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SERUM LEVELS OF POLYCHLORINATED DIBENZO-*P*-DIOXINS AND DIBENZOFURANS IN PULP AND PAPER MILL WORKERS

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ABSTRACT

Serum levels of polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) among 46 long-term workers at a pulp and paper mill were compared to the levels in 16 community residents who never worked at the mill. Overall, there were no appreciable differences among the three exposure groups (community resident, low-exposure-potential worker, high-exposure-potential worker) for specific PCDDs or PCDFs. Neither exposure group nor duration in high-exposure-potential-jobs was related to total toxic equivalents (I-TEQ). Serum levels of PCDDs and PCDFs in this study generally were within the range previously reported for persons with no known occupational exposure.
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INTRODUCTION

Findings from epidemiologic studies among pulp and paper mill workers have raised concerns about potential carcinogenic exposures in the work environment. In several studies, excesses of lung, gastrointestinal, lymphatic, and lymphopoietic cancers have been reported [1-8]. The results, however, have varied considerably among the studies in the specific types of cancer and the magnitude of the risk. Although exposure to halogenated organics, particularly polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) has been postulated as a causal factor, the work environment in a pulp and paper mill potentially involves a wide variety of chemical exposures [9].

PCDDs and PCDFs are formed during the bleaching of hardwood and softwood pulps with chlorine and chlorine derivatives. The presence of PCDDs and PCDFs, primarily the tetra-chlorinated congeners including 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD), has been documented in samples of process water, effluent, and sludge from Kraft pulp and paper mills [10-12]. Crandall et al. found 2,3,7,8-tetrachlorodibenzofuran (TCDF), but not TCDD, in air samples at the U.S. mill where the present study was conducted [13]. Rosenberg et al. measured airborne levels of PCDDs and PCDFs in a pulp and paper mill in Finland [14]. They reported that TCDD was not found in any samples, and that PCDFs were the major component in all samples. Potential routes of worker exposure include dermal absorption, inhalation and ingestion of particulates to which PCDDs and PCDFs have adsorbed, and inhalation of volatilized PCDDs and PCDFs [14-16]. The latter is thought to be the least likely due to the low vapor pressure of these substances.

Despite concern about the potential for human exposure, data describing serum or adipose tissue levels of PCDDs and PCDFs in pulp and paper mill workers are limited. In one previous study, there were no statistically significant differences in PCDD or PCDF concentrations in blood plasma between bleach plant or paper mill workers and unexposed controls [17]. In this report, we describe the results of a study in which serum levels of PCDDs and PCDFs in a group of long-term workers at a pulp and paper mill were compared to the levels in a comparison group of community residents who had never worked at the mill.

METHODS

Selection of Study Site

Walk-through evaluations were made at several pulp and paper mills where the U. S. Environmental Protection Agency (EPA) had previously identified PCDDs and PCDFs in bleached pulp, sludge, and effluent [12]. One mill was selected for this study based on its age, number of employees, the level of contaminants detected by EPA (nonpublished data provided to the National Institute for Occupational Safety and Health (NIOSH) by the EPA), concerns about an apparent cancer excess among employees [1] and the availability of previously collected industrial hygiene data [13].

The facility we studied is a fully integrated Kraft pulp and paper mill producing up to 1400 tons per day (tpd) of finished paper products. The mill has a hardwood and softwood line, and processes approximately 140 tpd of groundwood (thermomechanical process) products. The mill generates its own power and steam, and has a primary water treatment system before effluent discharge. The bleaching sequence during the study period involved treatment with chlorine gas, sodium hydroxide, sodium hypochlorite, and chlorine dioxide soaking. Chlorine dioxide was generated on-site. Liquid chlorine was delivered from 90-ton rail car containers and processed in a vaporization system to produce chlorine gas.

In 1989, NIOSH collected and analyzed five area air samples for the 2,3,7,8-tetra PCDDs and PCDFs and total tetra-PCDDs and PCDFs [18]. Five surface wipe samples were collected in 1991. The

2,3,7,8 congeners, and specific and total tetra- through octa-chlorinated PCDDs and PCDFs, were measured. Airborne I-TEQ concentrations (based only on measurement of tetra-isomers) ranged from .01 to .06 picograms per cubic meter (pg/m^3). The highest air levels were for TCDFs in the hardwood bleach plant. The I-TEQ levels on the surface wipe samples ranged from 13 to 651 picograms per square meter (pg/m^2) in the bleach plant and from 86 to 1049 pg/m^2 in the paper mill. The highest levels of surface contamination were found near the dry end of a paper machine and on the side of a hardwood chlorine bleaching rinse tank. PCDFs predominated in the rinse tank sample, whereas both PCDFs and PCDDs were found in similar concentration ranges at the one paper machine sampled.

Selection and Recruitment of Study Participants

A key assumption in selecting study participants was that job location in the process stream and duration of employment were important determinants of exposure potential. We classified jobs according to the potential for exposure to bleached pulp or paper dust and process water or effluent mists. Areas of the mill considered having a high exposure potential were the bleach plant, dry end of the paper machines, rewind areas, finishing areas, and effluent treatment plant. Areas of the mill considered having a low exposure potential were the groundwood mill/long log area, wood yard, and Kraft mill. Two worker groups were defined, those with 10 or more years in high exposure potential areas and those with 10 or more years in low exposure potential areas and less than one year in high exposure potential areas. Each participating worker was asked to identify a friend who lived in the community but never worked in the mill. Based on practical considerations, such as numbers of eligible workers and cost of serum analyses, a target sample size of 15 to 20 individuals per exposure group (workers with high exposure potential, workers with low exposure potential, community residents) was selected. Workers and friends were sent a letter explaining the study and inviting them to participate. A follow-up phone call was made to discuss the study and schedule a time for an interview and collection of blood.

Serum Collection and Analyses

Study participants each provided 250 milliliters of blood. Fasting was not required because of concern about the safety of workers who had to work before or after the blood draw. We considered that Hansson et al. [19] found no statistically significant differences between fasting and non-fasting serum levels of PCDDs and PCDFs and that all results would be adjusted for lipid content of the blood. Moreover, we arranged the blood draw schedule so that workers and referents were both tested throughout the day. Serum was analyzed for PCDDs and PCDFs using high-resolution gas chromatography/high-resolution mass spectrometry [20-21]. Each analytical run consisted of a method blank, three unknown samples, and a quality-control pool sample. Total cholesterol, free cholesterol, triglycerides, and phospholipids were measured in each sample and summed to estimate total serum lipids [22]. The result was used to calculate lipid-adjusted values for each congener.

Questionnaire

Each study participant was interviewed about personal characteristics related to serum concentrations of PCDDs and PCDFs, such as age, cigarette smoking, height, and weight. (The latter two values were used to calculate body mass index.) In addition, participants were asked about exposures other than from work at the mill that may affect serum concentrations of PCDDs and PCDFs. Questions were asked about past work in jobs with potential PCDD and PCDF exposure (including waste incineration, reclamation or hazardous waste work, work with transformers or capacitors, and herbicide manufacturing), military experience in Vietnam, consumption of fish caught in local rivers, use of herbicides at home, and use of pentachlorophenol to treat wood.

Statistical Analysis

Methods for handling nondetectable values in the serum concentrations can influence both the descriptive and analytic analyses. Some common approaches for handling these values (such as ignoring the nondetectables or setting them equal to zero) can bias the results. In this study, for serum results reported as below the limit of detection, we calculated an imputed value using a method shown to reduce bias [23]. When the proportion of nondetectable results for a particular congener is less than 50%, the imputed value is equal to the minimum detectable concentration of the congener in the sample divided by the square root of two. If the imputed value is greater than the median value, however, the median value is assigned. When the proportion of nondetectable results is 50% or more, the imputed value is equal to the minimum detectable concentration of the congener in the sample divided by two. To assess whether the imputation method affected our findings, analyses were repeated by replacing nondetectable values with zero.

Differences in individual congeners among high-exposure-potential workers, low-exposure-potential workers, and community residents were examined. Because PCDD and PCDF levels were log-normally distributed, the median levels in each group are reported. The median is unaffected by the method used to impute nondetectable values. The Wilcoxon rank-sum test was used to test the statistical significance of group differences.

Besides conducting statistical analyses for specific congeners, we also calculated the total I-TEQ (toxic equivalents), which sums the measured amount of each congener weighted for its toxicity relative to TCDD. The toxic equivalence factors were those adopted by the EPA in 1989, which were based on the international toxic equivalence factors [24]. We looked at total I-TEQ and the portion of the I-TEQ contributed by PCDDs and PCDFs. Because the I-TEQ was log-normally distributed, the natural logarithm (ln) of the I-TEQ was used in the multivariate analysis. Multiple linear regression models were used to examine the relationship between ln(I-TEQ) and exposure while controlling for the effects of potential confounders. Exposure was assessed as a categorical variable (high exposure potential and low exposure potential compared with community residents) and as a continuous variable (time spent in high exposure potential areas). We selected the following potential confounders for analysis based on published results of

other studies of PCDDs and PCDFs, and on examination of the bivariate relationships observed in our data: age, body mass index, cigarette smoking status (current, former, never), and consumption of locally caught fish (ever, never). Main effects and two-way interactions were considered. Terms remained in the model only if the level of statistical significance was <.10.

RESULTS

Based on seniority lists obtained from the mill, 76 workers were identified as possible study subjects. We were successful in contacting 68 of these workers by phone; 10 refused to participate in the study. Forty-six of the 58 workers with the longest seniority were selected for the study. Thirty-two workers worked for 10 or more years in high exposure potential areas. Seven of these no longer worked in these areas at the time of the study. Fourteen workers worked 10 or more years in low exposure potential areas. Seven of these workers also had been in high exposure potential areas for one to eight years. [These seven workers were considered to have mixed exposure potential.] Twenty-three community residents identified by participating workers were contacted. Twelve agreed and seven refused to participate, and four were excluded because of prior work at a mill. Workers and the union identified four replacements; all participated.

Table 1 compares mill workers and community residents with respect to the relevant covariates. All study participants were white males. As a group, community residents were somewhat younger and leaner than mill workers. Fewer community residents currently or ever smoked cigarettes. The proportion of persons who drank more than one alcoholic beverage per week at the time of the study was similar in the two groups. None of the community residents and only two mill workers were Vietnam veterans. Neither Vietnam veteran reported assignment to the Air Force Ranch Hand unit or the Army Chemical Corps, units that potentially handled dioxin-containing compounds. Community residents were less likely than mill workers to have ever eaten fish caught in local rivers, to have ever applied weed or brush killer outside, or to have lived in a house heated by wood or coal, through the differences were small.

Eight PCDDs and ten PCDFs were found in the sera of study participants (Table 2). The percentage of samples with values below the limit of detection ranged from 0 to 26 for the PCDDs and from 2 to 98 for the PCDFs. For four of the ten PCDFs, more than 50% of the persons tested had levels below the limit of detection. Because there were analytical problems with the OCDF analyses for 95% of the samples, data for this congener are not included in subsequent findings.

Table 1. Demographic and Non-occupational Exposure Characteristics of Mill Workers and Community Residents

		Community Residents		Mill Workers	
		No. Persons	%	No. Persons	%
Age (yrs.)	<20	3	19	0	0
	30-39	3	19	11	24
	40-49	4	25	8	17
	50-59	4	25	17	37
	60+	2	13	10	22
Body mass index	1st quartile (Lowest)	5	31	11	24
	2nd quartile	4	25	11	24
	3rd quartile	3	19	13	28
	4th quartile (Highest)	4	25	11	24
Cigarette smoking	Never	8	50	9	20
	Former	5	31	26	57
	Current	3	19	11	24
Current no. drinks/wk	>1	8	53	25	54
	<=1	7	47	21	46
Vietnam veteran		0	0	2	4
Eats locally caught fish		12	75	37	80
Ever applied pentachlorophenol		0	0	1	2
Ever applied weed or brush killer		0	0	8	17
Current house heated by wood or coal		4	25	16	35

Table 2. Dioxins and Furans Found in Sera of Study Participants

Tetrachlorodibenzo-*p*-dioxin	2,3,7,8-TCDD (26)[1]	Tetrachlorodibenzofuran	2,3,7,8-TCDF (63)
Pentachlorodibenzo-*p*-dioxin	1,2,3,7,8-PeCDD (6)	Pentachlorodibenzofuran	1,2,3,7,8-PeCDF (92)
			2,3,4,7,8-PeCDF (2)
Hexachlorodibenzo-*p*-dioxin	1,2,3,4,7,8-HxCDD (13)	Hexachlorodibenzofuran	1,2,3,4,7,8-HxCDF (6)
	1,2,3,6,7,8-HxCDD (0)		1,2,3,6,7,8-HxCDF (6)
	1,2,3,7,8,9-HxCDD (11)		1,2,3,7,8,9-HxCDF (98)
			2,3,4,6,7,8-HxCDF (11)
Heptachlorodibenzo-*p*-dioxin	1,2,3,4,6,7,8-HpCDD (0)	Heptachlorodibenzofuran	1,2,3,4,6,7,8-HpCDF (2)
	1,2,3,4,6,7,9-HpCDD (18)		1,2,3,4,7,8,9-HpCDF (60)
Octachlorodibenzo-*p*-dioxin	OCDD (10)	Octachlorodibenzofuran	OCDF (4)

[1] Number in parenthesis is the percentage of samples with values below the limit of detection.

Overall, there were no appreciable differences among the three exposure groups in the median values for specific PCDDs or PCDFs (Tables 3 and 4). The median value in high exposure potential workers was greater than in community residents for four of the eight PCDDs --2,3,7,8-TCDD, 1,2,3,7,8-PeCDD, 1,2,3,7,8,9-HxCDD, and 1,2,3,4,6,7,9-HpCDD-- and four of the nine PCDFs --1,2,3,4,7,8-HxCDF, 1,2,3,6,7,8-HxCDF, 2,3,4,6,7,8-HxCDF, and 1,2,3,4,6,7,8-HpCDF. The relative differences for 2,3,7,8-TCDD (6%) and 1,2,3,7,8-PeCDD (2%) were very small and probably not meaningful ($p=0.65$ and 0.44, respectively). There was a 20% difference for 1,2,3,7,8,9-HxCDD ($p=0.36$) and a 35% difference for 1,2,3,4,6,7,8-HpCDD ($p=.14$), but workers with low exposure potential had higher medians than workers with high exposure potential. The relative differences for 1,2,3,4,7,8-HxCDF (6%) and 1,2,3,6,7,8-HxCDF (2%) were also very small and probably not meaningful ($p=0.55$ and 0.50, respectively). There was an 18% difference for 2,3,4,6,7,8-HxCDF ($p=0.77$) and a 12% difference for 1,2,3,4,6,7,8-HpCDF ($p=0.88$), but workers with low exposure potential had a similar or higher median than workers with high exposure potential.

For all PCDDs and PCDFs except 2,3,7,8-TCDD and 1,2,3,7,8,9-HxCDD, high exposure-potential-workers no longer in these jobs had slightly higher levels than those whose presumed exposure was current. PCDD and PCDF levels in workers with mixed exposure did not consistently follow a pattern suggestive of occupational exposure (i.e., intermediate between those with high and those with low exposure potential).

The highest values for specific PCDDs and PCDFs consistently occurred in seven workers. These individuals ranged in age from 37 to 64 and had worked in the mill for 10 to over 40 years in a variety of jobs. One had a job involving exposure to bleached paper dust in the finishing department for four years and to effluent for five years. Five had jobs involving exposure to bleached paper dust at the paper machines for six to 44 years. One never worked in an area with high exposure potential. Six of the seven had potential exposure outside work that could have contributed to these findings. Six ate locally caught fish, four had lived in a home heated with wood, two had applied weed killer at home, and one had used pentachlorophenol to treat wood.

Both the median and maximum values of the total I-TEQ were higher in workers in the low exposure potential group than in workers in the high exposure potential group or community residents (Table 5, Figure 1). The lowest value for the median I-TEQ occurred in workers in the high exposure potential group. The relative differences between the highest and the other median values, however, were small (11% to 26%, $0.32 \leq p \leq 0.96$). Two workers in the low exposure potential group had considerably higher values than other workers or community residents (Figure 1). Both worked in the wood yard for at least 15 years. When these workers are excluded from the I-TEQ comparisons, the median and maximum values are decreased slightly for low-exposure-potential workers, but the pattern of the results remain unchanged.

Table 3. Lipid-adjusted Serum Concentrations of PCDDs in Mill Workers and Community Residents

			Concentration (ppt)[1]		
Congener	Exposure Group	N[2]	Median	Low	High
2,3,7,8-TCDD	Community Resident	16	1.8	1.5	3.5
	Worker - Low[3]	14	1.9	0.9	5.2
	Worker - High[4]	32	1.9	0.7	4.9
1,2,3,7,8-PeCDD	Community Resident	15	5.6	2.0	7.8
	Worker - Low	14	5.3	3.7	12.3
	Worker - High	32	5.7	2.6	11.3
1,2,3,4,7,8-HxCDD	Community Resident	16	6.2	1.8	11.3
	Worker - Low	12	7.4	1.8	19.1
	Worker - High	31	5.6	2.5	14.7
1,2,3,6,7,8-HxCDD	Community Resident	16	67.0	48.3	101
	Worker - Low	14	79.7	33.1	145
	Worker - High	25	65.9	29.4	117
1,2,3,7,8,9-HxCDD	Community Resident	16	6.9	3.3	12.8
	Worker - Low	14	9.4	1.9	19.7
	Worker - High	29	8.3	2.9	21.4
1,2,3,4,6,7,8-HpCDD	Community Resident	15	95.2	64.1	115
	Worker - Low	13	91.2	47.5	230
	Worker - High	31	73.9	34.0	161
1,2,3,4,6,7,9-HpCDD	Community Resident	15	5.2	3.3	14.7
	Worker - Low	9	7.7	3.5	26.8
	Worker - High	19	7.0	3.3	36.5
OCDD	Community Resident	11	547	230	1042
	Worker - Low	10	673	288	1600
	Worker - High	23	541	285	1489

[1] ppt = parts per trillion. Imputed values were calculated for samples with no detectable amount of a congener. (See text for explanation.)

[2] The number of samples may be fewer than 16 for community residents, 32 for high exposure workers, and 14 for low exposure workers because quality control criteria were not met in some samples.

[3] Low = low exposure potential (groundwood mill/long log area, wood yard, Kraft mill)

[4] High = high exposure potential (bleach plant, dry end of the paper machines, rewind areas, finishing areas, effluent treatment plant)

Table 4. Lipid-adjusted Serum Concentrations of PCDFs in Mill Workers and Community Residents

			Concentration (ppt)[1]		
Congener	Exposure Group	N[2]	Median	Low	High
2,3,7,8-TCDF[3]	Community Resident	14	1.3	0.8	4.9
	Worker - Low[4]	14	1.4	0.7	6.7
	Worker - High[5]	32	1.3	0.4	11.1
1,2,3,7,8-PeCDF[3]	Community Resident	15	1.3	0.8	2.8
	Worker - Low	14	1.3	0.4	2.1
	Worker - High	30	1.2	0.5	2.4
2,3,4,7,8-PeCDF	Community Resident	16	6.4	3.5	13.0
	Worker - Low	14	7.8	3.9	14.1
	Worker - High	31	5.9	2.1	11.3
1,2,3,4,7,8-HxCDF	Community Resident	16	6.4	2.4	9.6
	Worker - Low	14	6.9	2.2	16.2
	Worker - High	32	6.8	2.9	13.2
1,2,3,6,7,8-HxCDF	Community Resident	16	4.8	2.5	7.7
	Worker - Low	14	5.3	2.2	11.7
	Worker - High	31	4.9	2.5	9.4
1,2,3,7,8,9-HxCDF[3]	Community Resident	16	1.6	0.8	2.3
	Worker - Low	14	1.4	0.4	3.4
	Worker - High	31	1.3	0.5	3.3
2,3,4,6,7,8-HxCDF	Community Resident	15	3.9	2.5	14.6
	Worker - Low	7	4.7	2.3	7.9
	Worker - High	15	4.6	1.9	7.8
1,2,3,4,6,7,8-HpCDF	Community Resident	13	15.5	9.5	31.3
	Worker - Low	9	19.5	13.3	28.1
	Worker - High	22	17.3	7.5	33.7
1,2,3,4,7,8,9-HpCDF[3]	Community Resident	12	2.7	0.8	11.0
	Worker - Low	8	3.4	1.6	4.7
	Worker - High	20	2.6	0.6	7.0

[1] ppt = parts per trillion. (See text for explanation.)

[2] The number of samples may be fewer than 16 for community residents, 32 for high exposure workers, and 14 for low exposure workers because quality control criteria were not met in some samples.

[3]The proportion of detectables for this congener was less than 50% of all samples.

[4] Low = low exposure potential (groundwood mill/long log area, wood yard, Kraft mill)

[5]High = high exposure potential (bleach plant, dry end of the paper machines, rewind areas, finishing areas, effluent treatment plant)

Table 5. Toxic equivalents (I-TEQ) in workers and community residents

	Exposure Group		
	Community (n=16)	Worker- Low Exposure (n=14)	Worker- High Exposure (n=32)
PCDD Subtotal	13.5 (9.5-19.1)[1]	15.9 (6.5-31.8)	13.3 (7.5-24.9)
PCDF Subtotal	5.0 (3.4-8.8)	5.9 (3.2-11.0)	4.7 (1.9-8.1)
Total I-TEQ	19.1 (12.9-25.9)	21.2 (9.8-41.6)	18.1 (10.7-32.9)

[1] Numbers represent median, minimum, and maximum values.

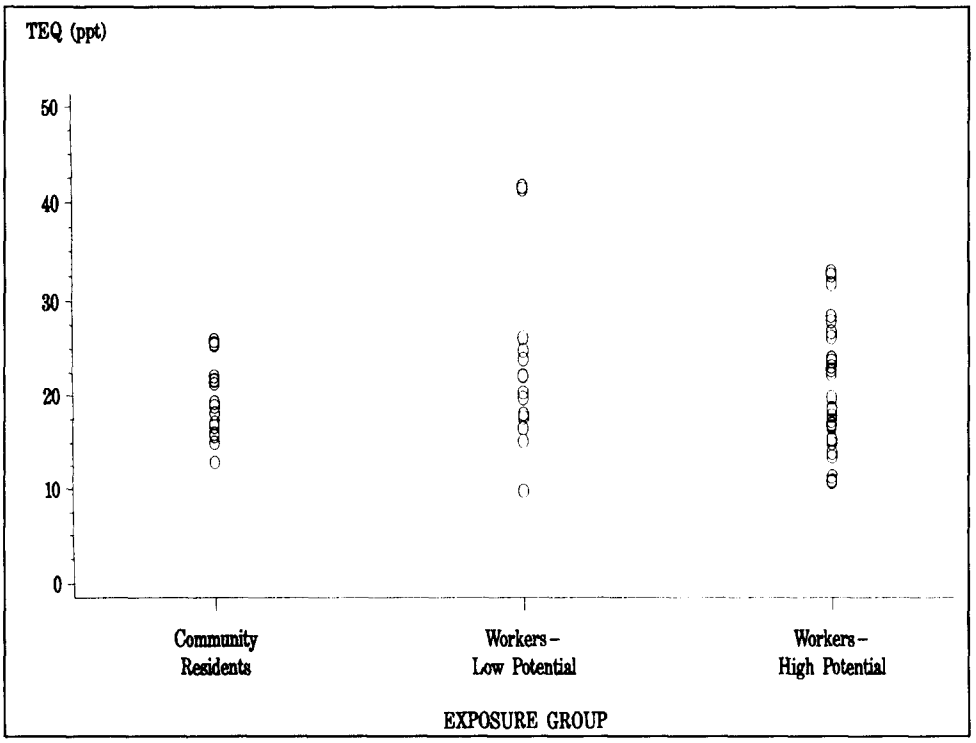

Figure 1. Toxic equivalents (TEQ) values by exposure group

None of the exposure variables (worker with low exposure potential, worker with high exposure potential, years in the mill, years in high exposure potential areas) remained in the final multivariate regression model for ln(I-TEQ) (Table 6). Ln(I-TEQ) was positively related to age (p=0.001), body mass index (p=0.01), and the consumption of locally caught fish (p=0.02) and negatively related to current cigarette smoking (p=0.05). Age, total duration in the mill, and duration in high exposure potential areas, however, were highly correlated. To clarify whether age or duration was actually more important, we examined the correlation between ln(I-TEQ) and duration in high exposure potential areas among workers stratified by age (30-39, 40-49, 50-59 years). For each age group, the correlation was small in magnitude and negative in direction (r=-.07, -.21 and -.37, respectively).

Table 6. Linear Regression Model for the Natural Logarithm of Total Toxic Equivalents (I-TEQ)

Variable	ParameterEstimate	Standard Error	p
Intercept	2.26	0.27	0.0001
Age (years)	0.009	0.003	0.001
Body mass index[1]	13.01	5.03	0.01
Fish consumption[2]	0.20	0.08	0.02
Cigarette smoking[3]	-0.17	0.08	0.05

[1] Weight/(height)^2

[2] Eats locally caught fish, No/Yes

[3] Current smoker, No/Yes

DISCUSSION

The extent to which the bleach plant operational parameters at this mill and, thus, the study results, represent other similar mills is unknown. This mill, however, was chosen for our study because of higher levels of PCDDs and PCDFs in bleached pulp, sludge, and effluent compared with other mills in the United States (based on nonpublished data provided to NIOSH by the EPA).

The differences in serum levels of PCDDs and PCDFs between mill workers and community residents were small and probably not meaningful. To assess whether our results were confounded by factors, other than pulp and paper mill work exposures, that may modify body burdens of the substances measured, we obtained data on several key factors by questionnaire. Although no differences were found between the exposure groups in the factors measured, some factors such as major changes in weight, hyperlipidemia, or hypercholesteremia, were not examined and could have influenced the results. Our

overall findings, however, were consistent with those of Rosenberg et al. [17], who did not find any statistically significant differences in PCDD or PCDF concentrations in blood plasma between controls and potentially exposed workers in the bleach plant or the paper mill of a Finnish pulp and paper mill.

Interpretation of the results for specific congeners is hampered by lack of a comprehensive environmental exposure assessment. Although available environmental data are useful in identifying areas in which exposure controls may be needed, they are less helpful for understanding serum levels. The environmental levels do not adequately describe exposure potential over a wide range of jobs or over a long time period. The only PCDDs for which any appreciable difference was detected between workers and community residents in our study were 1,2,3,7,8,9-HxCDD and 1,2,3,4,6,7,9-HpCDD. In the study of Rosenberg et al. (1994), median levels of 1,2,3,7,8,9-HxCDD were slightly greater in paper mill workers than in bleach plant or unexposed workers; the medians were the same for the latter two groups. Data were not reported by Rosenberg et al. (1994) for 1,2,3,4,6,7,9-HpCDD. The only PCDFs for which any substantial difference was detected between workers and community residents in our study were 2,3,4,6,7,8-HxCDF and 1,2,3,4,6,7,8-HpCDF. Exposed workers studied by Rosenberg et al. [17] had median levels similar to unexposed workers for 2,3,4,6,7,8-HxCDF, but bleach plant and paper mill workers had slightly higher median levels than unexposed workers for 1,2,3,4,6,7,8-HpCDF. Whether the differences between the studies in serum results for specific congeners are due to differences in actual exposure cannot be determined. Environmental data from the mill we studied and that of Rosenberg et al. [17] utilized dissimilar methods of analysis (i.e., our air samples were not analyzed for specific congeners other than 2,3,7,8-TCDD and 2,3,7,8-TCDF).

The individuals who consistently had the highest serum levels of PCDDs and PCDFs were mill workers, suggesting the possible influence of occupational exposure. Five of these seven workers had a job at some time in the past at the paper machines. All but one of the seven workers, however, also had nonoccupational exposure to materials that potentially were contaminated with PCDDs or PCDFs. The finding that the two highest values for I-TEQ occurred in workers with jobs in the wood yard was surprising, as this was initially considered to be a low exposure potential area. We subsequently learned that there was some potential for occasional exposure to bleach plant effluent used in a log flume to aid in moving logs from the wood pile to a saw, and then to a debarker. Additionally, the emission stack for the refuse burner, another potential source of PCDD/PCDF exposure, was lower in the past than now and the predominant wind direction is over the wood yard. It is not possible to determine, however, the extent to which these potential exposures may have contributed to serum PCDD/PCDF levels in wood yard workers.

Duration of employment in high exposure potential areas was not related to I-TEQ despite the fact that workers in the study reported infrequent use of personal protective equipment. Of those who reported getting their skin or clothes wet from bleached pulp, bleached process water, sludge, or effluent, 36 to 56% said they never or rarely wore waterproof gloves or clothing. Of those who reported working in an area dusty with bleached paper dust, 78% said they never or rarely wore a mask. Thus, use of personal protective equipment by workers in the plant is unlikely to explain the absence of substantial differences between the exposure groups or the lack of a relationship between serum PCDDs and PCDFs and duration of exposure.

Long-term workers in the mill we studied currently do not have high body burdens of PCDDs or PCDFs. Current levels, however, may not accurately describe maximum exposure levels achieved in the past, particularly if exposure has declined over time. The possibility of previously higher exposure is suggested by our finding that workers in the high-exposure-potential group who were no longer working in high-exposure-potential jobs at the time of the study had slightly higher levels of PCDDs and PCDFs than workers in the high-exposure-potential group whose exposure was current. PCDDs and PCDFs in blood of exposed and comparison populations have been measured in studies of other occupational groups [25-29], veterans exposed to Agent Orange [30-32], and in the general population [33-34]. Among these studies, protocols differ for specimen collection and analysis, statistical techniques for handling nondetectable values, number of subjects tested (and thus, precision of the results), and approaches to reporting results. These differences, and also temporal trends, may affect comparisons of the results across studies. Both workers and community residents in our study had serum PCDD and PCDF levels within the ranges reported for unexposed groups in most of the other studies cited above. The data of Papke et al. [33] and Patterson et al. [34], however, show lower values for some of the higher chlorinated PCDDs. These congeners may be more indicative of exposure to the by-products of municipal waste incineration than bleaching [10-12, 35].

Several factors other than mill work were related to serum levels of PCDDs and PCDFs, as summarized by the I-TEQ. The positive associations between I-TEQ, age and body mass index are consistent with previous reports [36-39]. A relationship between I-TEQ and fish consumption has also been reported previously, although in a population with heavy consumption of highly contaminated fish [38]. The relationship we found between serum levels of PCDDs and PCDFs and lighter levels of fish consumption warrants further examination. (Of the 79% of participants in this study who reported eating fish caught in local rivers, 80% did so once a month or less often). The negative relationship with current cigarette smoking was somewhat unexpected given the evidence that tobacco smoke contains PCDDs and PCDFs [40]. We did not, however, account for exposure to sidestream smoke among current

nonsmokers. Loforth and Zebuhr found that sidestream smoke contained higher levels of PCDDs/PCDFs than mainstream smoke [40].

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