Exposure Assessment to Dioxins from the Use of Tampons and Diapers

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Over the past several years there has been concern over exposure to dioxins through the use of tampons and other sanitary products. This article describes attempts to estimate dioxin exposures from tampons and infant diapers; we then compare exposure estimates to dietary dioxin exposures. We analyzed four brands of tampons and four brands of infant diapers obtained from commercial establishments in San Francisco, California, for dioxin concentrations. We estimated exposures to dioxins on the basis of a screening level analysis that assumed all dioxins present were completely absorbed. We also estimated exposures by using a more refined analysis that incorporates partition coefficients to estimate bioavailability. None of the products contained 2,3,7,8-tetrachlorodibenzo-*p*-dioxin, the most potent dioxin, although other dioxins were present at detectable concentrations in all samples. We observed minimal differences in the concentrations of dioxins between 100% cotton and cotton/pulp products. The refined exposure analysis indicates that exposures to dioxins from tampons are approximately 13,000–240,000 times less than dietary exposures. The refined exposure analysis showed that exposure to dioxins from the diet is more than 30,000–2,200,000 times the exposure through diapers in nursing infants. Although dioxins are found in trace amounts in both cotton and pulp sanitary products, exposure to dioxins through tampons and diapers does not significantly contribute to dioxin exposures in the United States. *Key words*: diapers, dioxins, exposure assessment, tampons, toxic equivalents.
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Recently there has been considerable concern over exposure to dioxins through the use of sanitary products containing wood pulp or pulp-based products, such as rayon, that have been bleached with chlorine. Rayon-containing products, particularly tampons, have been singled out in some forums. This concern is based on information disseminated predominantly through the internet via e-mails and web pages, but it has also been picked up by television news, newspapers, and magazines. These reports suggest exposure to dioxins through tampon use as the causative agent in endometriosis and potentially other reproductive tract diseases. The basis for this suggestion stems from two lines of data. First, there are several reports on the presence of dioxins in tampons (*1,2*). Second, in several experimental systems, dioxins increase the incidence and/or severity of endometriosis in primates (*3,4*), rats (*5*), and mice (*5–7*). However, there are considerable uncertainties in the role of dioxins in the development of endometriosis. There is limited information available on the potential exposure to dioxins from tampons and other sanitary products. In addition, no definitive human data refute or support the association between dioxin exposure and endometriosis or other reproductive tract diseases.

Dioxins are a class of persistent polyhalogenated aromatic hydrocarbons that induce a wide spectrum of toxic responses in experimental animals including reproductive, endocrine, developmental, and immunologic toxicities as well as carcinogenicity (*8*). Most if not all effects of dioxins are mediated by their binding to the aryl hydrocarbon (Ah) receptor (*9*). The Ah receptor is a ligand-activated transcription factor that is a member of the Per/ARNT/Sim family of transcription factors (*8–10*). The Ah receptor is found in a wide variety of species including fish, birds, rodents, nonhuman primates, and humans (*10*). The presence of an active human Ah receptor suggests that humans may respond to dioxins in a manner similar to experimental animals. In fact, there is mounting evidence of the health effects of dioxins in humans. Recently, the International Agency for Research on Cancer and the National Institutes of Health in the United States have independently upgraded 2,3,7,8-tetrachlordibenzo-*p*-dioxin (TCDD) to a known human carcinogen (*11,12*). Associations between TCDD exposure and noncancer health effects such as diabetes (*8,13–16*) and developmental delays (*8,17,18*) have also been reported.

In rhesus monkeys, dietary exposure to TCDD over 4 years causes a dose-dependent increase in the incidence and severity of endometriosis from 7 to 10 years after the end of exposure (*3*). In cynomolgus monkeys, exposure to TCDD enhances the survival and growth of surgically implanted endometrial tissue (*4*). In rodent models of endometriosis, TCDD exposure increases the size of surgically induced endometriosis in both rats and mice (*5–7*). Evidence suggests that increased exposures to dioxins are associated with increased incidence of endometriosis in humans (*19,20*). However, these human studies have small sample sizes, and further research is required to demonstrate a cause–effect relationship between dioxin exposure and endometriosis in humans.

Dioxins are produced through a variety of industrial and combustion processes. One industrial process is the bleaching of wood pulp with elemental chlorine (*21*). Consequently, so-called chlorine-bleached paper products are often the subject of speculation regarding potential risk of exposure to dioxins from consumer product use. Over the last decade there has been a global transition away from the use of elemental chlorine in pulp bleaching. Currently, a significant amount of bleached pulp is processed using elemental chlorine-free methods that virtually eliminate the presence of TCDD and greatly reduce the presence of dioxin equivalents (*21*).

The U.S. Environmental Protection Agency has estimated that > 95% of exposures to dioxins are through low-level contamination of the food supply (*8*). These exposures are caused by bioaccumulation of dioxins in animals and the subsequent consumption of animal products such as beef, pork, poultry, and fish, as well as dairy products (*8*). The major sources of dioxins in the food chain are combustion mechanisms such as municipal, hazardous, and medical waste incinerators (*8*). Recent evidence suggests that the open burning of trash may also be a significant source of emissions of dioxins (*22*). Present effluents from pulp and paper

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mills are minor contributors to current emissions of dioxins to the environment (*8,21*).

Industrial processes and combustion sources produce numerous forms of polychlorinated dibenzo-*p*-dioxins and the structurally related polychlorinated dibenzofurans. Only 17 of the 75 polychlorinated dioxins and 135 polychlorinated dibenzofurans induce dioxinlike effects (*23*). Humans are exposed to mixtures of dioxins. To assess the potential health effects of exposure to mixtures of dioxins, the toxic equivalency factor (TEF) method was developed (*8,23,24*). The TEF methodology is a relative potency scheme that compares the potency of a dioxinlike chemical to TCDD, the most potent of the dioxins. Multiplying the TEF value for a chemical by its concentration in a sample provides an estimate of the toxic equivalents (TEQ) of dioxin for that chemical. Summing the TEQs of a mixture provides an estimate of the total TEQ present and allows risk assessors to estimate the potential health risks associated with exposure to dioxinlike chemicals.

In the present study, we estimated the contribution of tampon use to dioxin exposure and compared it to dietary exposures of dioxins. Disposable diapers are also made from wood pulp-based products, so we also compared exposure to dioxins through the use of disposable diapers to the total dioxin exposure in infants. We performed an initial screening-level estimate of the dioxin exposure from tampons and diapers that incorporated several conservative assumptions. A second, more refined assessment also attempted to provide a more accurate estimate of potential exposures by incorporating information on the bioavailability of the dioxins in the pulp.

Materials and Methods

Sampling and dioxin analysis. In 1997, tampons and diapers were purchased in San Francisco, California by volunteers from the environmental organization Mothers and Others for a Livable Planet.

Tampon brands A and B, disposable diaper brands E and F, and the conventional cotton diapers were purchased at the same large department store. These tampons can be considered "brand name" products and are available throughout the United States. Brand A tampons were available in rayon or cotton, and both were obtained and analyzed separately for dioxin concentrations. Brand C tampons and brand G disposable diapers were obtained from a health food store belonging to a chain through which they were marketed. Brand D tampons were ordered from a specialty company. All boxes purchased of a given product were of the same lot number. The products were shipped in their commercial containers to ERGO Research Company in Hamburg, Germany. Polychlorinated dibenzo-*p*-dioxins and dibenzofurans were extracted from these products and analyzed at ERGO as described previously (*1,2,25*) (Table 1). The ERGO Research Company is certified by the World Health Organization for dioxin analysis.

Exposure estimates from tampons. To estimate exposure to dioxins from tampons and to compare these exposures to dietary intakes, the concentrations of the individual polychlorinated dibenzo-*p*-dioxins and dibenzofurans were converted to dioxin equivalents using the WHO TEF methodology (*23*) (Table 2). Two different exposure models were used to estimate exposures from tampons. In the screening-level analysis, women were assumed to use 6 tampons/day for 5 days per month. The average weight for each brand of tampon is presented in Table 3. We averaged exposure estimates over 30 days to estimate average daily exposure. We estimated the average body weight of an adult female at 60 kg (*26*). In the screening level analysis, we used the following equation to estimate dioxin exposure from tampons:

$$\text{Average daily intake} = \frac{N_t \times C_t \times T_w \times D_m}{bw \times 30}, \qquad [1]$$

where N_t is the number of tampons used per day; C_t is the concentration of dioxins in the tampon expressed as dioxin equivalents (picograms TEQ/gram); T_w is the mass of the tampons (gram); D_m is the number of days/month that women use tampons; and bw is the average women's body weight and 30 is the number of days in the month.

In the screening-level analysis, we assumed that all the dioxins in the tampons were bioavailable and that all dioxins in the tampons were released into the body. The assumption of 100% bioavailability is likely an overestimate of the true exposure. To estimate a more accurate assessment, we also performed a refined analysis, in which we estimated the bioavailability of the dioxins in the tampons using partition coefficients:

$$D_t \text{ (dioxin dose from a single tampon)} = \frac{C_t \times M_t}{M_t\left(\frac{K_p}{M_f}\right)}, \qquad [2],$$

where C_t is the concentration of dioxins in the tampons expressed as TEQs; T_w is the mass of the tampon; K_p is the partition coefficient of the 2,3,7,8-tetrachlorodibenzofuran (TCDF) from pulp to synthetic urine; and M_f is the mass of the menstrual fluid an average tampon could absorb. We estimated the partition coefficient for TCDF as the amount of 2,3,7,8-TCDF partitioning from the pulp to synthetic urine over 8 hr. This value was calculated as 5,340 (*27*). No other partitioning data from pulp are available for the other chlorinated dioxins and dibenzofurans. The K_p value for these chemicals should increase as their water solubility increases. Water solubility of dioxins decreases with increasing chlorination. Thus, the K_p value for 2,3,7,8-TCDF will likely overestimate the partitioning of the higher chlorinated dioxins and dibenzofurans present in the tampons, thus overestimating the bioavailability of these chemicals. The estimate of menstrual fluid volume was based on the amount of fluid an average tampon could absorb. This information was obtained from the package insert from several tampon products from different manufacturers and was estimated at 10 g/tampon. The average daily intake from tampons was then estimated using the following equation:

$$\text{Average daily dioxin dose from tampons} = \frac{D_d \times N_t \times D_m}{bw \times 30}. \qquad [3]$$

The estimates of dioxin intake from the diet range from 1 to 6 pg TEQ/kg/day (*8,28*). We used a value of 1 pg TEQ/kg/day as an estimate of the present daily dietary intake for adults based on estimates from the U.S. EPA (*8*). The 1 pg TEQ/kg/day is the best estimate of daily intake in the use from a statistically designed food basket survey and food consumption estimates (*8*).

Exposure estimates from diapers. We estimated exposure of infants and toddlers to dioxins from diapers using two different models with several assumptions. We assumed infants (0–6 months) used 10 diapers/day and toddlers (6–24 months) 6 diapers/day. We estimated the average weight of a diaper to be 40 g. And we assumed that infants nurse from 0–6 months and have an average body weight of 6.75 kg from birth to 6 months. The estimate of dioxins intake from breast milk is 980 pg TEQ/day or approximately 145 pg TEQ/kg/day (*8*). We estimated the average body weight for toddlers 6–24 months old to be 11 kg. Average body weights for infants and toddlers were adapted from Fleischer and Ludwig (*29*). We estimated dietary intake for toddlers (6–24 months) at 40 pg TEQ/day (*8*). Using these estimates, we assumed dietary intake for toddlers was 3.6 pg TEQ/kg/day.

Exposure to dioxins from diapers occurs through dermal absorption. In experimental systems, dermal absorption has been observed from aqueous and organic vehicles as well as from soil. Dermal absorption of dioxins bound to wood pulp products has not been experimentally examined. However, in diapers, the dioxins are bound to the pulp fibers and are not readily available for absorption. Estimates of the dermal absorption fraction for TCDD from soil range from 0.1 to 3% depending on the organic content of the soil (*30,31*). In soils with high organic content, dioxins are tightly bound and are less available for release, and a value of 0.1% is used for dermal absorption fraction. A recent study indicates that between < 0.1 and 3% of dioxins present in either polyester or cotton fabrics are transferred to human skin over 72 hr (*32*). Because pulp is a mixture of highly organic fibers, it is likely that the dioxins are tightly bound to the fibers and are not readily bioavailable. However, because the extent of the bioavailability is uncertain, we used an absorption fraction of 3% based on U.S. EPA estimates of dermal absorption from soil with low organic content (*31*), as well as on the studies examining dermal transfer from cotton fabrics (*32*).

In the screening-level analysis, we estimated dermal exposures of dioxins through diapers using the following equation:

Daily Diaper Dose (pg/kg/day) =

$$\frac{C_d \times M_d \times N_d \times \text{Abs}}{bw}, \qquad [4]$$

where C_d is the concentration of dioxins in the diaper (TEQ pg/g); M_d is the mass of the diaper (g); Abs is the absorption fraction; N_d is the number of diapers used per day; and bw is the body weight of the infant (6.75 kg) or toddler (11 kg). A weight of 40 g/diaper was used as the average diaper weight.

The above estimate of dioxin exposure from diapers is likely to greatly overestimate the exposures and can be considered a worst-case scenario. We also estimated a refined dioxin exposure analysis through diapers. In this analysis, we assumed that only dioxins that partition into the urine from the diaper are bioavailable, based on the following equation:

$$D_d = \frac{\left(\dfrac{C_d \times M_d}{M_d\left(\dfrac{K_p}{U_l}\right)}\right) \times N_d \times \text{Abs}}{bw}, \qquad [5]$$

where D_d is the mass of dioxins partitioning into the urine from a single diaper; C_d is the concentration of dioxins in the diaper expressed as TEQs; U_l is the urine load; and M_d, N_d, bw, and K_p are as defined above. In the refined analysis we assumed that the dioxins that are bioavailable are in solution in the urine. Dermal absorption of dioxins in solutions is greater than absorption from dioxins bound to organic matter (*8,27,31,32*). The Abs used in this scenario was estimated at 28% (*8*), based on dermal absorption of dioxins in aqueous solutions from *in vivo* and *in vitro* experimental data (*8,27,31,32*). The urine load was set at 45 g/diaper (*27*). We assumed that all of the urine is in contact with the skin. This is a conservative assumption that should overestimate the exposure. The average daily dioxin dose from diapers is the calculated based on the following equation

Daily Diaper Dose (pg TEQ/kg/day) =

$$\frac{D_d \times N_d \times \text{Abs}}{bw}. \qquad [6]$$

Results

Tampons

We analyzed all 17 of the 2,3,7,8-chloro-substituted dibenzo-*p*-dioxins and dibenzofurans included in the TEF methodology. The detection limits for the chemicals were 0.1–0.2 ppt (Table 1). In tampon brands A (rayon and cotton), B, C, and D, detectable concentrations of 1,2,3,4,6,7,8-heptachlorodibenzo-*p*-dioxin, octachlorodibenzo-*p*-dioxin, TCDF, 1,2,3,4,6,7,8-heptachlorodibenzofuran, and octachlorodibenzofuran were observed. The remaining 12 polychlorinated dioxins and dibenzofurans included in the TEF methodology were not detected in brands A (rayon and cotton), B, and C. In tampon brand D, detectable concentrations of several other polychlorinated dibenzofurans were observed (Tables 1 and 2). No detectable concentrations of TCDD or 1,2,3,7,8-pentachlorodibenzo-*p*-dioxin, the most potent dioxins, were observed in any of the samples. The concentrations of most of the analytes were at or within a factor of 5 of their detection limit.

The total concentration of polychlorinated dibenzo-*p*-dioxins and dibenzofurans

Table 1. Concentrations of polychlorinated dibenzo-*p*-dioxins and polychlorinated dibenzofurans present in tampons and diapers.

	Concentration in tampons (pg/g)					Concentration in diapers (pg/g)			
Dioxin compounds	Brand A (rayon)	Brand A (cotton)	Brand B	Brand C	Brand D	Brand E	Brand F	Brand G	Cotton
1,2,3,4,6,7,8-Hexachlorodibenzo-*p*-dioxin	0.2	0.4	2.1	0.8	0.7	0.2	0.3	0.3	0.3
Octachlorodibenzo-*p*-dioxin	0.9	2.2	20.7	7.5	3.7	2.8	1.6	1.3	2.0
2,3,7,8-Tetrachlorodibenzofuran	0.1	0.1	0.1	0.1	0.6	0.2	0.1	0.1	ND (0.1)
1,2,3,7,8-Pentachlorodibenzofuran	ND (0.1)	ND (0.1)	ND (0.1)	ND (0.1)	0.4	ND (0.1)	ND (0.1)	ND (0.1)	ND (0.1)
2,3,4,7,8-Pentachlorodibenzofuran	ND (0.1)	ND (0.2)	ND (0.1)	ND (0.1)	0.2	ND (0.1)	ND (0.1)	ND (0.1)	ND (0.1)
All hexachlorodibenzofurans	ND (0.1)	ND (0.1)	ND (0.1)	ND (0.1)	0.5	ND (0.1)	ND (0.1)	ND (0.1)	ND (0.1)
All heptachlorodibenzofurans	0.1	0.1	0.1	0.1	0.4	0.1	ND (0.1)	ND (0.1)	0.1
Octachlorodibenzofuran	0.2	0.3	0.6	0.2	1.2	0.4	0.2	0.1	0.1
Total dioxins	1.5	3.1	23.6	8.7	7.7	3.7	2.2	1.8	2.5

ND, not detected. Values in parentheses are detection limits.

Table 2. The concentrations of dioxin equivalents present in tampons and diapers.

		Concentration in tampons (pg TEQ/g)					Concentration in diapers (pg TEQ/g)			
Dioxin compounds	WHO-TEF	Brand A (rayon)	Brand A (cotton)	Brand B	Brand C	Brand D	Brand E	Brand F	Brand G	Cotton
1,2,3,4,6,7,8-Hexachlorodibenzo-*p*-dioxin	0.01	0.002	0.004	0.021	0.008	0.007	0.002	0.003	0.003	0.003
Octachlorodibenzo-*p*-dioxin	0.0001	0.00009	0.00022	0.00207	0.00075	0.00037	0.00028	0.00016	0.00013	0.0002
2,3,7,8-tetrachlorodibenzofuran	0.1	0.01	0.01	0.01	0.01	0.06	0.02	0.01	0.01	0
1,2,3,7,8-pentachlorodibenzofuran	0.05	0	0	0	0	0.02	0	0	0	0
2,3,4,7,8-pentachlorodibenzofuran	0.5	0	0	0	0	0.1	0	0	0	0
All hexachlorodibenzofurans	0.1	0	0	0	0	0.05	0	0	0	0
All heptachlorodibenzofurans	0.01	0.001	0.001	0.001	0.001	0.004	0.001	0	0	0.001
Octachlorodibenzofuran	0.0001	0.00002	0.00003	0.00006	0.00002	0.00012	0.00004	0.00002	0.00001	0.00001
Total TEQ		0.013	0.015	0.034	0.020	0.24	0.023	0.013	0.013	0.0042

in the tampons ranged from 1.5 to 23.6 pg/g (Table 1). Octachlorodibenzo-*p*-dioxin accounts for 48–88% of the total mass of dioxins in the tampons. The remaining dioxins make up < 1–16% of the total mass. The concentrations of TEQs in the tampon brands A (rayon and cotton), B, and C range from 0.013 to 0.034 pg/g tampon. Brand D tampons had considerably greater concentrations of TEQs (0.24 pg TEQ/g) than the other brands. Brand A tampons had similar TEQs, with the rayon product containing slightly less than the cotton, 0.013 and 0.015 pg/g tampon respectively. TCDF and the heptachlorinated dibenzo-*p*-dioxins account for approximately 90% of the TEQs found in tampon brands A, B, and C (Table 2). The concentration TCDF is at the detection limit for tampon brands A, B, and C, and these values should be viewed cautiously. The hexachlorinated dibenzo-*p*-dioxins, TCDF, and 2,3,4,7,8-pentachlorodibenzofuran account for > 90% of the dioxin equivalents present in brand D tampons. Except for brand D, as total dioxins increase in the tampon, so does the dioxin equivalents. Brand D has similar concentrations of total dioxins as brand C, but has more than 10 times the dioxin equivalents. In contrast, brand B has three times the total dioxin concentrations as brand D, but it has one-seventh the dioxin equivalents of brand D. The main difference between brand D and the other tampons is the greater concentration of 2,3,4,7,8-pentachlorodibenzofuran in brand D tampons.

With the screening-level analysis, estimated average daily intake of dioxins expressed, as TEQs, from tampon brands A, B, and C range from 0.00069 to 0.016 pg TEQ/kg/day. Compared to the daily intake of dioxins from these tampons, dietary intake of dioxins (1 pg dioxin TEQ/kg/day) is 65–1,453 times greater (Table 3). Daily intake of dioxins from brand D tampons is approximately 10 times higher than from the other brands. Compared to dietary intake, brand D tampons account for approximately 3.3% of the total daily dioxins exposure when the screening-level analysis is used.

With the refined analysis, exposures to dioxins (TEQs) are approximately 100–250 times less than in the screening-level analysis (Table 3). Dietary exposure to dioxins is approximately 13,000–240,000 times greater than dioxin (TEQs) exposures from tampons based on the refined exposure analysis.

Diapers

Only five of the 17 dioxins were detected in the diapers (Table 1). Concentrations of dioxins in diapers were similar between the disposable and the cotton diapers, and concentrations ranged from 1.6–3.0 pg TEQ/g diaper (Table 1). Two of the disposable diapers had lower concentrations of dioxins than did the cotton diapers. Octachlorodibenzo-*p*-dioxin accounted for 67–76% of the total dioxins in the diapers. Octachlorodibenzofuran and heptachlorinated dibenzo-*p*-dioxins accounted for 5–21% of the remaining dioxins. TCDF accounts for 2–6% of the total dioxins. Similar to the tampons, most of the analytes were observed at or near their limits of detection. The TEQs in the diapers range from 0.0042 pg TEQ/g in the cotton diaper to 0.023 pg TEQ/g in brand E disposable diaper (Table 2). Thus, although there is little difference among the total dioxin concentrations, there is a greater difference in the TEQ concentrations among the samples. The difference in dioxin equivalents between the disposable and the cotton diapers is that TCDF was not detected in the cotton diaper. The detection limit for TCDF is 0.1 pg TEQ/g diaper, and in two of the three disposable diapers TCDF concentrations are at the detection limit. If TCDF were present in the cotton diaper at one-half the detection limit, then the cotton tampon would have had similar TEQs as the disposable diapers. Because TCDF concentrations in the disposable diapers are at the detection limit, the difference in the TEQs between the disposable and the cotton diapers may not be significant.

In the screening-level analysis, the estimated daily exposures to dioxins from diapers range from 0.0075 to 0.041 pg TEQ/kg/day (Table 4). Estimated dietary intakes in nursing infants (145 pg TEQ/kg/day) are 3,498 to 19,374 times greater than the daily exposures from diapers. With the screening level analysis, toddler's exposures to dioxins from diapers range from 0.0023 to 0.013 pg TEQ/kg/day. Estimated dietary dioxins intake in toddlers (3.6 pg TEQ/kg/day) is 283–1,568 times greater than the modeled exposures through diaper use in toddlers (Table 4).

Estimates of dioxin exposure from diapers using the refined analysis are approximately 100 times less than the estimates using the screening-level analysis (Table 4). Dietary exposures to dioxins are approximately 30,000–2,200,000 times greater than exposure to dioxins through the use of diapers.

Table 3. Comparisons of dioxin exposure from tampons to dietary ingestion.

Brand	Concentration of dioxins in tampon (pg TEQ/g)	Tampon weight (g)	Intake from tampons (pg TEQ/kg/day)	Percent intake from tampons compared to dietary intake	Ratio of intake (diet/tampon)
Screening-level analysis					
A (cotton)	0.014	3.15	0.00083	0.17	1,211
A (rayon)	0.017	4.73	0.0014	0.29	698
B	0.054	1.9	0.0013	0.26	771
C	0.027	3.4	0.0013	0.26	771
D	0.247	4.04	0.019	3.9	51
Refined analysis					
A (cotton)	0.014	3.15	4.9×10^{-6}	9.8×10^{-4}	2.0×10^{5}
A (rayon)	0.017	4.73	5.7×10^{-6}	1.1×10^{-3}	1.8×10^{5}
B	0.054	1.9	1.3×10^{-5}	2.6×10^{-3}	7.8×10^{4}
C	0.027	3.4	7.4×10^{-6}	1.5×10^{-3}	1.4×10^{5}
D	0.247	4.04	9.0×10^{-5}	1.8×10^{-2}	1.1×10^{4}

Table 4. Comparisons of dioxin exposure from diapers to dietary ingestion.

Brand	Concentration of dioxins in diaper (pg TEQ/g)	Intake from diaper (pg TEQ/kg/day) 0–6 Months	Intake from diaper (pg TEQ/kg/day) 6–24 Months	Percent intake from diaper compared to dietary intake 0–6 Months	Percent intake from diaper compared to dietary intake 6–24 Months	Ratio of intake (diet/diaper) 0–6 Months	Ratio of intake (diet/diaper) 6–24 Months
Screening-level analysis							
E	0.023	0.041	0.013	0.029	0.35	3,498	283
F	0.013	0.023	0.0072	0.015	0.20	6,188	501
G	0.013	0.023	0.0072	0.015	0.20	6,188	501
Cotton	0.0042	0.0075	0.0023	0.0049	0.063	19,374	1,568
Refined analysis							
E	0.023	3.6×10^{-4}	1.1×10^{-4}	2.5×10^{-4}	3.1×10^{-3}	4.0×10^{5}	3.2×10^{4}
F	0.013	2.2×10^{-4}	6.3×10^{-5}	1.3×10^{-4}	1.7×10^{-3}	7.1×10^{5}	5.7×10^{4}
G	0.013	2.0×10^{-4}	6.3×10^{-5}	1.3×10^{-4}	1.7×10^{-3}	7.1×10^{5}	5.7×10^{4}
Cotton	0.0042	6.5×10^{-5}	2.0×10^{-5}	4.3×10^{-5}	5.5×10^{-4}	2.2×10^{6}	1.8×10^{5}

Discussion

We used concentrations of dioxins in samples of commercially available tampons and diapers to estimate potential exposure to dioxins through the normal use of these products. We examined both pulp-based and all-cotton products, and the present analysis allowed for a comparison between these two products. In all products examined, dioxins were present at trace concentrations (Table 1). However, the most potent dioxins, TCDD and 1,2,3,7,8-pentachlorodibenzo-*p*-dioxin, were not present. Most of the wood pulp-based and cotton products had similar dioxin concentrations and profiles. These profiles suggest that the dioxins present in these products may be derived from low-level, diffuse background contamination present in many different matrices (*8*) and not from the pulp manufacturing process.

The present study suggests that exposure to dioxins from tampons and diapers does not significantly contribute to human exposure to TEQs or dioxin equivalents. To estimate this exposure, we made a number of assumptions. Some of these assumptions are conservative, such as the use of the partition coefficient for TCDF, and will tend to overestimate the exposures. Others represent average values that represent a best estimate, such as the use of average body weights and intakes. However, given the large difference between dietary exposures and exposure from these products, changes in these assumptions would not produce differences in our overall conclusions.

Some of these assumptions can be considered conservative. For example, we assumed that the partitioning of dioxins from the tampons and diapers could be estimated based on dioxin equivalents and assuming all dioxins partition similarly as does TCDF. The differences in the physical chemical properties of dioxins should result in differences in absorption and partitioning from different matrices. These differences are not accounted for in the present analysis. We used these assumptions because the only partition coefficients for pulp-based products available were for TCDF. Of the dioxins present in the tampons and diapers, TCDF should be the most soluble in aqueous solutions. The use of the partition coefficient for TCDF likely overestimates the partitioning of the other dioxins present in the tampons and diapers and subsequently overestimates the exposures.

The estimates of dioxin exposures through tampons varied by approximately 100- to 250-fold depending on the assumptions used. The estimates based on the screening analysis were higher than those based on the more refined analysis and should be viewed with some caution for several reasons. The screening analysis assumed that all dioxins were absorbed from the tampons. This assumption is highly unlikely for several reasons. The concentration of dioxins in human serum is approximately 30–60 pg dioxin equivalents/g lipid (*8,33*). If serum is assumed to contain 0.4% lipid, then the concentration of dioxins in serum is approximately 0.12–0.24 pg/g. This is 1–15 times the concentration in the tampons. Because chemicals will diffuse from higher to lower concentrations, the likelihood decreases that significant concentrations of the dioxins in the tampons will diffuse into the body. Although menstrual fluid is not equivalent to serum, it is not expected to contain significantly less dioxin than serum when expressed on a lipid basis. The present analysis suggests that exposure to dioxins through tampon use is negligible.

Most of the dioxins and dibenzofurans analyzed were below the detection limit. In fact, the concentrations of some of the chemicals detected—TCDF and the heptachlorodibenzo-*p*-dioxins, for example—are at the detection limits of the analytic methods used in most of the samples. Thus our confidence that these chemicals are present in the samples and are accurately determined is limited. Often, when chemicals are not detected, one-half the detection limit is used as a default concentration. If we had assigned concentrations at one-half the detection limits for all chemicals not detected, the dioxin equivalents would have increased by approximately one order of magnitude. We chose to assign values of zero concentration to chemicals not detected because using one-half the detection limit would calculate that 90% of the dioxin equivalents attributable to those chemicals were not detected. Use of such an assumption would increase tampon and diaper exposures by approximately an order of magnitude. Even if this assumption were used, tampon and diaper exposures from dioxins would still be less than 1% of the TEQ exposures from the diet.

The tampons and infant diapers were obtained from large retail stores in and around San Francisco. The products selected were produced by major suppliers of sanitary products and can be purchased throughout the United States. Although we have used a small sample size, the products analyzed should be representative of sanitary products throughout the United States for several reasons. Most manufacturers have only one or two facilities manufacturing these products, so there should be limited variability within a product. We examined concentrations of dioxins in tampons and diapers from several manufacturers, and the concentrations and profiles of dioxins were similar between brands and products. The only exception was brand D tampons, which contained approximately five times the TEQs as the other brands or products. These data suggest that variability in dioxin concentrations between different products and manufacturer is limited and that these data should be representative of products throughout the United States. In addition, for tampon or diaper exposures to affect human exposures to dioxins, concentrations in these products would have to be at least 100–1,000 times greater than the concentrations found in the present study. Although we would expect some variations in concentrations of dioxins in these products, it is unlikely that they would vary by two to three orders of magnitude.

The dermal absorption of TCDD has been examined in several experimental systems as well as in humans. Dermal absorption of TCDD ranges from < 0.1% to approximately 28% in these studies. In studies examining the absorption of dioxins from solid matrices, such as soil and fabrics, the absorption ranges from 0.1% to 3% over 24 hr. In the screening analysis for diapers, we used the upper range of these absorption values. These values should be conservative estimates for dermal absorption. Even if dermal absorption from a solid matrix were 10 times higher, this would not affect our conclusion that dermal absorption of dioxins from diapers is not a significant source of exposure to TEQs.

Our analysis indicates that the use of either tampons or infant diapers does not contribute significantly to dioxin exposures in the United States. In addition, given the minute quantities of dioxins in these products and the slight differences between the cotton and the pulp-based products, there does not appear to be a significant difference in dioxin exposures between the cotton and pulp-based products.

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