Polybrominated diphenyl ethers (PBDEs) in human milk; occurrence worldwide

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Introduction

The seminal papers by Norén and Meironyté [1,2] were instrumental in targeting the presence of polybrominated diphenyl ethers (PBDEs) in man and the environment. These studies showed, in Swedish human milk samples collected in the area of Stockholm in the early 1970s to 1997, that the concentrations of most persistent organic pollutants (POPs) such as PCBs, dioxins/furans, DDTs, and chlordanes decreased by at least a factor of two. A notable exception to this downward trend was the class of brominated compounds, PBDEs used as flame retardants. These compounds increased steadily in the time period and reached levels of 3-4 ug total PBDEs/kg (ppb; 10^{-9}) on a milk lipid basis prior to stabilization or even decreasing somewhat [3-4]. It is now known that PBDEs are ubiquitous environmental contaminants being found in environmental samples, biota, and humans[5-8]. Since this important finding there have been a number of reports on the PBDE content in humans in general and human milk in particular, a food of nutritional, physiological and psychological distinction. Most of these studies have originated from developed countries where brominated flame retardants (BFRs) are widely used for the control of accidental fires. This overview compiled from the scientific literature and unpublished reports gives details of the levels of PBDEs in human milk world wide including our own work in Canada. The data are compared among countries and regions, most notably North America, Europe and Asia. Comparison is also made within Canada between levels from the populous southern regions and the more remote Arctic. The determinants of residues of PBDEs in human milk are also considered as is the possible presence of the deca congener and polybrominated dioxins and furans.

Experimental

Most of the human milk samples have been collected from medical clinics or milk banks with occasional use of *ad hoc* or convenience specimens. In most instances demographic information (age, parity, duration of feeding, and time post partum of sampling) were available but more detailed information on diet and life styles usually were not. Typical methods used to determine PBDEs in human milk involve extraction of the lipid with or without addition of isotope labelled compounds, fat removal and chromatographic separation from related coextracted compounds. Identification and quantification are effected almost always with non polar gas chromatographic (GC) columns coupled to

mass spectrometry (MS). MS techniques used for low resolution GC-MS are either negative chemical ionization (NCI) monitoring the bromine ion at m/z 79/81 or electron impact ionization (EI) monitoring either M^+ or M^+-Br ions. Alternatively, high resolution GC-MS with EI ionization can be used with its higher selectivity and lower detectability. Quality control measures usually consist of MS calibration with a multipoint curve, correction for laboratory blank values (significant for PBDEs) and the repeat analyses of reference samples.

Results and Discussion

The PBDE content of most reported studies on human milk are summarized in table 1 for Europe and in table 2 for North America and Asia. Values are reported as the sum (Σ) of the individual congeners in µg per kg milk lipid (ppb; parts per billion) whose number vary from 4 to 11. Congeners included are always the major contributors to the total, 47, 99, 100, and 153, with smaller contributions from congeners 28, 66, 85, 154, 183. Other pertinent parameters listed by country for the PBDE concentration are the year of collection, the median value and the range. The median is chosen over the mean for individual samples since most studies show a skewed statistical distribution.

Table 1: PBDEs in human milk from Europe

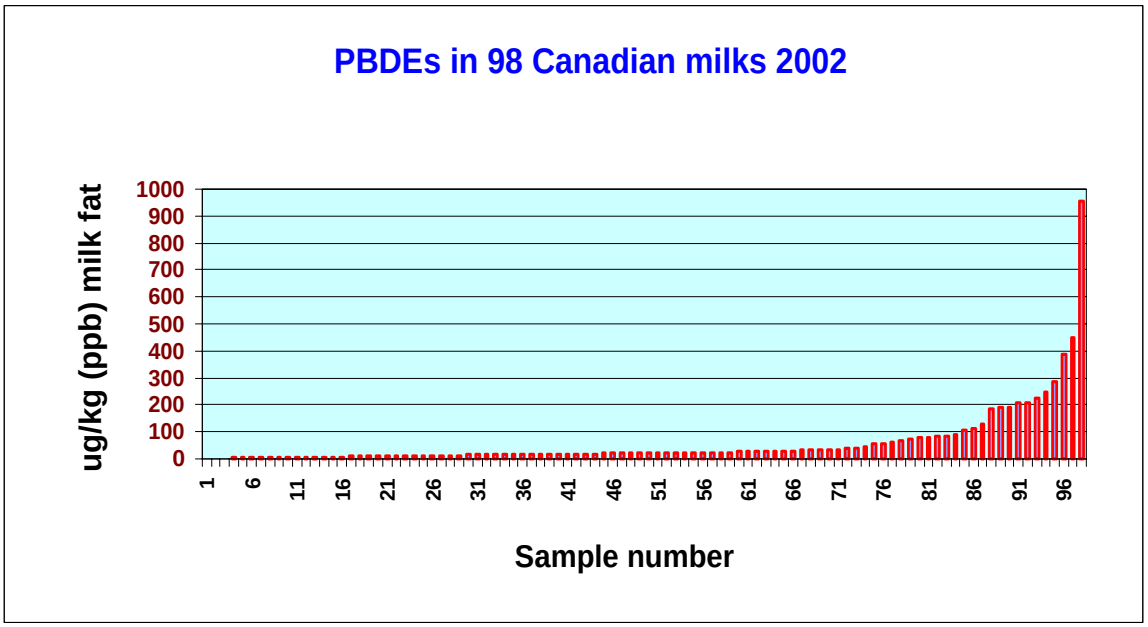
Country	Collection year	Sample Type[a] n= number	Total PBDEs ppb lipid		Reference
			Median	Range	
Sweden	1972 1984-5 1994 1997 2000-1	P; n=227 P; n=102 P; n=20 P; n=40 I; n=15	**0.1** **0.7** **2.2** **4.0** **2.1**	— --- — --- 0.6-7.7	1-3
Sweden	1996-99 2000-1	I; n=93 I; n=31	**3.2** **2.9**	0.9-28 1.5-8.1	4
Germany	1992 2000 2002	P; n>500 I; n=7 I; n=8	**1.7** **1.8** **6.6**	— --- 4.3-12	9 10
Finland	1994-8	I; n=11	**1.6**	0.9-5.9	11
UK	2001-2	I; n=52	**6.6**	0.3-69	12
Norway	1993, 2001 2001	P; n=10-12 I; n=9	**1.9, 2.9** **2.8**	— 2.0-10	13
Holland	1998	I; n=103	**3.3**	1.0-13	14
Belgium	2000-1	I; n=14	**2.9**	---	15

a- P= pooled sample; I= individual samples

Table 2: PBDEs in human milk from North America and Asia					
Country	**Collection year**	**Sample Type n=number**	**Total PBDEs ppb lipid**		**Reference**
			Median	**Range**	
Canada	1982 1986 1992 2001-2	P; n=200 P; n=100 I; n=72 I; n=98	**<0.2** **0.6** **3.0** **22**	— --- 0.6-580 0.8-956	16 16 17 18-20
Canadian Arctic (Nunavik)	1989-91 1996-2000	I; n=20 I; n=20	**1.7** **6.8**	ND -14 0.2-318	19
USA; New York	1997	P; n=17	**147**	---	18
USA	2000	P; n=20	**196**	---	21
USA; Texas	2002	I; n=47	**34**	6.2-419	20
USA	2002-3	I; n=20	**58**	10-1080	22
USA; west coast	2003	I; n=9	**50**	13-156	23
Japan	late 1990's	I; n=12	**1.3**	0.7-1.8	24
Japan	1973 1983 1993 2000 1999	P; n=21 P; n=19 P; n=35 P; n=27 I; n=13	**<0.1** **0.6** **2.3** **1.4** **1.6**	— --- — --- 0.6-4.0 (291)	25

Contemporary PBDE concentrations in Europe and Asia are remarkably similar with median values on a lipid basis for all countries in the low ppb area with a relatively small variation. The situation in North America is completely different with median values for individual studies in the range of 20-50 ppb with some samples reaching values of parts per million (ppm; 10^{-6}). This dichotomy between Europe and North America appears well established and is believed to be linked to the amount of use of BFRs in the respective regions related to standards for the control of accidental fires. Also noteworthy in table 2 is the presence and increase of PBDEs in the Arctic probably related to long range transport. The individual variation of PBDEs is illustrated in figure 1 showing the spread of values for 98 human milks collected in Canada in 2002. The values span more than three orders of magnitude with a few samples showing a much greater level than the mean or median for, as yet, unknown reasons. This variation in general population exposure is not seen with the older more familiar POPs such as PCBs and dioxins.

The pattern of the PBDEs as defined by the number and relative amounts of the individual congeners is comparable both within and even among countries. Congener 47 is always dominant with either congener 99 or 153 second in abundance. This pattern is similar to



that of one of the commercial penta products, Great Lakes DE-71™, in which congener 99 followed by 47 are the highest. It is believed that these congeners are the most bioaccumulative and resistant to degradation.

Determinants of exposure

Several studies[3-5,7] have examined the PBDE concentration in human milk in relation to such common demographic factors as age, body mass index, parity, breast feeding and ethnicity. Other parameters such as diet, smoking, alcohol consumption, partitioning and pharmacokinetics have also been considered. In general and in contrast to known work on other POPs, no consensus or determinative factor which influences the PBDE levels in people has yet been discovered except possibly for fish consumption. This anomaly or uncertainty for the source of PBDEs in humans may be related to correlations between the flame retardants and other POPs. Such correlations are low whereas within the class of POPs correlations are often high and their determinative factors have been established for some time.

Related compounds

A large amount of effort has been invested in order to both measure and define human exposure to the deca congener of PBDEs, i.e. deca 209. This activity is related to the high production and use of this BFR and the possibility of breakdown into known lower brominated congeners. PBDE 209 is relatively difficult to measure and its ubiquity in the environment including the laboratory makes measurement in human milk unreliable. If it is consistently present in human milk, the concentrations are probably low, i.e. less 1 ppb.
The other class of compounds that may impact on PBDE exposure are the polybrominated dibenzodioxins and furans (PBDDs/PBDFs). These materials are even more difficult to measure than any of the PBDEs or the related PCDDs/PCDFs. What few studies that have

been conducted indicate the presence of low and variable parts per trillion (10^{-12}) levels of 2,3,7,8-brominated congeners in human lipid of the general population.

Conclusions

PBDEs occur in human milk samples in all industrialized countries with levels in the ppb range. Concentrations in all countries have increased markedly in the last few decades. Values in North America are about an order of magnitude higher than Europe or Asia. The source and factors giving rise to these body burdens are still relatively unknown.

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