Arch. Environ. Contam. Toxicol. 17, 55–63 (1988)

Archives of Environmental Contamination and Toxicology

Organochlorine Pesticides and Polychlorinated Biphenyls in Maternal Adipose Tissue, Blood, Milk, and Cord Blood From Mothers and Their Infants Living in Norway

Janneche Utne Skaare, Jon Morten Tuveng, and Hans Andreas Sande

The Norwegian College of Veterinary Medicine, Department of Pharmacology and Toxicology, Postbox 8146 Dep., 0033 Oslo 1, Norway

Abstract. Samples of maternal blood, milk, and umbilical cord blood were collected from mothers and their infants at Ullevål University Hospital in Oslo, Norway. All the mothers had lived in Oslo during the last two years. Of the Norwegian mothers, 16 were delivered by Caesarean operation, and samples of subcutaneous fat tissues were collected. Hexachlorobenzene (HCB), polychlorinated biphenyls (PCBs), *p,p'*-DDE, *p,p'*-DDT, and dieldrin were found in 157, 135, 168, 22, and 12, respectively, of the 168 samples analyzed, while β, and γ-hexachlorocyclohexane (HCH) were found in 93 and 26, respectively, of the 152 samples analyzed for these compounds. In the samples obtained from the Norwegian mothers and infants, PCBs and *p,p'*-DDE were the major contaminants present. In contrast, only traces of PCBs were found in six immigrant samples, which, however, contained 4–6 times higher levels of *p,p'*-DDE plus *p,p'*-DDT than the corresponding Norwegian samples. Of the HCH isomers, the β-HCH was the predominant isomer present. Two to three times significantly higher *p,p'*-DDE and PCBs levels were found in maternal serum than cord serum. No significant differences were found between the organochlorine residue levels in subcutaneous fat and milk fat. A significant positive linear correlation was found between the levels of *p,p'*-DDE and PCBs in maternal serum and in milk fat, and between the levels of *p,p'*-DDE in maternal serum and cord serum from Norwegian mothers giving birth normally.

Significantly higher PCBs and *p,p'*-DDE residues were found in the maternal and cord serum samples obtained after Caesarean operation than after normal delivery, while no other such differences were found in the milk samples 5 days *post partum*.

The results demonstrate that organochlorines are transferred from mother to fetus and newborn babies through the placenta and milk and that human milk is a good indicator in monitoring human beings and their environment for organochlorine contamination. Possible toxicological implications of the present results are discussed.

The intensive use of persistent organochlorine chemicals (OC), both in agriculture and industry, have lead to widespread contamination of the environment, and residues are found at every level of the food chain (Hayes 1975). Human beings are placed at the top of most chains, and it is not surprising that high levels of these compounds have been found in human adipose fat and milk fat (Jensen 1983; Slorach and Vaz 1983). For these reasons, many industrial countries have restricted or banned the use of these chemicals. Thus, in Norway, the use of all persistent pesticides, except lindane (γ-hexachlorocyclohexane), which is still certified for plant protection and insect and parasite control, has been prohibited since 1971. Furthermore, the use of the industrial chemicals, polychlorinated biphenyls (PCBs) have been restricted to closed systems since 1971, and a ban was imposed in 1979. Many of the developing countries, however, are still using considerable amounts of persistent pesticides.

Human milk monitoring programs have been used in many countries for assessing levels of environmental pollution by lipophilic substances in different areas within or between countries. Thus, in industrial countries, PCBs have been the major organochlorine contaminant in human samples during the last 10–15 years (Jensen 1983), while developing countries have avoided the PCB contamination. In contrast, persistent pesticide contamination is generally much higher in the developing as compared to the industrial countries (Kanja *et al.* 1986; Slorach and Vaz 1983). In Norway, human milk monitoring surveys were organized in our laboratory in 1970, 1976 and 1979 (Bjerk 1972; Brevik and Bjerk 1978; Skaare 1981). Adipose fat was also analyzed in 1970 and 1976. However, organochlorine residue levels in Norwegian maternal and infant blood were not analyzed. Results from similar surveys have been published from India (Ramakrishnan *et al.* 1985; Siddiqui and Saxena 1985; Slorach and Vaz 1983).

The aims of the present study were to assess the organochlorine contamination level in maternal adipose tissue, blood, milk, and cord blood of Norwegian mothers and their infants, and to examine the relationship between them. Also, the trends in contamination levels in Norway, and the effectiveness of governmental regulations on the use of OC, was evaluated by comparing the present results with corresponding results from the human milk surveys done earlier in the same laboratory. Finally, an investigation of the difference in pattern and levels of organochlorines in blood and milk between Norwegian mothers and their infants and Indian and Pakistanian immigrant mothers and their infants, was included. The immigrant mothers had lived in Norway the last two years.

Materials and Methods

Sampling and Collection

A total of 43 women (28.2 ± 4.5 years of age) participated in the study voluntarily and agreed with its aims. The women were giving birth to their first or second child and all had lived in the Oslo area during the last two years. Apart from these selection criteria, they were selected at random. Immediately after delivery, either by Caesarean operation (16 Norwegians) or normally (20 Norwegians plus 7 immigrants to Norway from developing countries) at Ullevål University Hospital in Oslo during 1981–1982, samples of maternal blood serum (3–5 ml) and umbilical cord serum (3–5 ml) were obtained. Specimens of subcutaneous fat were also collected from the mothers during Caesarean operations. Samples of colostrum and milk (10–20 ml) were obtained 3 and 5 days *post partum*. The milk samples were expressed manually preferentially before the infant was nursed in the morning. The samples were frozen immediately in clean glass bottles and stored at −20°C until analysis. All samples were taken from donors with normal and healthy babies. Thirteen of 16 Caesarean operations were planned in advance and 6 and 10 women received epidural anesthetics (bupivacaine Marcain®) and narcosis (thiopentone Penthotal®), respectively. A questionnaire including background data on mother and child, such as sex, length, and weight of the infant, weight, height, occupation, nationality, dietary habits, and smoking habits of the mother was completed by each donor.

Sample Analysis

Extraction, clean-up, and analysis of milk and serum samples were made according to a method described by Brevik (1978), slightly modified. The method comprised extraction of milk samples (10 ml) and serum samples (3–5 ml) with acetone (15 ml) and *n*-hexane (20 ml) by ultrasonic disintegration, repetition of the extraction using 5 and 10 ml acetone and n-hexane, respectively, and final evaporation of the *n*-hexane to an appropriate volume. The milk fat content was determined by evaporation to dryness and redissolving in *n*-hexane (0.05 g fat/ml hexane). The subcutaneous fat tissue samples were prepared by a slight modification of the method described by Bjerk and Sundby (1970). Details of the extraction procedures are described by Skaare *et al.* (1985). Two aliquots of the different hexane extracts were treated with concentrated sulphuric acid and methanolic potassium hydroxide, respectively. Aliquots of the purified hexane extracts were made up to an appropriate volume and analyzed by gas chromatography (GLC), using a Varian model 3700, and a Carlo Erba model 2350 with the following instrument parameters and operating conditions: Detectors: ^{63}Ni electron capture; columns: glass 1.5 m × 2 mm i.d. packed with a mixture of 1.5% SP-2250 and 1.95% SP-2401 on Supelcoport 100/120 mesh (a), a mixture of 1.5% OV-1 and 1.5% OV-225 on Supelcoport 80/100 mesh (b); Column temperature: 205°C (a); temperature program 190°C (1 min.) to 230°C, 5°C/min. (b); Carrier gas: Nitrogen 30 ml/min, and injection volume: 2–5 μl. No isolation of PCBs from the DDT compounds was made prior to GLC analysis. The organochlorine compounds were identified by analysis of both acid and alkali-treated hexane fractions on both GLC-columns after which the retention times of organochlorine chemical residues and standards were compared. Recoveries of pesticides, and PCBs were checked periodically by fortification of cow's milk and serum. The average recoveries for all compounds varied from 80–115%. Repeated analysis gave a standard error of about 10%. Participation in an interlaboratory analytical quality assurance (AQA) test organized by WHO/UNEP, with spiked cow milk samples provided from The National Food Administration in Sweden, demonstrated that our laboratory had good analytical quality (percentage deviation from spike concentration of β-HCH, *p,p'*-DDE and PCBs were less than ±20%). The data do not include corrections for recovery. The quantification limits were set to 0.001 mg/kg wet weight for HCB and β-HCH, and 0.002 mg/kg wet weight for the other organochlorines in serum samples. In extractable fat from milk and s.c. fat the quantification limits were set to 0.002 mg/kg for HCB, lindane (γ-hexachlorocyclohexane, γ-HCH), α-HCH, and β-HCH, 0.015 mg/kg for *p,p'*-DDT and *p,p'*-DDE (sum DDT = 1.11 *p,p'*-DDE + *p,p'*-DDT), 0.004 mg/kg for aldrin and 0.050 mg/kg for the other organochlorines.

The limit of PCB quantification was 0.020 mg/kg fat. The PCBs were determined gas chromotographically via pattern recognition using the commercial standard Aroclor 1254®. The sum of as many peaks as possible was taken for comparison.

Table 1. Residues (ppb, μg/kg wet weight, μg/kg fat weight listed in parentheses) of HCB, PCBs, *p,p'*-DDE, and β-HCH in samples from Norwegian mothers and their infants delivered by Caesarean operation

Sample	Days *post partum*	% extr. fat	HCB	PCBs	*p,p'*-DDE	β-HCH
Subcutaneous fat	0	80.5 ± 48.1	494 ± 686 (630 ± 841) 16/16	662 ± 401 (952 ± 518) 16/16	448 ± 389 (638 ± 531) 16/16	not analyzed
Maternal serum	0	—	2 ± 2[*,a] 15/15	10 ± 4* 14/15	19 ± 21[*,a] 15/15	<1 11/15
Umbilical cord serum	0	—	2 ± 1[a] 10/12	5 ± 4[a] 9/12	10 ± 9[a] 12/12	<1 2/12
Colostrum	3	1.8 ± 1.8	1 ± 0 (54 ± 36)[a] 12/12	21 ± 18 (1165 ± 508)[a] 11/12	11 ± 7 (1054 ± 831)[a] 12/12	<1 (79 ± 72) 11/12
Milk	5	2.6 ± 1.1	2 ± 2 (80 ± 30) 14/14	20 ± 11 (810 ± 410) 14/14	20 ± 13 (820 ± 520) 14/14	2 ± 1 (60 ± 50) 14/14

Results are expressed as means ± S.D. Ratios of the number of samples containing quantifiable amounts over total number analyzed are also given

* Significant differences ($P < 0.05$) between organochlorine residues in maternal serum and umbilical cord serum

[a] Significant differences ($P < 0.05$) between corresponding samples from Norwegian mothers and their infants delivered normally (Table 2)

Statistical Analysis

The different sets of data were examined for significant difference ($p < 0.05$) by Wilcoxon's two-sample test (Hodges and Lehmann 1970). Correlation analyses were done by simple linear regression.

Results

Residue Levels of HCB, p,p'*-DDE,* p,p'*-DDT, PCBs and α, β, and γ-HCH*

The results, expressed on fat and wet weight basis, respectively, are presented in Tables 1–3. The means and the standard deviations together with the ratios of the number of samples containing quantifiable amounts over the total number analyzed are listed.

Hexachlorobenzene (HCB), PCBs, *p,p'*-DDE and *p,p'*-DDT were found in 157, 135, 168, and 22 samples, respectively, of the 168 samples analyzed. In the samples obtained from Norwegian mothers and infants, *p,p'*-DDE was the only detectable DDT metabolite (Tables 1 and 2). In the samples of the immigrants to Norway and their infants, the major DDT derived compound was *p,p'*-DDE. However, low levels of *p,p'*-DDT were also found in all samples (Table 3). PCBs are major organochlorine contaminants in the Norwegian material (Tables 1 and 2), while quantifiable PCB residues were found in immigrant serum samples only (Table 3).

Of the HCH-isomers, the β-HCH was the predominant isomer found in 93 of 152 samples analyzed (Tables 1–3) while quantifiable residue levels of lindane, γ-HCH, were found in serum samples only. In 8 of 35 serum samples of Norwegian mothers and 6 of 35 corresponding umbilical cord serum samples lindane residues ranged from 0.2–27 μg/kg wet weight. In all the serum samples of immigrant mothers and in 5 of 7 corresponding umbilical cord serum samples, lindane residues ranged from 0.1–3.4 μg/kg wet weight. α-HCH was not found in amounts that could be quantified. In general, a wide variation between individual samples was observed.

Norwegian mothers and their infants: According to Table 1, the highest mean contamination levels of HCB, PCBs and *p,p'*-DDE were found in subcutaneous (s.c.) fat samples. However, no significant differences were found between the residue levels in the extractable fat of s.c. fat and milk respectively. Furthermore, significant higher mean residues for *p,p'*-DDE and PCBs, were found in the maternal serum as compared to the umbilical cord serum samples (Tables 1 and 2). On a fat weight basis, no significant differences were found between mean residue levels in colostrum and milk from the mothers delivering their infants by Caesarean operation (Table 1), while a significant higher mean concentration of *p,p'*-DDE was found in milk

Table 2. Residues (ppb, µg/kg wet weight, µg/kg fat weight listed in parentheses) of HCB, PCBs, *p,p'*-DDE, and β-HCH in samples from Norwegian mothers and their infants delivered normally

Sample	Days *post partum*	% extr. fat	HCB	PCBs	*p,p'*-DDE	β-HCH
Maternal serum	0	—	1 ± 1* 18/20	10 ± 7* 20/20	10 ± 8* 20/20	<1 6/20
Umbilical cord serum	0	—	1 ± 2 17/20	3 ± 1 13/20	3 ± 2 20/20	<1 2/20
Colostrum	3	1.7 ± 0.7	0 ± 0 (35 ± 23)* 13/17	18 ± 9 (866 ± 382) 12/17	12 ± 13 (640 ± 450)* 17/17	1 ± 1 (51 ± 30) 7/17
Milk	5	2.4 ± 1.2	2 ± 1 (90 ± 50) 20/20	23 ± 12 (1000 ± 350) 20/20	24 ± 23 (970 ± 660) 20/20	2 ± 1 (80 ± 110) 19/20

Results are expressed as means ± S.D. Ratios of the number of samples containing quantifiable amounts over total number analyzed are also given

* Significant differences ($P < 0.05$) between organochlorine residues in maternal serum and umbilical cord serum, and in colostrum and milk

Table 3. Residues (ppb, µg/kg wet weight, µg/kg fat weight listed in parentheses) of HCB, PCBs, *p,p'*-DDE, sum-DDT (1.11 *p,p'*-DDE + *p,p'*-DDT), and β-HCH in samples from immigrants to Norway from developing countries and their infants delivered normally

Sample	Days *post partum*	% extr. fat	HCB	PCBs	*p,p'*-DDE	sum-DDT	β-HCH
Maternal serum	0	—	7 ± 12[a] 5/5	4 ± 5[a] 4/5	126 ± 62[a] 5/5	150 ± 75 5/5	2 ± 1 5/5
Umbilical cord serum	0	—	5 ± 13 7/7	1 ± 3[a] 2/7	49 ± 81[a] 7/7	59 ± 100 7/7	1 ± 2 6/7
Colostrum	3	0.9 ± 0.9	0 ± 0 (80 ± 49)[a] 4/4	—	42 ± 54 (8570 ± 96501) 4/4	59 ± 76 (12040 ± 13620) 4/4	2 ± 2 (400 ± 340)[a] 4/4
Milk	5	3.0 ± 3.3	1 ± 1 (47 ± 46) 6/6	—	78 ± 30 (4421 ± 1759)[a] 6/6	107 ± 45 (5981 ± 1541) 6/6	8 ± 7 (443 ± 492)[a] 6/6

Results are expressed as means ± S.D. Ratios of the number of samples containing quantifiable amounts over the total number analyzed are also given

[a] Significant differences ($P < 0.05$) between organochlorine residues in corresponding samples of Norwegian mothers and their infants delivered normally (Table 2)

fat as compared to colostrum fat of mothers who delivered their infants normally (Table 2).

No significant difference in mean weight/height ratio was found between the mothers delivering their infants by Caesarean operation or vaginally. The mean residue levels of organochlorines were significantly higher in the samples of maternal serum, umbilical cord serum, and colostrum obtained 0, and 3 days, respectively following Caesarean operation as compared to the corresponding samples from mothers and their infants delivered normally. The only exception was the mean residue level of PCBs, which was similar in the maternal serum samples. There were, however, no significant differences in mean organochlorine residue levels in milk obtained five days *post partum* between the 2 groups of mothers (Tables 1 and 2). Furthermore, by subdividing the group of mothers delivering their infants by Caesarean operation according to the anaesthesia used during the operation, comparison of the residue levels in maternal and cord blood and colostrum between these groups revealed no significant differences.

Immigrants to Norway from developing countries and their infants: Significantly higher mean levels of the organochlorine pesticides DDT and HCH were found in the samples from the immigrants and their infants. Thus, the mean *p,p'*-DDE and β-HCH residue levels in milk fat were about five times higher than the corresponding levels in Norwegian human milk fat.

Other Organochlorine Chemical Residues

In addition to the organochlorines mentioned, residues of dieldrin were found in some of the samples. Thus, residues of dieldrin were found in the 12 serum samples of the immigrants and their infants (7 ± 7 μg/kg wet weight).

Correlation Analysis

A positive correlation between the levels of *p,p'*-DDE and PCBs in extractable fat of human milk and subcutaneous fat was found to be significant (*p,p'*-DDE: $y = 0.8x + 0.4$, $r = 0.76$, $n = 14$, $P < 0.05$; PCBs: $y = 0.5x + 0.3$, $r = 0.65$, $n = 14$, $P < 0.05$). Furthermore, a significant positive correlation was found between the levels of *p,p'*-DDE and PCBs in maternal serum and in extractable milk fat ($r = 0.46$–0.79, $n = 19$, $p < 0.05$) and the levels of *p,p'*-DDE in maternal serum and umbilical cord serum from Norwegian mothers giving birth normally ($r = 0.45$, $n = 19$, $P < 0.05$).

Time Trends of HCB, DDT and PCBs

In Table 4, the present levels of some organochlorines in Norwegian human milk from Oslo are compared with the corresponding levels obtained in our laboratory in 1970, 1976 and 1979. Basically the same analytical methods were used in all the surveys.

The significant decrease in mean sum-DDT levels in human milk observed during the period from 1970 to 1976 continues during the period from 1976 to 1979, while no further decrease was observed from 1979 to 1982.

The mean HCB levels were significantly reduced during the period 1976 to 1979, however, no change was observed during the period 1979–1982.

Furthermore, it is illustrated in Table 4 that the mean PCB levels significantly increased by more than 100% from 1970 to 1976. From 1976 to 1982 no significant change in PCB levels was found.

Discussion

The organochlorines included in the present survey constitute pesticides and their metabolites (DDT, DDE, aldrin, dieldrin, lindane, and α, β-HCH), as well as industrial chemicals (PCBs and HCB). The results demonstrate that these organochlorines are transferred from mother to fetus and newborn babies through the placenta and milk.

The observed large individual variations in the present residue levels were not unexpected, since it is well known that many factors may influence the results. These factors cannot easily be controlled in a monitoring survey *e.g.*, exposure, age and weight of the mothers, dietary habits, cigarette smoking, parity of the mothers, and fat content of milk. The results also depend on time of sampling during the meal, the day, and the lactation period, and seasonal variations (Jensen 1983).

The finding that significantly higher organochlorine residues were found in the maternal and cord serum samples obtained after Caesarean operation than after vaginal delivery, while no such differences were found in the human milk samples 5 days *post partum*, is difficult to explain. The mean weight/height ratio of the groups were similar, and different types of anaesthesia applied during the Caesarean operations did not affect these results. Brown and Lawton (1984) demonstrated that the partitioning of PCBs between adipose tissue and serum in humans is related to variations in the lipid content of the serum. During pregnancy, the plasma lipid concentration is changing (Vaysse 1986). This change is probably partly under hormonal control and plasma hormone status is changing dramatically before parturition (Ganong 1977). The women undergoing elected Caesarean section and vaginal delivery, respectively, may be in different stages of gestation, thus having different endocrinogical status. This may be related to the residue differences at delivery as opposed to five days *post partum* when no differences were observed.

Organochlorine Residues

The mean levels of the actual organochlorines in Norwegian human milk are low compared to the corresponding concentrations reported from some other European countries (Jensen 1983; Weisenberg *et al.* 1985; Acker 1981). Furthermore, the

Table 4. Residues (ppb, μg/kg) of some organochlorines in Norwegian human milk from mothers living in Oslo 1970[a], 1976[b], 1979[c], and 1982

HCB			Sum-DDT				PCBs			
1976	1979	1982	1970	1976	1979	1982	1970	1976	1979	1982
6 ± 4	2 ± 1[e]	2 ± 1	82 ± 73	50 ± 38[d]	24 ± 19[e]	24 ± 21	11 ± 5	24 ± 9[d]	27 ± 15	22 ± 12
(14)	(19)	(34)	(25)	(14)	(19)	(34)	(25)	(14)	(19)	(34)

Results are expressed as means ± S.D., number analyzed as listed in parentheses

[a] Bjerk (1972)

[b] Brevik and Bjerk (1978)

[c] Skaare (1981)

[d] Significant difference ($P < 0.05$) between 1976 and 1970.

[e] Significant difference ($P < 0.05$) between 1979 and 1976.

present Norwegian results correspond well with results from Denmark, Sweden and Finland, which are among the lowest reported (Andersen and Orbæk 1984; Unger *et al.* 1982; Wickström *et al.* 1983; Norén 1983; Hofvander *et al.* 1981; Slorach and Vaz 1983; Jensen 1983).

The difference in pattern and mean levels of organochlorine contamination in human milk between Norwegians and immigrants to Norway from Pakistan and India, is assumed to reflect a difference in previous exposure between the groups, since the immigrants had lived in Norway at least during the last 2 years prior to the present parturition. This assumption is supported by the fact that the relatively high mean organochlorine pesticide levels found in immigrant milk fat correspond well with, or are lower than, the levels reported from India (Ramakrishnan *et al.* 1985; Siddiqui and Saxena 1985; Slorach and Vaz 1983). In this country DDT, lindane and aldrin/dieldrin are used continuously as insecticides for vector control, and HCB is used as a fungicide. Norway, like most other industrialized countries, banned the use of aldrin/dieldrin in 1967 and DDT in 1970, while lindane is still in use on a relatively small scale (6 tons in 1982). HCB has not been used directly in agriculture in Norway, but is an industrial waste product.

The main metabolite *p,p′*-DDE is more persistent in the environment than DDT (Hayes 1982). Thus, when the use of *p,p′*-DDT in a country ceases, the levels of this compound decreases more rapidly than the levels of *p,p′*-DDE, resulting, in an increasing DDE/DDT ratio. The present finding that *p,p′*-DDE is the only DDT-related compound present in detectable amounts in Norwegian human milk, therefore, demonstrate the effectiveness of the governmental imposed ban on the use of DDT. The DDE concentrations in the Norwegian samples represent either past exposure of the mother to DDT, or exposure to DDE as such through consumption of foods. In contrast, both *p,p′*-DDE and *p,p′*-DDT were found in the immigrant milk. However, the discontinuation in the exposure to DDT due to the immigration is probably accounting for the more than 40% higher mean DDE/DDT ratio in the present material as compared to corresponding results from India (Slorach and Vaz 1983).

The insecticide lindane, the γ-isomer of HCH was found in some serum samples only, while the β-HCH was the only isomer found in the present milk samples.

In Norway, the lindane used is the γ-isomer of high purity grade. However, technical HCH of which β-HCH is a minor component is probably continuously applied in most developing countries (Slorach and Vaz 1983; Kanja *et al.* 1986). The purity of the pesticide may be partly responsible for the ratio of the HCH isomers found since the different isomers has different biological properties. The β-isomer is the most persistent HCH-isomer (Steinwandter and Schlüter 1978; Jensen 1983) and is eliminated more slowly from the body than lindane (Pfeilsticker 1973). It has a 10–30 times higher ability to accumulate in fat tissues than lindane (Heeschen 1980). Also, the α- and γ-isomers may isomerize into the β-isomer in living organisms (Jensen 1983). Thus, the ratio between different HCH-isomer changes from the start of food chains until the excretion in human milk, resulting in the more persistent β-HCH being the predominant isomer in human milk (Szokolay *et al.* 1977; Jensen 1983). Thus, the present results indicate that the major route of exposure to lindane is via the food.

In industrial countries, including Norway, PCBs are major contaminants in human milk (Jensen 1983). The finding that no quantifiable amounts of PCBs were present in immigrant human milk, and only traces were found in the immigrant plasma samples, corresponds well with results from organochlorine monitoring surveys done in developing countries where actually no PCB contamination has been reported (Slorach and Vaz 1983; Kanja *et al.* 1986; Ramakrishnan *et al.* 1985; Siddiqui and Saxena 1985).

Correlations

When maternal to cord serum regression was calculated for DDE and PCBs to determine the mother/child dependency, a significant regressive coefficient was found only for DDE, and the magnitude of the correlation corresponds well with earlier findings (Bazulic *et al.* 1984; Bush *et al.* 1984; Saxena *et al.* 1983). Opposedly, evidence concerning the placental passage of PCBs is somewhat contradictory, and the relationship between PCB concentrations in maternal and cord blood has been found to differ for each PCB congener (Akiyama *et al.* 1975; Ando *et al.* 1985; Bush *et al.* 1984; Jacobson *et al.* 1984). In the present study, a significant correlation was found between PCB and DDE content in maternal blood and milk. Thus, the present lack of correlation for PCBs in maternal and cord serum may possibly be due to a selectivity of the placenta towards the transfer of specific PCB components. Furthermore, we and others have found lower levels of PCBs and DDE in cord blood than in maternal blood at term (Akiyama *et al.* 1975; Bush *et al.* 1984; Jacobson *et al.* 1984; Kodoma and Ota 1977; Rogan *et al.* 1986; Saxena *et al.* 1981). This is in part reflecting the greater concentration of lipids in maternal serum, and it is also consistent with the notion that the placenta may function as a partial barrier (Masuda *et al.* 1978).

The significant correlation found between DDE and PCBs residue levels in subcutaneous fat and milk fat corresponds with the results of others (Acker 1981; Westöö and Norén 1978), and demonstrates that human milk is a suitable indicator substance in biological monitoring of the human body burden of persistent lipophilic pollutants.

Time Trends in Norway

Hexachlorobenzene is an industrial by-product and a contaminant in some pesticides (1–3%), and may thus find its way into the environment. The slight decrease in the average HCB level in human milk observed in the period 1976 to 1979 could be due to increased awareness of HCB as an environmental pollutant and the resulting improvements in the industrial processes producing HCB as a by-product (Ottar *et al.* 1980).

A result of the ban in 1970 on the use of DDT is the significant decrease in both sum-DDT levels and DDE levels in Norwegian human milk during the period 1970 to 1979 (Table 4). As expected, the levels of the parent compound DDT accounted for most of the losses which are reflected in the DDE/DDT ratios of 3.1, 3.7, and 6 in 1970, 1976, and 1979, respectively (Bjerk 1972; Brevik and Bjerk 1978; Skaare 1981). In the present study, *p,p'*-DDE was the sole contributor to the Σ DDT. It is believed that the DDT contamination in Norway now is reflecting global pollution and further reduction will require restrictions on the use of DDT globally.

In spite of the fact that the use of PCBs in Norway has been restricted to closed systems since 1971, the average levels in Norwegian human milk doubled in the period 1970 to 1976. The same trend has been found in Sweden and Germany (Westöö and Norén 1978; Ottender 1984). In 1979, a ban was imposed in Norway on the use of PCB. The plateauing of the PCB contamination from 1976 to 1979, followed by the slight downward trend from 1979 to 1982, may indicate an effect of the restrictions and the ban.

These results indicate that human milk is a good indicator for monitoring the environment for organochlorine chemical contamination.

Toxicological Evaluation

Overall, our data are consistent with the notion that the general population exposure in Norway to PCBs and DDE is the result of widespread low-level contamination.

The possible toxicological implications of the present results are difficult to interpret, since no recommendations specifically aimed at infants have been given by international bodies. However, for adults, WHO/FAO expert groups have estimated acceptable daily intakes, ADI-values, for some chlorinated pesticides (FAO/WHO 1970 and 1974). When applying such values for evaluation of the potential health hazard for infants, the average infant body weight is set to five kg and the mean intake of milk is set to 800 g/day (Jensen 1983). Thus, a Norwegian infant will receive an average of 0.003 mg/kg/day of HCB, which is half the temporary ADI-value. Of Σ-DDT an infant of a Norwegian-born mother will receive an average of 0.005 mg/kg/day, which is identical to the ADI-value, while the infant of an immigrant mother will receive four to five times this value. Nine of the 34 infants of Norwegian-born mothers, and all the infants of immigrant mothers, will have daily intakes of sum-DDT exceeding the proposed ADI-value. In the present survey, individual PCB compounds were not quantified, only the sum of PCBs. Thus, the well-known differences in biological and toxic effects of the various isomers and congeners (Safe 1984; Bush *et al.* 1985) cannot be taken into consideration in a toxicological evaluation of the present PCB results. A five kg infant consuming 800 g of milk daily containing the mean PCB concentration found here (0.023 mg/kg) will consume 0.004 mg PCB/kg/day. Nine of 34 infants of Norwegian-born mothers will have daily intakes of PCBs exceeding 0.010 mg/kg/day which Cordle *et al.* (1982) estimated as a safe intake of PCBs for infants. Even though some of the Norwegian infants will have daily intakes of the actual organochlorines exceeding present proposed acceptable daily intakes, there is no positive evidence that the present levels does any harm to infants. However, given the lack of well-founded, long-lasting epidemiological investigations, undesirable or injurious long-term effects cannot be excluded. Thus, human milk should be under regular surveillance with respect to organochlorine contamination to control the quality and to discover any changes in the environmental pollution load.

Acknowledgments. Thanks are extended to Anuschka Polder and Reidun Torp for their valuable technical assistance.

References

Acker L (1981) Zur Kontamination der Frauenmilch mit chlororganischen Verbindungen. Geburtshilfe Frauenheilkd 41:882–886

Akiyama K, Ohi G, Fujitani K, Yagu H, Ogino M, Kawana T (1975) Polychlorinated biphenyl residues in maternal and cord blood in Tokyo metropolitan area. Bull Environ Contam Toxicol 14:588–592

Andersen JR, Orbæk K (1984) Organoclorine contaminants in human milk in Denmark. Ambio 13:266–268

Ando M, Saito H, Wakisaka J (1985) Transfer of polychlorinated biphenyls (PCBs) to newborn infants through the placenta and mother's milk. Arch Environ Contam Toxicol 14:51–57

Bazulic D, Štampar-Plasaj B, Bujanovic V, Stojanovski N, Nastev B, Rudelić I, Šišul N, Žužek A (1984) Organochlorine pesticide residues in the serum of mothers and their newborns from three Yugoslav towns. Bull Environ Contam Toxicol 32:265–268

Bjerk JE (1972) Rester av DDT og polyklorerte bifenyler i norsk humant materiale. Tidsskr norske Lægefor 92:15–19

Bjerk JE, Sundby R (1970) Rester av klorinsekticider og polyklorerte bifenyler i testorganismer fra jord og vann. Norsk vet.-Tidsskr 82:241–246

Brevik EM, Bjerk JE (1978) Organochlorine compounds in Norwegen human fat and milk. Acta Pharmacol Toxicol 43:59–63

Brevik EM (1978) Gas chromatographic method for the determination of organochlorine pesticides in human milk. Bull Environ Contam Toxicol 19:281–286

Brown JF, Lawton RW (1984) Polychlorinated biphenyl (PCB) partitioning between adipose tissue and serum. Bull Environ Contam Toxicol 33:277–280

Bush B, Snow J, Koblintz R (1984) Polychlorobiphenyl (PCB) congeners, *p,p'*-DDE, and hexachlorobenzene in maternal and fetal cord blood from mothers in upstate New York. Arch Environ Contam Toxicol 13:517–527

Bush B, Snow J, Connor S, Koblintz R (1985) Polychlorinated biphenyl congeners (PCBs), *p,p'*-DDE and hexachlorobenzene in human milk in three areas of upstate New York. Arch Environ Contam Toxicol 14:443–450

Cordle F, Locke R, Springer J (1982) Risk assessment in a Federal Regulatory Agency: An assessment of risk associated with the human consumption of some species of fish contaminated with polychlorinated biphenyls (PCBs). Environ Hlth Persp 7:171–182

Ganong WF (1977) Review of medical physiology. 8th ed. Lange Medical Publications. Los Altos, CA, pp 341

FAO/WHO (1970) Pesticide residues in food, Rome

———(1974) Pesticide residues in food, Geneva

Hayes WJ Jr (1982) Pesticides studies in man. William and Wilkins, Baltimore, Md

———(1975) Toxicology of pesticides. Williams and Wilkins, Baltimore, Md

Heeschen W (1980) Toksikologische Bewertung von HCH-Rückständen. Kiel Milchwirtsch Forschungsber 32:151–155

Hodges JL, Lehmann EL (1970) Basic concepts of probability statistics. Holden Day, San Francisco

Hofvander Y, Hagman U, Linder CE, Vaz R, Slorach S (1981) WHO collaborative breast feeding study 1. Organochlorine contaminants in individual samples of Swedish human milk 1978–1979. Acta Pædiatr Scand 70:3–8

Jacobson JL, Fein GG, Jacobson SW, Schwartz PM, Dowler JK (1984) The transfer of polychlorinated biphenyls (PCBs) across the human placenta and into maternal milk. Amer J Public Health 74:378–379

Jensen AA (1983) Chemical contaminants in human milk. Residue Reviews 89:1–128

Kanja L, Skaare JU, Nafstad I, Matai CK, Løkken P (1986) Organochlorine pesticides in human milk from different areas of Kenya 1983–1985. J Toxicol Environ Health 19:449–464

Kodoma H, Ota H (1977) Studies on the transfer of PCB to infants from their mothers. Jpn J Hyg 32:567–573

Masuda V, Kuroki H, Kuratsune M, Yoshimura T, Taki J, Kusuda M, Yamashita F, Hayashi M (1978) Transfer of polychlorinated biphenyls from mothers to foetuses and infants. Food Cosmet Toxicol 16:543–546

Noren K (1983) Levels of organochlorine contaminants in human milk in relation to the dietary habits of the mothers. Acta Pædiatr Scand 72:811–816

Ottar B, Pettersen JM, Semb A (1980) NILU oppdragsrapport nr 63/78, ref 23878. Norsk institutt for luftforskning, Postbox 130, 2001 Lillestrøm, Norway

Ottender H (1984) Organochlorpesticide und Polychlorierte Biphenyle (PCB) in Muttermilch; Auswertung einer Langzeitstudie. Lebensmittelchem Gerichtl Chem 38:139–143

Pfeilsticker K (1973) Pesticide in der Kinderernährung. MSchr Kinderheilk 121:551–553

Ramakrishnan N, Kaphalia BS, Seth TD, Roy NK (1985) Organochlorine pesticide residues in mothers milk: A source of toxic chemicals in suckling infants. Human Toxicol 4:7–12

Rogan WJ, Gladen BC, McKenney JD, Carreras N, Hardy P, Thullen J, Tingelstad J, Tully M (1986) Polychlorinated biphenyls (PCBs) and dichlorodiphenyl dichloroethene (DDE) in human milk: Effects of maternal factors and previous lactation. Amer J Public Health 76:172–177

Safe S (1984) Polychlorinated biphenyls (PCBs) and polybrominated biphenyls (PCBs): Biochemistry, toxicology, and mechanism of action. CRC Crit Rev Toxicol 13:319–395

Saxena MC, Siddiqui MKJ, Agarwal V, Kemty D (1983) A comparison of organochlorine insecticide contents in specimens of maternal blood, placenta, and umbilical-cord blood from stillborn and live-born cases. J Toxicol Environ Health 11:71–79

Saxena MC, Siddiqui MKJ, Bhargava AK, Krishna Murti CRK, Kutty D (1981) Placental transfer of pesticides to humans. Arch Toxicol 48:127–134

Siddiqui MKJ, Saxena MC (1985) Placenta and milk as excretory routes of lipophilic pesticides in women. Human Toxicol 4:249–254

Skaare JU, Stenersen J, Kveseth N, Polder A (1985) Time trends of organochlorine chemical residues in seven sedentary marine fish species from a Norwegian fjord during the period 1972–1982. Arch Environ Contam Toxicol 14:33–41

Skaare JU (1981) Persistent organochlorinated compounds in Norwegian human milk in 1979. Acta Pharmacol Toxicol 49:384–389

Slorach AS, Vaz R (1983) Assessment of human exposure to selected organochlorine compounds through biological monitoring. Global environmental monitoring system (GEMS) UNEP/WHO. Prepared by the Swedish National Food Administration, Uppsala, Sweden, p 134

Steinwandter H, Schlüter H (1978) Experiments on lindane metabolism in plants IV. A kinetic investigation. Bull Environ Toxicol 20:174–179

Szokolay A, Rosival L, Uhnák J, Maďarić A (1977) Dynamics of benzene hexachloride (BHC) isomers and other chlorinated pesticides in the food chain and in human fat. Ecotoxicol Environ Safety 1:349–359

Unger M, Ipsen L, Clausen J (1982) Forekomsten of polyklorerede bifenyler i human ammemælk, komælksprodukter samt i kostprøver. Ugeskr Læger 144:1849–1852

Vaysse J (1986) Plasma and erythrocyte lipid composition in normal pregnancy. Biol Res Pregnancy Perinatal 7:89–92

Weisenberg E, Arad I, Grauer F, Sahm Z (1985) Polychlorinated biphenyls and organochlorine insecticides in human milk in Israel. Arch Environ Contam Toxicol 14:517–521

Westöö G, Norén K (1978) Organochlorine contaminants in human milk, Stockholm 1967–1977. Ambio 7:62–64

Wickström K, Pyysalo H, Siimes MA (1983) Levels of chlordane, hexachlorobenzene, PCB and DDT compounds in Finnish human milk in 1982. Bull Environ Contam Toxicol 31:251–256

Manuscript received March 3, 1987 and in revised form May 24, 1987.