Environmental Health Perspectives Supplements
101 (Suppl. 2): 45–52 (1993)

Nurturing and Breast-feeding: Exposure to Chemicals in Breast Milk

by Arpad Somogyi[1] and Hans Beck[1]

All chemicals that are not normal constituents of human milk should be considered undesirable contaminants. In the present review, the following substances detected in human milk are considered: persistent organochlorine pesticides; polychlorinated biphenyls (PCB); polychlorinated dibenzodioxins (PCDD) and dibenzofurans (PCDF); polybrominated compounds; polycyclic aromatic hydrocarbons (PAH); trace elements; mycotoxins; nitrate, nitrite, nitrosamines; nicotine, caffeine, ethanol; and drugs. The levels of most of these substances found in human milk were within a range that would not constitute health hazards for breast-fed infants. For many of these, there is a comfortable safety margin. This applies also to organochlorine pesticides and PCB, particularly since, as a result of their discontinued use, the levels of these compounds have clearly declined in recent years. On the other hand, the aflatoxin burden mediated through breast milk, at least in certain tropical countries, appears to pose a definite health hazard. Detailed reference are given on the contamination of human milk with PCDD/PCDF which has to be considered as a matter of concern from the viewpoint of preventive public health. Although the low PCDD/PCDF levels found in the adipose tissue of infants indicate that there is no appreciable health risk emanating from these substances for breast-fed infants, appropriate measures to reduce the current rate of their emission into the environment have to be taken.

Introduction

In recent years, the benefits of breast-feeding have increasingly been recognized. This has resulted in an increase in the frequency and duration of breast-feeding in many countries. At the same time, however, many chemicals have been detected in breast milk by means of analytical methods requiring, in part, sophisticated technical equipment. These residues have given rise to concern in some cases. In principle, each substance that is not naturally present in breast milk or whose concentrations are above the normal levels is considered a contaminant. In some cases such a differentiation is relatively difficult because the composition of breast milk is not consistent (*1*). Apart from analytical problems of precisely determining traces of chemicals, there are both physiological and nonphysiological factors influencing the composition and thus the concentration of the chemicals in human milk.

Despite these limitations, the substances listed in Table 1 should be included in a comprehensive consideration of the chemicals in breast milk (*2*). Moreover, it is to be expected that in the future other chemicals will detected in human milk. The relation between concentrations and the toxic effects continues to be the decisive factor in the evaluation of health risks of any chemicals.

In this short overview, it is not possible to cover the high number of communications on this item. A more comprehensive review on chemical contaminants in human milk was published in 1990 by Jensen and Slorach (*3*).

Transfer of Chemicals into Breast Milk

Exposure of the mother to chemicals is a condition *sine qua non* for their transfer to breast milk. In most cases, the intake from food is the main route of exposure, whereas the inhalatory and dermal routes are of minor importance. The importance of substances with short half-lives is limited to their intake during the period of breast feeding. Substances with long half-lives, however, are stored from infancy in a depot in the mother's body, which leads to the corresponding concentrations in her blood.

The transfer of chemicals to breast milk depends on their concentrations in the serum of the mother and on their pharmacological properties. Apart from their pH value, molecular weight and capacity of binding to plasma proteins, their lipophilic properties are the most important factors. Nonpolar lipophilic compounds easily pass through the membranes that form a barrier between blood and mammary gland cells and establish an equilibrium between blood fat and milk fat.

[1]Max von Pettenkofer-Institut des Bundesgesundheitsamtes, Postfach 33 00 13, D-1000 Berlin 33, Germany.

This manuscript was presented at the Conference on the Impact of the Environment on Reproductive Health that was held 30 September–4 October 1991 in Copenhagen, Denmark.

Table 1. Chemicals in breast milk.

Polychlorinated compounds
Persistent organochlorine pesticides
Polychlorinated biphenyls (PCB)
Polychlorinated dibenzodioxins (PCDD) and dibenzofurans (PCDF)
Polybrominated compounds
Polycyclic aromatic hydrocarbons (PAH)
Trace elements
Mycotoxins
Nitrates, nitrites, and nitrosamines
Nicotine, caffeine, and ethanol
Drugs

Table 2. Mean organochlorine pesticide concentrations (mg/kg fat) in breast milk from Münster and Kiel/Germany, 1979–1981 (2).

Pesticide	Münster (n = 836)	Kiel (n = 1873)	Mean
α-Hexachlorocyclohexane	0.01	0.03	0.02
β-Hexachlorocyclohexane	0.24	0.43	0.37
γ-Hexachlorocyclohexane	0.02	0.08	0.06
Hexachlorobiphenyl	1.68	0.90	1.14
Dieldrin	0.03	0.03	0.03
Heptachlor epoxide	0.04	0.03	0.03
p,p'-DDT	0.28	0.31	0.30
o,p'-DDT	0.02	0.02	0.02
p,p'-DDE	1.73	1.53	1.59
p,p'-DDD	0.01	0.01	0.01
Σ(DDT + DDE)	2.04	1.84	1.90

Polychlorinated Compounds

The substances accumulating in the food chain due to their high persistence in the environment and their lipophilic properties are of major importance. Humans constantly ingest such compounds because humans are the final link of the food chain. These chemicals are, in part, difficult to metabolize and therefore have long half-lives in humans. Chemicals are stored in the body fat, which is in equilibrium with blood fat. The best-known compounds in this group of substances are the persistent organochlorine pesticides as well as the polychlorinated biphenyls, dibenzodioxins, and dibenzofurans.

Persistent Organochlorine Pesticides

About 50 years ago, a number of organochlorine compounds was discovered which was insecticidal and thus used for purposes of plant protection and pest control in large amounts. DDT is the best-known representative of this group. As early as 1951, DDT was found to be present in human milk in considerable concentrations (*4*). Its metabolite, DDE, is characterized by a long half-life. This group also includes the isomers of hexachlorocyclohexane (HCH). Of these, β-HCH is particularly noteworthy because of its extended half-life in the human body. Other representatives are hexachlorobenzene (HCB) and a number of polychlorinated cyclodienes such as heptachlor epoxide, chlordane, and dieldrin. Because of their persistence and accumulation in the food chain, these substances were banned in many countries about 20 years ago.

There are numerous studies in which the presence of organochlorine pesticides in human milk has been demonstrated worldwide (*3*). In the former Federal Republic of Germany, systematic studies to evaluate the levels of these substances in human milk were performed in 1984 by a commission of Deutsche Forschungsgemeinschaft (*2*). As an example, analytical results of that study from two laboratories have been listed in Table 2.

Meanwhile, the bans have resulted in a considerable reduction of the levels of these substances in human milk, as illustrated by the data in Table 3. In contrast, studies from the former East Germany reveal that up to the present, DDT levels have been clearly higher because the use of DDT in plant protection was continued in that territory. For this reason, attention must be drawn to the fact that in countries lacking strict bans on the use of the organochlorine pesticides, levels of these substances may still be present in human milk that are considerably higher than those in the Federal Republic of Germany.

Polychlorinated Biphenyls

Due to their high persistence and dielectric properties, polychlorinated biphenyls (PCBs) have been widely used in electric devices (transformers and condensers), hydraulic oils, additives for paints and sealing materials, etc. Particularly as a result of uncontrolled disposal, these substances have also been introduced into the environment, accumulated in the food chain, and resulted in an exposure of the entire population.

In 1970, PCBs were determined for the first time in human body fat and milk, with levels between 0.5 and 21 mg/kg fat [mean 3.3 mg/kg fat (*8*)]. Examination of a major number of samples has even resulted in a mean level of 8.3 mg PCB/kg fat (*9*).

Unfortunately, quantitative analysis of PCB was difficult because the technical products consist of about 150 individual components and only some of them are present in human milk. Thus, the use of technical products as a standard and reference, which was common in former times, has led to higher levels that frequently cannot be compared (*10*). For standardization, the Federal Health Office of Germany has selected six PCB congeners as indicators (PCB-28, 52, 101, 138, 153 and 180), which are to be analyzed precisely and the results recorded (*11*). In the meantime, this procedure has also been approved in other countries and in international intercomparison studies.

Table 3. Organochlorine pesticide concentrations (mean values, mg/kg fat) in breast milk from Germany.

Years	HCB	β-HCH	Σ DDT
Federal Republic of Germany			
1979–81 (n = 2709)[a]	1.14	0.37	1.90
1975–88 (n = 6070) (*5*)	0.81	0.24	1.44
1986 (n = 3778) (*6*)	0.31	0.12	0.79
Former German Democratic Republic			
1990 (n = 90) (*7*)	0.25	0.18	2.72

Abbreviations: HCB, hexachlorobiphenyl; HCH, hexachlorocyclohexane.

[a]See Table 2.

Particularly, the congeners PCB-138, 153, and 180 accumulate in breast milk due to their long half-lifes. The sum of these three congeners accounts for about 60% of the total PCB content (*12*).

Recent studies carried out in the former Federal Republic of Germany have also shown a gradual decrease of PCB content in human milk that is, however, only recognizable when longer periods are taken into consideration. The average content in the 1979–1981 period had decreased to 1.8 mg PCB/kg fat (*2*), but this was still elevated, and a further decrease has subsequently occurred to the present levels of about 1 mg/kg fat (*6,7*). In contrast to this decreasing trend in the industrialized countries, high concentrations (up to 14.7 mg/kg fat PCB, calculated as Aroclor 1260) have been determined in the breast milk of Inuit women, who have a high consumption of fish and sea mammals (*13*).

Due to their high toxicity, the coplanar PCB congeners with four to six chlorine atoms (PCB-77, 126 and 169) are of particular importance; for example, PCB-77 is isosteric with 2,3,7,8-TCDD (*14*). Because PCB-77 is present in very low concentrations, the determination of this compound has been possible for only a few years. In studies performed at the Federal Health Office of Germany, mean concentrations of 22 pg/g fat were measured for PCB-77 in breast milk (*15*). PCB-126 and PCB-169 levels were not determined precisely. However, they have been estimated at about 80 and 40 pg/g milk fat, respectively, in accordance with the data obtained from the literature (*16*).

Polychlorinated Dibenzodioxins and Dibenzofurans

The ubiquitous distribution of polychlorinated dibenzodioxins (PCDDs) and polychlorinated dibenzofurans (PCDF) has become known only within the last few years. The presence of these substances also indicates that chemicals that have never been produced as such, but that develop only in extremely small concentrations in almost any combustion processes or in a few chemical procedures, are relevant contaminants in human milk.

In 1984, Rappe (*17*) examined five human milk samples from Germany for PCDD/PCDF for the first time. Since then, more than 1500 human milk samples have been analyzed in the Federal Republic of Germany, so it is now possible to make representative statements on the levels of these substances. The results obtained from 728 samples in 3 laboratories are presented in Table 4 (*18*).

In all samples, only 15 compounds containing chlorine atoms in positions 2,3,7, and 8 out of a total of 210 PCDD/PCDF congeners were found. This means that in this substance group, the congeners with the highest toxicity also show the highest accumulation. It is striking that the contamination of the samples is rather homogeneous, which is reflected by both the high correlations between the individual congeners (*19*) and the small range between minimum and maximum, which is commonly 1 log only. By analyzing foods, it could be shown that the main route of exposure of the mothers to dioxin is from food, in particular foods of animal origin (*20,21*).

Table 4. PCDF/PCDR concentrations (pg/g fat) in 728 breast milk samples from Germany.

Congener	Mean	Minimum	Median	Maximum
2,3,7,8-TCDF	1.8	0.15	1.6	12.0
2,3,7,8-TCDD	3.2	0.5	3.0	10.0
1,2,3,7,8-PeCDF	0.6	0.1	0.5	21.5
2,3,4,7,8-PeCDF	28.3	0.4	26.0	104
1,2,3,7,8-PeCDD	10.4	1.7	9.6	35.0
1,2,3,4,7,8-HxCDF	7.7	1.1	7.2	28.0
1,2,3,6,7,8,HxCDF	7.3	1.0	6.8	24.0
2,3,4,6,7,8-HxCDF	3.5	0.1	3.2	16.0
Σ HxCDF	18.5	3.1	17.3	55.0
1,2,3,4,7,8-HxCDD	8.5	1.2	7.8	33.0
1,2,3,6,7,8-HxCDD	37.9	3.0	36.0	126
1,2,3,7,8,9-HxCDD	7.0	0.4	6.3	21.0
Σ HxCDD	53.4	3.2	50.5	178
1,2,3,4,6,7,8-HpCDF	7.3	0.5	5.9	106
1,2,3,4,6,7,8-HpCDD	47.2	6.4	42.4	161
OCDF	2.2	0.1	1.5	223
OCDD	226	19.0	192	1300
TEq	30.6	5.6	29.2	87.1

Abbreviations: T, tetra; CDF, chlorodibenzofuran; CDD, chlorodibenzodioxin; Pe, penta; Hx, hexa; Hp, hepta; O, octa; TEq, international toxicity equivalents.

The levels of 2,3,7,8-TCDD are between 0.5 and 10 pg/g fat (mean level 3.2 pg/g). If the toxicity of the congeners is summarized in the form of the so-called international toxicity equivalents (TEq), a range of 5.6–87.1 pg TEq/g fat is obtained, with a mean level of 30.6 pg/g. The frequency distribution of these data (Fig. 1) is characterized by a lognormal distribution.

Differences between rural and urban regions within Germany are not recognizable (*22,23*). In a field study coordinated by the World Health Organization (*24*), it has been shown that in the more industrialized countries, PCDD/

Table 5. Levels of polychlorinated dibenzodioxins and dibenzofurans in pooled samples of breast milk (pg/g fat, Nordic toxic equivalency factor).[a]

Country	Level
Austria	17.1, 18.6
Belgium	40.2, 38.8
Canada	15.8, 18.1, 16.9, 18.1, 19.4, 23.0
Denmark	17.8
Finland	18.0, 15.5
Germany	27.6, 32.0, 32.8, 35.4, 30.1, 36.8, 31.7
Hungary	9.1, 11.3
Japan	20.2, 27.6
New Zealand	17.2[b]
Netherlands	37.4, 39.6
Norway	18.9, 15.0, 19.4
Poland	20.8
Sweden	22.4, 22.8, 22.6, 20.2
Thailand	4.9
United Kingdom	37.0, 29.1, 16.6
United States	16.7
Vietnam	8.4, 18.7, 22.1, 31.8, 26.3, 19.5, 13.2, 6.8
Yugoslavia	11.8, 12.0

[a]Data from WHO-coordinated studies (*22*).
[b]Data from Bates et al. (*25*).

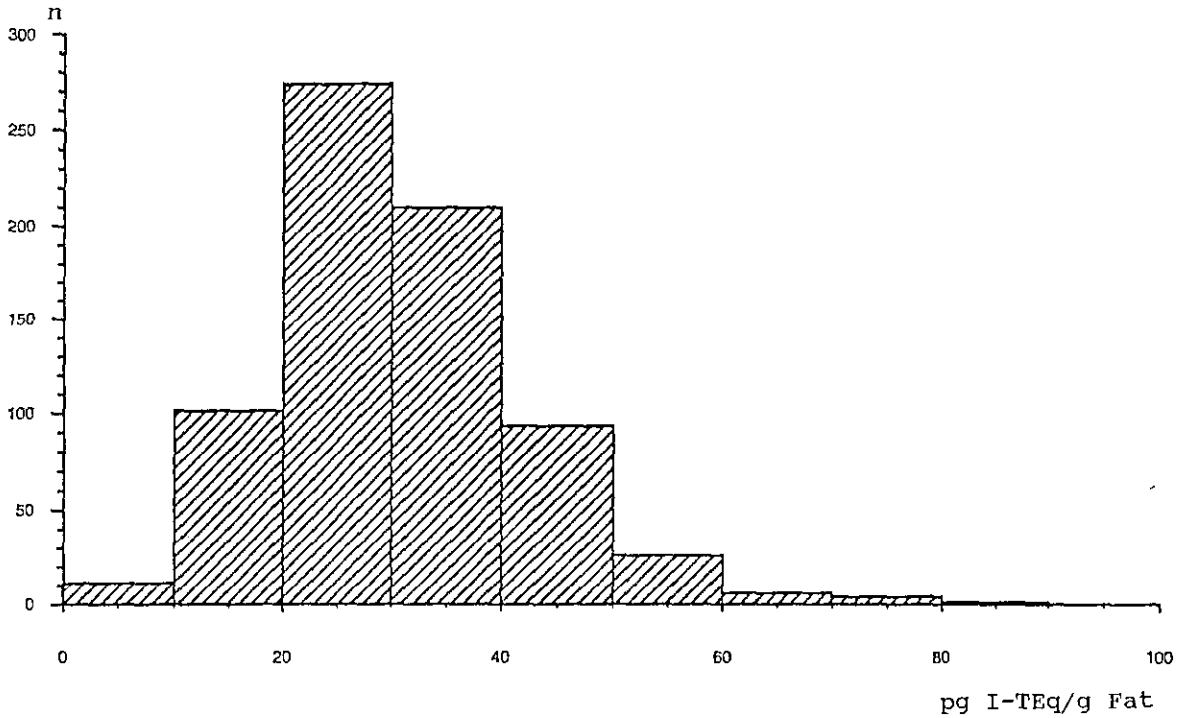

FIGURE 1. Frequency distribution of polychlorinated dibenzodioxin/dibenzofuran levels in 728 breast milk samples from Germany (*18*).

PCDF concentrations are roughly in the same range. In the developing countries, levels are lower (Table 5).

There was an obvious decrease of the dioxin levels in human milk with an increasing number of nursing periods (*26*): at the time of the second nursing period, the mean decrease of TEq concentrations was 22% and when the third child was nursed, 43%. Within the nursing period, a decrease of the dioxin level (TEq) by 15% was measured after 6 weeks and by 25% after 12 weeks (*26,27*). Furst et al. (*28*) even found a decrease of the dioxin level by 72% in a mother who had nursed her child for 1 year. Studies performed at the Federal Health Office of Germany (*26*) also revealed a distinct rise in the dioxin levels of human milk as a function of the age of the mother, but Lindstrom et al. (*23*) did not find such dependency. We also found in our studies (*26*) somewhat lower levels of PCDDs and PCDFs in milk from vegetarian mothers. It must be added that such differences can be expected only where the mothers have observed a strict vegetarian diet for many years, which is rare in Germany.

Polybrominated Compounds

Polybrominated compounds are used primarily as flame retardants. Following an incident in Michigan, in 1973, when misdeclaration of a product resulted in a contamination of feeds and foods with polybrominated biphenyls (PBB), PBB concentrations between 32 and 93000 ng/g fat were found in human milk (*29*). In Germany, levels of about 2 ng PBB/g fat were found to be present in human milk (*30*).

Data on polybrominated dibenzodioxins and furans have not been available so far. It can be expected, however, that these compounds are also present in human milk in very low concentrations.

Polycyclic Aromatic Hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) also form during combustion processes but accumulate in the food chain to a lesser degree. Due to the large number of individual compounds involved and the complicated analytic procedures, very few data are available. It has been documented by a study conducted in the Federal Republic of Germany (*2*) that a number of single PAH compounds were found to be present at concentrations of 5–15 ng/kg milk and, among these, benzo[*a*]pyrene, which often serves as an indicator of this group, was detected at a concentration of 6.5 ng/kg.

Trace Elements

A considerable number of communications on trace element levels in human milk has been published (*3*), but the data given are of quite different types. To exemplify this, Table 6 lists data published by Deutsche Forschungsgemeinschaft (DFG) in 1984 (*2*) and data from a World Health Organization (WHO) study published in 1988 (*31*). Reproduced from the latter study are the minimum, maximum, and median values established in the field study for selected elements; a median value from the literature given in that study; and proposed "normal" levels.

Table 6. Comparison of trace element concentrations (μg/L) in breast milk.

	WHO/IAEA study (*31*)				DFG (*2*)
	Levels observed		Data from literature	Defined as normal	Normally found
Element	Range	Median	Median	Range	Range
Arsenic	0.13–0.82	0.26	19.6	0.2–0.6	ND–50
Cadmium	0.10–3.8	0.10		<1	ND–20
Cobalt	0.09–1.9	0.36	2.0	0.15–0.35	ND–30
Chromium	0.0–86	15.0	22.9	0.8–1.5	0.3–0.5
Copper	57–715	201	280	180–310	200–700
Lead	0.0–41.1	5.0	22.5	2–5	ND–100
Manganese	7–102	18	20.0	3–4	20–104
Mercury	0.64–257.1	2.66	3.30	1.4–1.7	5
Selenium	7.9–65.8	19.3	19.0	13–24	15–50

ND, not detected.

With regard to some elements, the differences may be due to geochemical variations. In other cases, exposure of the mother may have been of a different type (e.g., to mercury from consumption of fish, to cadmium from smoking, to lead from motor vehicle exhausts). It would seem, however, that in many cases, such discrepancies can be attributed to poor analytic quality.

It is hardly possible to derive generally valid standard concentration ranges for these elements. In corresponding studies, it was found that the levels of essential trace elements in human milk could not be directly influenced by the diet of the nursing mothers (*32*). On the other hand, the levels in human milk published in the WHO study have demonstrated that the elevated levels of arsenic, lead, cadmium and mercury can be attributed to an elevated intake of the elements through food over long periods. In a study conducted in Berlin (*33*), it was shown that the use of a mercury-containing disinfectant (Merfen) had not resulted in elevated mercury levels in human milk.

Mycotoxins

Mycotoxins are usually highly toxic metabolic products of molds. The most prominent representatives of this group, of which about 150 compounds are known so far, include the carcinogenic aflatoxins. Aflatoxins are frequently found as contaminants in foods and feeds (cereals, nuts, etc.). Since in mammals, 1–3% of aflatoxin B_1 is metabolized to aflatoxin M_1 which is excreted in milk, this aflatoxin might also be present in human milk. However, in a study conducted in Kiel, Germany (*2*), in which 120 human milk samples were examined, no aflatoxin M_1 was found (detection limit 0. 3 ng/kg). On the other hand, aflatoxins have been detected in breast milk samples from tropical countries in Africa and Asia where mold-infected food is consumed frequently. In 90 out of 264 breast milk samples from Ghana and Nigeria (*34*), aflatoxins were found with seasonal fluctuations. Aflatoxin M_1 was most frequently detected in concentrations ranging from 20 to 1816 ng/L and aflatoxin B_1 in concentrations of up to 8218 ng/L. In addition to these two compounds, aflatoxins M_2 and B_2 were also found. A similar frequency of positive breast milk samples, although containing lower concentrations of aflatoxins, was found in Sudan (*35*).

Ochratoxin A, a nephrotoxic mycotoxin, was detected in 4 out of 36 samples of breast milk at concentrations of 20–30 ng/L (*36*). Investigations into the presence of other mycotoxins or their metabolites in human milk have not been conducted at this time.

Nitrates, Nitrites, and Nitrosamines

Nitrate is one of the natural components of human milk measured at concentrations of 1–3 mg/kg. In contrast, nitrites could not normally be detected in human milk as a rule, whereas levels of up to 1.2 mg/kg were detected in human milk samples containing bacteria (*2*).

Nitrosamines may develop in the reaction of secondary amines with nitrite. Because a series of nitrosamines are carcinogenic, human milk was also examined for nitrosamines (*2*). Unfortunately, the analysis of these compounds is rather difficult, so the sensitivity of the detection methods is not high enough. At a detection limit of 0.4 ng/g, nitrosamines could not be found in any sample.

Nicotine, Ethanol, and Caffeine

When discussing the presence of chemicals in human milk, it should always be taken into consideration that stimulants may pass from the blood of the mother into milk. Due to the relatively high milk/plasma quotient of approximately 3, nicotine may even reach higher levels in milk than in the blood of the mother, whereas this quotient is much lower (0.78) for cotinine (*37*). Ekstroem and Gustavsson (*38*) found levels of up to 95 ng/mL nicotine in breast milk from smokers. Concentrations from 0.2 to 1.6 ng/mL nicotine and from 5 to 30 ng/mL cotinine were detected in serum of nurslings from smoking mothers (*39*) and concentrations of up to 140 ng/mL cotinine were found in the urine of these nurslings (*40*). The direct inhalation of tobacco smoke by the infant, however, has to be viewed in a more critical way than the transfer via breast milk.

As the milk/plasma quotient for ethanol is 1, drinking alcohol by nursing mothers leads to an ingestion of ethanol by breast-fed infants. It was shown that even short-term alcohol consumption by mothers has an effect on the flavor of their milk and the feeding and sleeping behavior of their infants (*41*). After consumption of higher doses than 1 g ethanol/kg, a significant reduction in the milk ejection was observed (*42*).

As a distribution coefficient of 0.78 between milk and plasma has been reported for caffeine (*2*), this compound may also occur in breast milk and in serum of breast-fed infants (*43,44*). Nevertheless, no significant effect of caffeine exposure on heart rate and sleep time of the infants was found (*45*).

Drugs

It is a well-known fact that numerous drugs may enter human milk in concentrations that are a potential risk to the infant. Since there is a great variety of compounds, this substance group cannot be treated in detail in this review.

Health Evaluation

As has been shown, numerous chemicals may occur in breast milk. Because these substances are, in principle, undesirable in human milk, appropriate measures should be taken to prevent or at least minimize such contamination. The easiest way to achieve this would be to reduce the contamination associated with stimulants, as the behavior of the mother is the decisive factor. As for drugs, the possible introduction into human milk should be attributed greater importance (*46*). This does not only apply to over-the-counter drugs but also to those prescribed during the nursing period.

The levels of nitrite and nitrosamines are of no importance at the present time. By establishing limit values for nitrates (e.g., in drinking water and some foods) an increase of the nitrate level in human milk may also be prevented.

There are not enough data available to evaluate the mycotoxin levels in human milk, especially since it is not known which other mycotoxins besides aflatoxins and ochratoxin A may pass into the milk. An increased intake of aflatoxins has been prevented in many countries by establishing and controlling maximum limits for aflatoxins in foods and feeds. The fact that aflatoxins have been detected in human milk samples from tropical countries with high frequency and in concentrations of up to 8218 ng/mL is a matter of concern with regard to the possible consequences of this exposure for the infants.

For a series of chemicals, limit values were set by the Food and Agricultural Organization (FAO) and WHO for an acceptable daily intake (ADI) and a tolerable daily intake (TDI). These limits, however, serve the purpose of preventive health care and have been defined for a life-long daily intake of the substances, taking into account corresponding safety factors. It is not possible to apply these to a comparably short nursing period because a period of 6 months accounts for less than 1% of the normal life expectancy. If the daily intake of a substance during the nursing period is within the ADI or TDI range, a risk for the infant can be reliably excluded. Exceeding this level during the nursing period does not automatically involve a health risk because, for a risk estimation, other models would have to be used. However, for precautionary reasons, suitable measures in this field should be demanded to reduce the levels of these chemicals in human milk.

If the TDI levels set for a number of trace elements (*47*) are compared with the intake of these elements from breast milk (*31*), it is seen that only in single samples from certain countries have TDI levels for arsenic, mercury, and cadmium been exceeded, or, in the case of lead, the levels have almost been reached. It is thus possible to exclude a health risk for breast-fed infants even at the concentrations found. However, in the interest of preventive health care, the reasons for such elevated burden should be examined in more detail. With regard to mercury, a differentiation should be made between methyl mercury and inorganic mercury because a considerable part of the mercury intake is in the form of methyl mercury if fish is consumed in large quantities.

The intake of polycyclic aromatic hydrocarbons should be evaluated with more caution because this group of substances includes initiating as well as promoting carcinogens. It is thus impossible to set a TDI value for such a variety of substances. From the above-mentioned mean level of 6.5 ng/kg benzo[*a*]pyrene, an intake of this substance of 1 ng/kg body weight/day can be calculated for an infant weighing 5 kg and fed 800 mL of breast milk. At this dose, a risk for the infant is not to be expected. There should be further studies to establish representative data.

The levels of polybrominated biphenyls in "non-contaminated" human milk samples are of no health relevance. Although no data are available, the same may be expected with regard to the concentrations of polybrominated dibenzodioxins and dibenzofurans.

As a consequence of the ban of organochlorine pesticides in most countries, the levels in human milk have clearly declined. A risk for infants cannot be derived from the levels listed in Table 3, so a reduction of breast-feeding after a period of 4 months as recommended in a communication by a commission of Deutsche Forschungsgemeinschaft (*2*) is not justified. The data available do not permit an assessment of the situation in the developing countries where, for example, DDT concentrations of up to 100 ppm have been measured in breast milk.

A TDI value for the PCB congener patterns found in breast milk has not been established. Considering a life-long PCB intake, a tolerable dose of 1–3 μg/kg body weight/day has been used by the Federal Health Office of Germany. On the basis of PCB levels of about 1 ppm in breast milk, an intake of 4.8 μg/kg body weight/day is calculated for an infant of 5 kg fed an amount of 800 mL, thus only slightly exceeding the range mentioned above. From these levels a health risk for the infant cannot be derived, especially since PCB levels in human milk are also decreasing. However, a congener-specific evaluation of these substances is necessary taking into account, in particular, the coplanar and the mono-*ortho*-substituted PCBs. Further toxicological investigation of the relevant individual congeners is still lacking.

If the daily intake of dioxins is calculated from the PCDD/PCDF concentrations in breast milk (Table 4), a

Table 7. Daily intake of polychlorinated dibenzodioxin/dibenzofuran (pg/kg body weight/day) by infants via human milk.[a]

	Minimum	Maximum	Mean
2,3,7,8-TCDD	2	48	15
TEq	27	418	147

TEq, international toxicity equivalents.
[a]Body weight = 5 kg; milk quantity = 800 mL; fat content = 3%. See Table 4.

mean intake of 147 pg TEq/kg body weight/day will result for the infant (Table 7). Considering a life-long daily intake, the Federal Health Office of Germany has established a tolerable dose of 1–10 pg TCDD/kg body weight/day (*48*). An expert group of the WHO Regional Office for Europe also has derived a TDI of 10 pg TCDD/kg body weight/day (*49*). This level is considerably surpassed during the nursing period of the infant. For reasons of preventive public health, the dioxin burden should therefore be considered as a matter of concern, and further measures to minimize dioxin introduction into the environment should be taken.

As has been explained before, a comparison with the TDI value does not seem to be sensible in assessing the risk. A risk assessment made by WHO (*50*) shows that the total dioxin intake during a nursing period of 6 months is only about 4% of the dioxin ingested during a life span of 70 years. At the same time it is emphasized that only about 50% of the PCDD/PCDF contained in breast milk is taken up by the infant.

A comparison of the concentrations in the human body (and in the target organs) with those that do not have an adverse effect in exposed persons or in animal experiments (no-observed-adverse-effect concentrations) seems to be better suited for the risk assessment of accumulating substances.

It has been concluded from pharmacological models that there could be a 2- to 3-fold increase of the dioxin concentrations in the breast-fed infant as compared to those present in human milk. In investigations performed in rhesus monkeys (*51*), an increase in dioxin concentration up to four times the concentration in breast milk was found. In order to determine the true burden, samples from German infants who died from the sudden infant death syndrome were examined by the Federal Health Office (*52*). Even infants who had been breast-fed for 3 months showed low levels of dioxins (6.6 and 8.4 pg TEq/g fat). Thus, the levels were lower than the mean levels in breast milk and, moreover, only slightly higher than levels found in bottle-fed babies.

In view of such low dioxin concentrations in the body of infants, no risk to their health is to be expected in the opinion of both the Federal Health Office and WHO (*50*). So far, no study has been published that would have proved adverse effects on the health of infants caused by dioxin contained in breast milk. For further confirmation of this evaluation, however, investigations into the distribution of PCDD/PCDF in the human body and into the toxicology of these substances will be necessary.

REFERENCES

1. WHO. The Quantity and Quality of Breast Milk. Report on the WHO Collaborative Study on Breastfeeding. World Health Organization, Geneva, 1985.
2. Deutsche Forschungsgemeinschaft. Ruckstande und Verunreinigungen in Frauenmilch. Verlag Chemie, Weinheim, 1984.
3. Jensen, A. A., and Slorach, S. A. Chemical Contaminants in Human Milk. CRC Press, Boca Raton, FL, 1990.
4. Lang, E. P., Kunze, F. M., and Prickett, C. S. Occurrence of DDT in human fat and milk. Arch. Ind. Hyg. Occup. Med. 3: 245–246 (1951).
5. Beck, H. Schwerfluchtige Organohalogenverbindungen im Menschen. In: VDI Berichte, No. 745. VDI-Verlag GmbH, Dusseldorf, 1989, pp. 627–657.
6. Kubler, W. Organochlorverbindungen in Frauenmilch 1986. Report to the Federal Minister of Youth, Family, Women and Health. GieBen, 1987.
7. Horn, M. Thesis. Humboldt-Universitat, Berlin, 1990.
8. Acker, L., and Schulte, E. Uber das Vorkommen chlorierter Kohlenwasserstoffe im menschlichen Fettgewebe und in Humanmilch. Dtsch. Lebensm.-Rdsch. 66: 385–390 (1970).
9. Acker, L., and Schulte, E. Chlorkohlenwasserstoffe im menschlichen Fett. Naturwissenschaften 61: 32 (1974).
10. Deutsche Forschungsgemeinschaft. Polychlorierte Biphenyle. Verlag Chemie, Weinheim, Germany, 1988.
11. Beck, H., and Mathar, W. Analysenverfahren zur Bestimmung von ausgewahlten PCB-Einzelkomponenten in Lebensmitteln. Bundesgesundheitsblatt 28: 1–12 (1985).
12. Schulte, E., and Malisch, R. Calculation of the real PCB content in environmental samples. Fres. Z. Anal. Chem. 319: 54–59 (1984).
13. Dewailly, E., Nantel, A., Weber, J. P., and Meyer, F. High levels of PCBs in breast milk of Inuit women from Arctic Quebec. Bull. Environ. Contam. Toxicol. 43: 641–646 (1989).
14. McKinney, J., and McConnel, E. Structural specificity and the dioxin receptor. In: Chlorinated Dioxins and Related Compounds (O. Hutzinger, Ed.), Pergamon Press, Oxford, 1981, p. 367.
15. Beck, H., Droß, A., and Mathar, W. 3,3′,4,4′-Tetrachlorobiphenyl in human fat and milk samples. Chemosphere 19: 1805–1810 (1989).
16. Noren, K., Lunden, A., Sjovall, J., and Bergmann, A. Coplanar polychlorinated biphenyls in Swedish human milk. Chemosphere 20: 935–941 (1990).
17. Rappe, C., Bergqvist, P.-A., Hansson, M., Kjeller, L.-O., Lindstrom, G., Marklund, S., and Nygren, M. Chemistry and analysis of polychlorinated dibenzodioxins and dibenzofurans in biological samples. In: Biological Mechanisms of Dieldrin Action (A. Poland and R. D. Kimbrough, Eds.), Banbury Report 18. Cold Spring Harbor Laboratory, Cold Spring Harbor, NY, 1984, pp. 17–25.
18. Beck, H., Droß, A., Ende, M., Furst, Chr., Furst, P., Hille, A., Mathar, W., and Wilmers, K. Ergebnisse von Ruckstandsuntersuchungen auf polychlorierte Dibenzofurane und Dibenzodioxine in Frauenmilch aus der Bundesrepublik Deutschland. Bundesgesundheitsblatt, in press.
19. Beck, H., Eckart, K., Kellert, M., Mathar, W., Ruhl, Ch.-S., and Wittkowski, R. Levels of PCDFs and PCDDs in samples of human origin and food in the Federal Republic of Germany. Chemosphere 16: 1977–1982 (1987).
20. Beck, H., Eckart, K., Mathar, W., and Wittkowski, R. PCDD and PCDF body burden from food intake in the Federal Republic of Germany. Chemosphere 18: 417–424 (1989).
21. Furst, P., Furst, Chr., and Groebel, W. Levels of PCDDs and PCDFs in foodstuffs from the Federal Republic of Germany. Chemosphere 20: 787–792 (1990).
22. Beck, H., Eckart, K., Mathar, W., and Wittkowski, R. Dependence of PCDD and PCDF levels in human milk on various parameters in the Federal Republic of Germany. Chemosphere 18: 1063–1066 (1989).
23. Lindstrom, G. U. M., Sjostrom, M., Swanson, S. E., Furst, P., Kruger, Chr., Meemken, H.-A., and Groebel, W. Multivariate statistical approach to a data set of dioxin and furan contaminations in human milk. Bull. Environ. Contam. Toxicol. 40: 641–646 (1988).
24. Yrjanheikki, E. J., Ed. Levels of PCBs, PCDDs, and PCDFs in Breast Milk. Environmental Health Series 34, World Health Organization, Copenhagen, 1989.

25. Bates, M. N., Buckland, S. J., Hannah, D. J., Taucher, J. A. and van Maanen, T. Organochlorine Residues in the Breast Milk of New Zealand Women. Report to the Department of Health, Wellington, New Zealand, May 1990.
26. Beck, H., Droß, A., and Mathar, W. PCDD and PCDF exposure and levels in humans in Germany. Environ. Health Perspect. 101(Suppl. 6): in press.
27. Beck, H., Droß, A., and Mathar, W. Bestimmung von polychlorierten Dibenzofuranen und Dibenzodioxinen in Frauenmilch in Abhangigkeit von der Stilldauer. In: Tatigkeitsbericht des Bundesgesundheitsamtes 1990. MMV Medizin Verlag, Munchen, 1991, pp. 171–172.
28. Furst, P., Kruger, Chr., Meemken, H.-A., and Groebel, W. PCDD and PCDF levels in human milk-dependence on the period of lactation. Chemosphere 18: 439–444 (1989).
29. Brilliant, L. B., Wilcox, K., Van Amburg, G., Eyster, J., Isbister, J., Bloomer, A. W., Humphrey, H., and Price, H. Breast milk monitoring to measure Michigans contamination with polybrominated biphenyls. Lancet ii: 643–646 (1978).
30. Kruger, Chr., Furst, P., and Groebel, W. Nachweis und Bestimmung von polybromierten Biphenylen in Frauenmilch. Dtsch. Lebensm.-Rdsch. 84: 273–276 (1988).
31. WHO. Minor and Trace Elements in Breast Milk. Report of a Joint WHO/IAEA Collaborative Study. World Health Organization, Geneva, 1989.
32. Knochel-Schiffer, I., and Großklaus, R. Einfluß der mutterlichen Ernahrung auf die Spurenelement- und Mineralstoffzusammensetzung der Frauenmilch. MvPI-Hefte 1/1986, Max von Pettenkofer-Institut des Bundesgesundheitsamtes, Berlin, 1986.
33. Muller, J., Gotze, S., Negretti De Bratter, V., Weigert, P. I.,arkut, G., Hildebrandt, A. G., and Bratter, P. Quecksilber-, Magnesium- und Zinkgehalte in der Frauenmilch, im Blutserum und Fettgewebe der Mutter. ZEBS-Hefte 1/1986, Bundesgesundheitsamt, Berlin, 1986.
34. Lamplugh, S. M., Hendrickse, R. G., Apeagyei, F., and Mwanmut, D. D. Aflatoxins in breast milk, neonatal cord blood and serum of pregnant women. Br. Med. J. 296: 968 (1988).
35. Coulter, J. B. S., Lamplugh, S. M., Suliman, G. I., Omer, M. I. A., and Hendrickse, R. G. Aflatoxins in human breast milk. Ann. Trop. Paediatr. 4: 61–66 (1984).
36. Deutsche Forschungsgemeinschaft. Ochratoxin A—Vorkommen und toxikologische Bewertung. VCH Verlagsgesellschaft, Weinheim, 1990.
37. Luek, W., and Nau, H. Nicotine and cotinine concentrations in serum and milk of nursing smokers. Br. J. Clin. Pharmacol. 18: 9–16 (1984).
38. Ekstroem, G., and Gustavsson, H. Nicotine in mothers milk from mothers who smoke. Var Foeda 32: 447–457 (1980).
39. Luck, W., and Nau, H. Nicotine and cotinine concentrations in serum and urine of infants exposed via passive smoking or milk from smoking mothers. J. Pediatr. 107: 816–820 (1985).
40. Woodward, A., Gregurinovich, N., and Ryan, P. Breast feeding and smoking hygiene: major influences on cotinine in urine of smokers' infants. J. Epidemiol. Comm. Health 40: 309–315 (1984).
41. Mennella, J. A., and Beauchamp, G. K. The transfer of alcohol to human milk. Effects on flavor and the infants' behavior. N. Engl. J. Med. 325: 981–985 (1991).
42. Cobo, E. Effect of different doses of ethanol on the milk-ejecting reflex in lactating women. Am. J. Obstet. Gynecol. 115: 817–821 (1973).
43. Berlin, C. M., Denson, H. M., Daniel, C. H., and Ward, R. M. Disposition of dietary caffeine in milk, saliva, and plasma of lactating women. Pediatrics 73: 59–63 (1984).
44. Ryu, J. E. Caffeine in human milk and in serum of breast-fed infants. Dev. Pharmacol. Ther. 8: 329–337 (1985).
45. Ryu, J. E. Effect of maternal caffeine consumption on heart rate and sleep time of breast-fed infants. Dev. Pharmacol. Ther. 8: 355–363 (1985).
46. Spielmann, H., and Steinhoff, R. Taschenbuch der Arzneimittelverordnung in Schwangerschaft und Stillperiode. G. Fischer Verlag, Stuttgart, 1989.
47. WHO. Trace Elements in Human Nutrition. WHO Technical Report Series No. 532, World Health Organization, Geneva, 1973.
48. Appel, K. E., Beck, H., Hildebrandt, A. G., and Lingk, W. An initial health assessment of dioxins and furans. In: Report on Dioxins, Update to Nov., 1984. Federal Environmental Agency and Federal Health Office, Berlin, 1986, pp. 259–297.
49. WHO. Consultation on Tolerable Daily Intake from Food of PCDDs and PCDFs—Executive Summary. World Health Organization, Copenhagen, in press.
50. WHO. Assessment of Health Risks in Infants Associated with Exposure to PCBs, PCDDs and PCDFs in Breast Milk. Environmental Health Series No. 29, World Health Organization, Copenhagen, 1988.
51. Bowman, R. E., Schantz, S. L., Weerasinghe, N. C. A., Gross, M. L., and Barsotti, D. A. Chronic dietary intake of 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) at 5 or 25 parts per trillion in the monkey: TCDD kinetics and dose-effect estimate of reproductive toxicity. Chemosphere 18: 243–252 (1989).
52. Beck, H., Droß, A., Kleemann, W. J., and Mathar, W. PCDD and PCDF concentrations in different organs from infants. Chemosphere 20: 903–910 (1990).