

Isomer-specific biological monitoring of polychlorinated biphenyls

by Marita Luotamo, MSc¹

Polychlorinated biphenyls (PCB) are ubiquitous in the environment. People may be exposed to PCB not only at work or in connection with accidents, but also through the environment. Since different exposures may be of different toxicologic significance, it is important to pinpoint the source and specific type of exposure.

There are, in all, 209 different homologues and isomers of PCB; up to 100 components may be detected in commercial PCB mixtures. There are several commercial PCB products, eg, Clophen A30, A50 and A60, Aroclor 1224, 1232 and 1264, etc, with different levels of chlorination (1, 6, 9) and different isomer compositions (6). In biological specimens the peak pattern usually differs from that of the commercial products because different isomers undergo variable biotransformation and elimination in the organism. The quantitation of PCB in biological material is therefore complicated, and several approaches to this problem have been adopted (3, 7, 12).

The primary objective of this study was to develop an isomer-specific analytical method for measuring parts-per-billion levels of PCB in human serum. The direct assessment of human exposure to PCB was made through analyses of blood and adipose tissue samples.

Materials and methods

The material included 200 serum samples for the assessment of the environmental background level of PCB among workers not known to be exposed to PCB at work or through accidents. More than 100 PCB accidents have taken place in Finland since 1982 (explosions, fires, leaks, etc), and PCB concentrations in serum samples of workers have been monitored in more than 30 accidents. Occupational exposure to PCB was similarly assessed in capacitor manufacturing (seven years after the exposure, N = 42), in capacitor paper manufacturing, and in cleanup work after accidents.

After purification the serum samples were analyzed with capillary gas chromatography. All the analyses were done with an HP 5880A gas chromatograph (splitless injection, silica capillary column OV-1701, temperature programming, electron capture detection).

It is very important to use pure isomers as standards because the detector response for different chloro-substituted PCB may differ by more than 50-fold (4). To verify the identity of the PCB isomers, mass spectrometric analyses were also done using multiple ion detection (Luotamo et al, in preparation).

The different sources of exposure (occupational, accidental, and environmental) could be separated with a pattern recognition method (soft independent modeling of class analogies, SIMCA) for classification (8, 10). For the classification analysis 35 different serum PCB specimens were used (occupational, accidental, and environmental exposure) (3).

Twenty-five different PCB isomers on the di-, tri-, tetra-, penta-, hexa-, and heptachlorination levels were used for gas chromatographic (electron capture) quantitation. Up to 60 additional isomers were used in gas chromatographic-mass spectrometric identification (3, 4, Luotamo et al, unpublished). The quantitation was isomer specific (4).

Results and discussion

Biological monitoring of polychlorinated biphenyls in serum

The summated concentrations of 12 lower chlorinated PCB isomers in serum have been used for the routine biological monitoring of PCB. The reference limit for an unexposed person was set at $<3 \mu\text{g/l}$ [mean 0.7 ($3 \text{ SD } 0.52$) $\mu\text{g/l}$] (4, 5).

In three of the more than 30 accidents, the mean serum PCB concentrations exceeded $15 \mu\text{g/l}$, in five accidents it exceeded $10 \mu\text{g/l}$, and in 14 accidents the serum PCB concentrations exceeded the reference value of $3 \mu\text{g/l}$ for the general population.

The most severe capacitor accident occurred in a paper mill in 1982. Over 100 l of a commercial PCB product (Clophen A30) was involved in a fire in the electricity room, and the plant was partly contaminated through the ventilation system (2). A group of 15 workers was heavily exposed, and 150 workers were at risk to become exposed. Serum specimens were collected from the exposed workers immediately after the accident and one day, one week, two weeks, one month, six months, and one year after the accident. Immediately after the accident, PCB concentrations of up to $50 \mu\text{g/l}$ of serum were measured. All the elevated

¹ Laboratory of Biochemistry, Institute of Occupational Health, Helsinki, Finland.

serum PCB concentrations were reduced to the "normal" level of $<3 \mu\text{g/l}$ within one month. After the accident serum specimens were also collected from the 150 workers who were potentially exposed. In the analysis of the samples an apparent excess exposure was detected only at the group level [mean 1.2 (SD 0.74) $\mu\text{g/l}$] (5).

For a comparison of the different types of exposure, samples were also analyzed from workers engaged in capacitor manufacturing seven years after the cessation of exposure (geometric mean 6.4 $\mu\text{g/l}$, 95 % confidence limits 0.9–44.1 $\mu\text{g/l}$, $N=42$), from workers engaged in capacitor repairing (geometric mean 0.7 $\mu\text{g/l}$, 95 % confidence limits 1.0–4.0 $\mu\text{g/l}$), from workers manufacturing capacitor paper (geometric mean 5.5 $\mu\text{g/l}$), and from workers cleaning up after PCB accidents (geometric mean 1.0 $\mu\text{g/l}$, 95 % confidence limits 0.5–2.0 $\mu\text{g/l}$). All these analytical results pertained to the lower chlorinated PCB (di- to pentachlorinated isomers, 12 altogether), which correspond to the commercial PCB product (Clophen A30) most widely used in Finland and which are comparable with the lower chlorinated isomer category of Wolff et al (11). The workers could clearly be classified according to the likely type of exposure (occupational, accidental, or environmental) (4).

Isomer-specific analytical method

The results of the isomer-specific analysis of PCB in human serum showed characteristic differences between the types of exposure. Three trichlorinated isomers were found in the environmentally exposed group (2,5,2', 2,4,4', and 3,4,2' at the level of 0.037–0.088 $\mu\text{g/l}$). In accidental exposure the concentrations of these isomers were 10- to 20-fold higher, and in occupational exposure 4- to 50-fold higher, the main component being 2,4,4'. According to Wolff et al (12) 2,4,4'-trichlorinated biphenyl was the main component of trichlorinated PCB in the plasma of workers in capacitor manufacturing. Three tetrachlorinated isomers (2,3,2',5', 2,4,3',4', and 3,4,3',4' at the level of 0.003–0.128 $\mu\text{g/l}$) were found in the unexposed group. In accidental exposure the concentrations of these isomers were 5- to 220-fold higher (main component 2,4,3',4') and in occupational exposure 1- to 340-fold higher (main component 2,4,3',4'). According to Wolff et al (12) the two main components in the plasma of workers in capacitor manufacturing were 2,4,5,4'- and 2,4,3',4'-tetrachlorinated biphenyl. Only one pentachlorinated isomer was found in the group of unexposed workers (2,4,6,3',5' at the level of 0.014 $\mu\text{g/l}$) of the present study, whereas in accidental exposure five more isomers were detected. In the study by Wolff et al (12) several pentachlorinated isomers were found, the main components being 2,4,5,2',4'-, 2,4,5,3',4', and 2,3,4,2',5'-pentachlorinated biphenyl. Four different hexachlorinated isomers (2,2',3,3',6,6', 2,2',4,4',5,5', 2,2',3,4,4',5', and 2,3,3',4,4',5' at the level

of 0.078–3.363 $\mu\text{g/l}$) were found in each of the exposure groups of the present study. The differences in the concentration of these isomers between accidental and occupational exposure were not great, however. Wolff et al (12) found six hexachlorinated isomers (among them 2,2',4,4',5,5'-, 2,2',3,4,4',5'-, and 2,3,3',4,4',5'-pentachlorinated biphenyl). In the present study two heptachlorinated isomers, 2,2',3,4,4',5',6' and 2,2',3,3',4,4',6' at the level of 0.016–1.424 $\mu\text{g/l}$, were detected. The 2,2',3,4,4',5',6'- and seven other heptachlorinated isomers were found in the plasma of workers in capacitor manufacturing by Wolff et al (12). Preliminary results indicate that runs from gas chromatography with electron capture and gas chromatography-mass spectrometry are in agreement, with some exceptions (Luotamo et al, in preparation).

In Finland the most widely used commercial PCB product has been Clophen A30, which consists of di- to pentachlorinated isomers (1, 6). It was shown that elevated serum concentrations of specific isomers of different chlorination levels are typical for the different sources and types of exposure. The method presented enables one to detect exposure which is in excess of that from the general environment and to trace its likely origin.

References

1. Ballschmitter K, Zell M. Analysis of polychlorinated biphenyls (PCB) by class capillary gas chromatography: Composition of technical Aroclor and Clophen PCB mixtures. *Fresenius Z Anal Chem* 302 (1980) 20–31.
2. Elo O, Vuojolahti P, Janhunen H, Rantanen J. Recent PCB accidents in Finland. *Environ Health Perspect* 60 (1985) 315–319.
3. Luotamo M, Aitio A, Wold S. Serum polychlorinated biphenyls: Quantitation and identification of source of exposure by the SIMCA pattern recognition method. *Chemo Intelligent Lab Syst* (in press).
4. Luotamo M, Järvisalo J, Aitio A. Analysis of polychlorinated biphenyls (PCB) in human serum. *Environ Health Perspect* 60 (1985) 327–332.
5. Luotamo M, Järvisalo J, Aitio A, Elo O, Vuojolahti P. Biological monitoring of workers exposed to polychlorinated biphenyl compounds in capacitor accidents. In: Berlin A, Draper M, Hemminki K, Vainio H, ed. *Monitoring human exposure to carcinogenic and mutagenic agents*. International Agency for Research on Cancer, Lyon 1985, pp 307–311. (Scientific publications no 59).
6. Schulte E, Malish R. Berechnung der wahren PCB-Gehalte in Umweltproben: 1. Ermittlung der Zusammensetzung zweier technischer PCB-Gemische. *Fresenius Z Anal Chem* 314 (1983) 545–551.
7. Schwartz TR, Campbell RD, Stalling DL, Little RL, Petty JD, Hogan JW, Kaiser EM. Laboratory data base for isomer-specific determination of polychlorinated biphenyls. *Anal Chem* 56 (1984) 1303–1308.
8. Sjöström M, Wold S, Lindberg W, Persson J-Å, Martens, H. A multivariate calibration problem in analytical chemistry solved by partial least-squares models in latent variables. *Anal Chim Acta* 150 (1983) 61–70.
9. World Health Organization, Polychlorinated biphenyls and terphenyls. Geneva 1976. (WHO Environmental health criteria 2).

10. Wold S, Albano C, Dunn WJ III, Esbensen K, Hellberg S, Johansson E, Sjöström M. Pattern recognition: Finding and using regularities in multi-variate data. In: Martens, Russwurm Jr, ed. Food research and data analysis. Applied Science Publishers Ltd, London & New York 1983, pp 147—188.
11. Wolff MS, Fischbein A, Thornton J, Rice C, Lilis R, Selikoff IJ. Body burden of polychlorinated biphenyls among persons employed in capacitor manufacturing. *Int Arch Occup Environ Health* 49 (1982) 199—208.
12. Wolff MS, Thornton J, Fischbein A, Lilis R, Selikoff IJ. Disposition of polychlorinated biphenyl congeners in occupationally exposed persons. *Toxicol Appl Pharmacol* 62 (1982) 294—306.