0.78	5.20	5.90	0.12	14.00	0.47	0.24	1.10	0.24	1.10	(2.00)	**61.00**
15	(0.01)	0.31	5.00	0.03	(0.01)	0.14	1.10	1.00	0.02	1.50	0.10	0.09	0.33	0.15	0.58	1.50	**10.70**
16	0.01	0.44	13.00	0.13	(0.01)	0.62	5.50	2.70	0.10	5.50	0.32	0.08	0.20	0.17	0.31	(1.00)	**28.50**
17	(0.01)	1.80	24.00	0.08	(0.01)	0.42	2.90	8.50	0.13	20.00	0.45	0.56	1.70	0.38	1.30	2.00	**60.70**
18	(0.01)	0.58	12.00	0.07	(0.01)	0.36	3.10	4.00	0.07	7.50	0.33	0.34	1.00	0.28	1.10	2.90	**31.70**
19	(0.01)	0.67	9.30	0.08	(0.01)	0.19	2.10	1.30	0.03	1.80	0.15	0.07	0.40	0.15	0.54	2.00	**17.80**
20	(0.01)	0.31	4.20	0.02	(0.01)	0.14	0.80	0.98	0.02	5.30	0.13	0.10	0.38	0.15	0.60	2.30	**14.20**
21	(0.01)	0.51	13.00	0.05	(0.01)	0.37	2.80	3.40	0.04	12.00	0.20	0.11	0.30	0.19	0.39	(0.90)	**32.50**
22	0.02	2.40	42.00	0.28	0.01	1.40	9.70	5.70	0.15	23.00	0.48	0.20	0.98	0.26	0.87	2.00	**87.60**
23	(0.01)	0.35	6.20	0.05	(0.01)	0.18	1.50	1.50	0.04	4.10	0.26	0.41	2.50	0.66	6.90	23.20	**37.50**
24	(0.01)	0.26	4.40	0.03	(0.01)	0.14	1.10	1.20	0.03	4.40	0.13	0.36	1.20	0.48	0.87	1.50	**13.00**
25	(0.01)	0.77	21.00	0.12	(0.01)	0.51	5.10	4.60	0.10	4.60	0.44	0.32	1.10	0.31	3.40	19.30	**57.90**
26	(0.01)	0.59	7.70	0.07	(0.01)	0.18	2.20	1.10	0.02	5.60	0.22	0.17	1.10	0.22	1.80	ND (4.00)	**20.97**
27	(0.01)	0.64	8.80	0.06	(0.01)	0.16	1.60	1.50	0.02	4.50	0.15	0.27	1.10	0.25	1.40	ND (4.00)	**20.50**

ID	*17*	*28*	*47*	*66*	*77*	*85*	*99*	*100*	*138*	*153*	*154*	*183*	*197*	*203*	*207*	*209*	Total
28	(0.01)	0.23	1.40	(0.01)	(0.01)	0.03	0.23	0.18	(0.01)	1.20	0.07	0.03	0.26	0.13	0.79	ND (4.00)	**4.60**
29	(0.01)	0.30	4.10	0.02	(0.01)	0.01	0.94	0.86	0.02	5.70	0.20	0.18	0.84	0.26	1.40	ND (4.00)	**14.80**
30	(0.01)	0.05	0.79	(0.01)	(0.01)	0.02	0.33	0.18	(0.01)	2.00	0.17	0.09	0.29	0.21	3.10	37.00	**44.20**

*Numbers in parenthesis represent values below the limit of detection, with the limit of detection given. NA are samples not analyzed.

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