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Environmental and occupational exposures and serum PCB concentrations and patterns among Mohawk men at Akwesasne

EDWARD F. FITZGERALD[a], SYNI-AN HWANG[b], MARTA GOMEZ[b], BRIAN BUSH[c], BAO-ZHU YANG[d] AND ALICE TARBELL[e]

[a]*University at Albany, School of Public Health, Rensselaer, NY, USA*
[b]*New York State Department of Health, Center for Environmental Health, Troy, NY, USA*
[c]*Formerly with New York State Department of Health, Wadsworth Center, Albany, NY, USA*
[d]*Yale University School of Medicine, Department of Psychiatry, New Haven, CT, USA*
[e]*Akwesasne Task Force on the Environment, Mohawk Nation at Akwesasne, Hogansburg, NY, USA*

A study was conducted to address the question of how fish consumption, occupation, and outdoor air affected serum PCB concentrations and congener patterns among 139 Native American men living near three hazardous waste sites. They were interviewed about their residential, occupational, and dietary histories, and donated 20 ml of venous blood for congener-specific PCB analysis. The similarity in the congener pattern between that found in the serum and that detected in local environmental samples was measured by calculating the Euclidean distance between them. The results indicated that serum PCB concentrations were positively associated with cumulative lifetime exposures to PCBs from local fish consumption and occupation. However, participants who lived in the last 10 years at Raquette Point, which is the area of the Reserve closest to the hazardous waste sites and the only location where elevated levels of PCBs were found in outdoor air, did not have higher serum PCB concentrations than participants who lived elsewhere at Akwesasne. Regarding pattern matching, Mohawk men with the greatest cumulative lifetime exposure to PCBs from local fish consumption had a serum PCB congener pattern that more closely resembled that in fish caught off-shore from one of the hazardous waste sites than did men who ate less local fish. Similarly, Mohawk men who were occupationally exposed to PCBs were more likely than those without occupational exposure to have a serum PCB congener pattern that was similar to that of Aroclor 1248, the commercial PCB mixture used locally. The serum PCB congener pattern of Raquette Point residents more closely resembled the pattern in outdoor air only if the men ate relatively few local fish. The study is among the first to demonstrate that outdoor air may affect serum PCB congener patterns, at least in the absence of heavy fish consumption.
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Introduction

Polychlorinated biphenyls (PCBs) are a family of halogenated aromatic hydrocarbons**.** They consist of 209 congeners with unique physical and chemical properties, including thermal stability and resistance to acids, oxidation, and hydrolysis, that resulted in their widespread use in a variety of industrial and commercial applications (Erickson, 2001). Although their production has been banned in the US since 1977, PCBs are still in use in some cases such as older electrical capacitors and transformers. They are of environmental concern, as they degrade very slowly. They also have long biological half-lives, which vary by congener according the number and position of the chlorine atoms present and may range from months to decades (ATSDR, 2000). Worksite exposures via inhalation and dermal absorption have been reported among various occupational groups (Wolff, 1985), but ingestion is the major pathway of exposure for the general population, especially the consumption of contaminated sport fish (Humphrey, 1988; Asplund et al., 1994; Hanrahan et al., 1999). Duarte-Davidson and Jones (1994) have speculated that inhalation may be the second most important exposure pathway for the general population after ingestion, but relatively few studies have investigated this hypothesis directly. The current study addresses the question of how occupational and environmental exposures have affected serum PCB concentrations and congener patterns among Mohawk men at Akwesasne.

Akwesasne is a Native American community of more than 10,000 persons located along the St. Lawrence River in New York, Ontario, and Quebec (Figure 1). Less than 100 feet to the west of Akwesasne is the General Motors — Central Foundry Division Superfund hazardous waste site. This facility used Aroclor 1248, a commercial mixture of various

1. Address all correspondence to: Dr. Edward F. Fitzgerald, Department of Epidemiology and Biostatistics, School of Public Health, University at Albany, Rensselaer, NY 12144 USA.
Tel.: +518 402 1062.
Fax: +518 402 0380.
E-mail: eff02@health.state.ny.us
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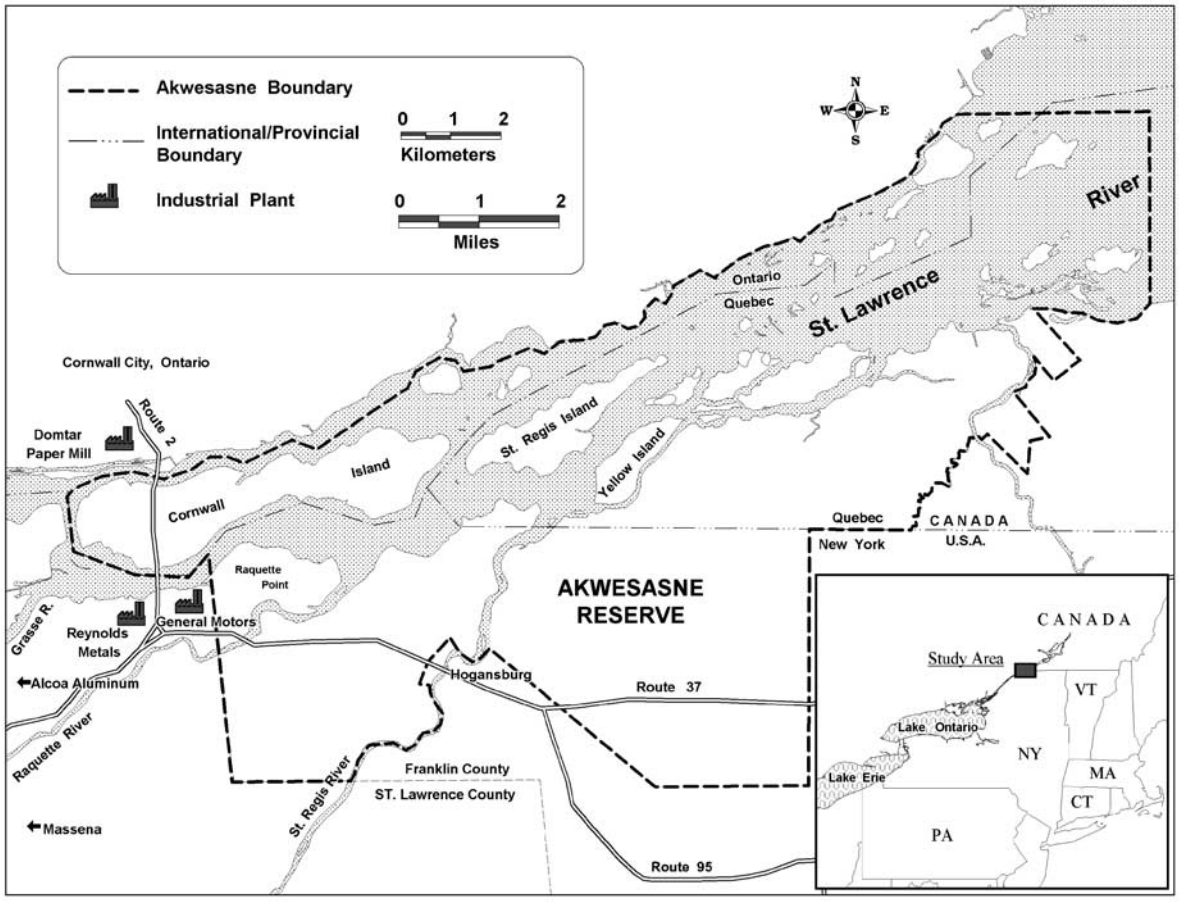

Figure 1. Map of the Mohawk Nation at Akwesasne.

PCB congeners, as a hydraulic fluid in its die-casting machines from 1959 to 1974 (Lacetti, 1993). When these machines leaked, the fluids were collected in the wastewater system and disposed of on the property. In the past, concentrations of PCBs have ranged up to 40,000 parts per million (ppm) in on-site soils and sludges, and up to 5,700 ppm off-shore in St. Lawrence River sediment (RMT, Inc., 1986). The Aluminum Company of America (ALCOA) operates two aluminum-processing facilities in the area (ALCOA Plant West and ALCOA Plant East, the latter being formerly operated by Reynolds Metals, Inc.), and also has used Aroclor 1248 in its heat-transfer equipment. These facilities also have released PCBs directly into the St. Lawrence and its tributaries (Ecology and Environment, Inc., 1992).

The PCBs have entered the local food chain, with some species of local fish, reptiles, amphibians, birds, and mammals having levels that exceed the US Food and Drug Administration's tolerance limits for human consumption of 2 ppm (wet weight) for local fish and 3 ppm (lipid weight) for poultry (Sloan and Jock, 1990; Skinner, 1992). Elevated outdoor air PCB levels have also been observed near the General Motors facility, with maximum monthly values of 20 ng/m^3 during the summer (Chiarenzelli et al., 2000). Dredging of the St. Lawrence River off-shore from the General Motors facility has been completed, but remedial alternatives for the St Lawrence River off-shore from Reynolds and for the Grasse River near ALCOA West are still being evaluated. On-site remediation is complete at both ALCOA plants, but plans for remedial work at some on-site locations at General Motors await final review and approval.

This pollution is a major concern of the Mohawk people, because their tradition and culture emphasize the interdependence of humans and the environment and because many residents formerly depended on local fish, waterfowl, and mammals for food. Our previous articles described local fish consumption patterns among 139 Mohawk men (Fitzgerald et al., 1996, 1999). These reports noted a three-fold decline in the average rate of local fish consumption when current rates were compared with those in the past. That is, for the period beginning more than 2 years before they were interviewed, the men reported an annual mean of 88.6 local fish meals, compared with a mean of only 21.2 during the last year. Such changes may be related to the advisories that have been issued over the past decade by Mohawk, state, and provincial authorities against the consumption of contaminated local

fish (NYSDOH, 2002; NYSDEC, 2003). Our previous reports also found a significant positive association between local fish consumption and serum total PCB levels (Fitzgerald et al., 1996, 1999).

The present article expands these previous studies in two major ways. First, it examines whether PCB exposures from occupation and outdoor air, in addition to local fish consumption, are associated with total and congener-specific serum PCB concentrations. Second, it statistically matches the congener pattern in serum to those in environmental source samples. Using a Euclidean distance measure, we previously demonstrated that contaminated fish caught off-shore from the General Motors facility had a congener profile that more closely matched Aroclor 1248 than did fish obtained elsewhere at Akwesasne (Hwang et al., 1993). In turn, nursing Mohawk women who had the greatest exposure to PCBs from local fish consumption had a congener pattern in their breast milk that more closely resembled that in contaminated fish caught off-shore from the General Motors facility (Hwang et al., 2001). The current study extends this analysis to Mohawk men, and matches congener patterns in serum with those in outdoor air as well as local fish and Aroclor 1248 to "fingerprint" PCBs as they migrate from hazardous waste sites and ultimately result in human exposure.

Specifically, we hypothesize higher serum PCB concentrations will be observed among men who may have been exposed through fish consumption, occupation, or outdoor air, especially for the more lightly chlorinated congeners characteristic of Aroclor 1248 (Frame et al., 1996). We also hypothesize greater similarities between the congener patterns in local sources, namely fish and outdoor air, and those in serum for men who ate the most local fish or who had the greatest potential for inhalation exposure. Similarly, we expect that men who were exposed occupationally will have a serum congener pattern that more closely resembles Aroclor 1248.

Materials and methods

Recruitment and Interview

The project was a collaborative effort among the New York State Department of Health, the St. Regis Mohawk Tribe, the Mohawk Council of Akwesasne, the Akwesasne Task Force on the Environment, and the University at Albany. Community members ascertained participants and conducted personal interviews, the details of which have already been published (Fitzgerald et al., 1996, 1999). Briefly, all adult men who were the spouses, partners or close relatives of the women in a parallel study of Mohawk mothers and infants (Fitzgerald et al., 2004) were invited to participate in an interview and to donate a non-fasting sample of 20 ml of venous blood for PCB analysis. Both the men and women had to reside at Akwesasne and the women had to have become pregnant between April 1, 1992 and March 31, 1995. A total of 139 men participated, 69% of those eligible. The leading reason for non-participation was failure to provide a blood sample.

The interview included questions about sociodemographic background, residential and occupational history, cigarette and alcohol use, and dietary intake. The dietary assessment emphasized consumption of local fish at three points in time: (1) 1 year before the interview; (2) 1–2 years before the interview; and (3) more than 2 years before the interview. The men marked on a map where any local fish that they consumed were obtained, and these maps were digitized and linked with fish PCB sampling data in a geographic information system (GIS).

Serum PCB Analysis

The chemical analysis was performed using methods (including quality assurance and control, accuracy, and precision) published elsewhere (Bush and Snow, 1982; Bush et al., 1984). To summarize, approximately 10 ml of serum were extracted using methanol, diethyl ether, and hexane, and then transferred to a Florisil clean-up column containing 10 g of 4% deactivated Florisil topped with 1 cm anhydrous sodium sulfate. The eluate was evaporated to 1 ml and analyzed with a Hewlett-Packard 5890 gas chromatograph using a phenylmethyloctadecyl silyl-bonded fused-silica capillary column and an electron-capture detector. A computerized data management system reported each of 68 PCB-containing zones, or peaks. In some cases, the capillary column was unable to resolve between congeners and, therefore, the result was reported as a mixed peak consisting of two or more congeners. These 68 chromatographic peaks included 88 congeners commonly observed in human serum, and were summed to calculate total PCBs.

The method detection limit (MDL) for the 68 chromatographic peaks in serum ranged from 0.01 to 0.10 ppb, with a median MDL of 0.02 ppb per congener. The MDL for total serum PCB was 1.0 ppb. However, values less than the MDL were reported by the laboratory and were included in the statistical analysis. This decision was based on the fact that many chemists and statisticians believe that a reported result, even if it is below the "criterion for detection", is the best available estimate of the true value, and is preferable to assigning a zero or an arbitrary constant, such as one-half the detection limit (ASTM, 1989). Nevertheless, to prevent misinterpretations regarding the certainty of the data, results for individual congeners are only presented if the geometric mean concentration for that congener equaled or exceeded the MDL.

Exposure from Local Fish Consumption

Each Mohawk man's exposure to PCBs through the consumption of local fish was estimated by multiplying the

total number of local fish meals that he reported eating during each time period (during the past year, 1 to 2 years before, and more than 2 years before the interview) for a particular species by the location-specific contaminant concentration of that species and the duration of consumption. Detailed discussions of the fish sampling scheme and fish sampling scheme and fish contaminant levels are given elsewhere (Sloan and Jock, 1990; Fitzgerald et al., 1995), but the highest concentrations were found in the vicinity of the General Motors facility and among species with high lipid content such as brown bullhead (mean = 21 ppm, range < 1–81 ppm). The fish sampling results were composited by species and location, focusing on the 11 regions and six species most commonly utilized by the Mohawks. If a man failed to recall the location or his duration of consumption, the results were imputed using methods described previously (Fitzgerald et al., 1999). These estimates were adjusted for reduction in PCB levels due to trimming and/or frying, if applicable (Sherer and Price, 1993). The result was summed over all species and time periods to estimate each man's cumulative lifetime exposure to total PCBs from local fish consumption. Lifetime exposures were also estimated for the leading congeners found in local fish off-shore from the General Motors facility, for example, PCB-28, 52, and 66, but they were highly correlated with the estimate for total PCB ($r = 0.99$).

Occupational Exposure

Occupational exposure was assessed by two industrial hygienists who independently rated the probability of exposure to PCBs for all jobs of greater than 6 months duration reported by each study participant. Their review was based on information concerning the name and location of the company, type of industry, and a brief description of work duties. They assigned one of four qualitative ratings to each of the self-reported jobs: (1) definitely not exposed; (2) possibly exposed; (3) probably exposed; and (4) definitely exposed. When their ratings differed, they jointly reviewed the data and agreed upon a rating. These ratings were assigned weights of zero, 0.25, 0.5, and 1.0, respectively. The weights for each job were then multiplied by how long the man worked in that job, and the results summed over all jobs to estimate cumulative lifetime exposure to PCBs from occupation for each man.

Outdoor Air Exposure

Air monitors were set up at Raquette Point, which is adjacent to the General Motors facility, and at several locations on Cornwall Island, which is on the St. Lawrence River and off-shore from General Motors. Details of the methods and results are available elsewhere (Chiarenzelli et al., 2000; Fitzgerald et al., 2004), but to summarize briefly, the only elevated concentrations of PCBs in outdoor air were found at Raquette Point during the warm weather months. The highest monthly average was 20 ng/m^3. Consequently, we defined potential outdoor air exposure according to whether a participant ever lived at Raquette Point. Such residence was limited to the last 10 years to take into account the fact that the airborne PCBs were predominantly volatile, lightly chlorinated congeners that tend to be less persistent environmentally and biologically (Chiarenzelli et al., 2000).

Statistical Analysis for Serum PCB Concentration Data

Multiple linear regression analysis was used to test for the association between total serum PCB concentrations and local fish consumption, occupational exposure, and Raquette Point residence, after controlling for significant background variables that could potentially confound any association between exposure and serum PCB level. Potential confounders were first identified using bivariate analysis to evaluate 10 background variables (age, education, height, weight, body mass index, marital status, cigarette smoking, alcohol consumption, coffee consumption, and prescription drug use), some of which have been related to serum or plasma PCB levels in other studies (Rylander et al., 1997; Laden et al., 1999; Moysich et al., 2002). Variables that were associated in the bivariate analysis at $P < 0.20$ were then regressed on total serum PCB concentrations, using backward elimination to delete non-significant ($P > 0.10$) variables one at a time. The environmental exposure variables were next added to the model to estimate their effects after adjusting for all remaining background variables. The inclusion of the background variables was confirmed by determining whether the parameter estimates for the exposure variables changed by more than 10% when they were removed (Rothman and Greenland, 1998). Total serum PCB concentrations, as well as the estimates of cumulative PCB exposure from local fish consumption and occupation, were log-transformed for the multiple regression analysis. Multiple linear regression analysis also was used to test for the association between congener-specific serum PCB concentrations and local fish consumption, occupational exposure, and Raquette Point residence for those congeners with a geometric mean concentration that equaled or exceeded its MDL.

Statistical Analysis for Serum PCB Pattern Matching

In this analysis, the serum PCB congener patterns of the Mohawk men were compared to those found in environmental source samples. For local fish exposure, the source was a composite of five yellow perch samples caught from the St. Lawrence River off-shore from the General Motors facility. Yellow perch was the species selected for this purpose because it was the local species most frequently consumed by the Mohawk men. For residential outdoor air exposure, the source was the average of air samples taken at Raquette Point in June, July, and August. These months were chosen because air PCB concentrations were highest during the

summer, and they represent the peak potential exposure from outdoor air when outdoor activity increases. Aroclor 1248 was the source for occupational exposure because it is the commercial PCB mixture used at the three local facilities, and has been detected in high concentrations in the soil and sediment samples collected on and near these sites.

The concentration of each congener first was normalized to the percent of the total PCB it accounted for in the serum sample or environmental source. The similarity in congener patterns then was quantified by calculating the Euclidean distance between the human serum and source sample regarding this normalized concentration for each congener. By treating each record of n congeners as a point in an n-dimensional Euclidean space, the Euclidean distance is defined as:

$$d(S_i, T) = \sqrt{\sum_{j=1}^{J} (s_{ij} - t_j)^2}$$

where $S_i = (s_{i1}, s_{i2}, \ldots, s_{iJ})$ and $T = (t_1, t_2, \ldots, t_J)$; s_{ij} is the jth normalized serum PCB congener concentration for the ith participant; t_j is the jth normalized PCB congener concentration for the environmental source; $i = 1, 2, \ldots, 139$ is the number of Mohawk men in the analysis and $j = 1, 2, \ldots, n$, where n is the number of the PCB congeners in the comparison. Three distances $d(S_i, T)$ are computed for each participant, one each for yellow perch, Raquette Point air, and Aroclor 1248. A Euclidean distance of zero indicates that a given serum sample has the same congener pattern as an environmental source sample, that is, every congener accounts for the same proportion of total PCB in the serum sample as in the source sample. Conversely, the less similar the congener patterns, the greater the Euclidean distance between the serum and source sample. More details about the properties of this Euclidean distance measure are available elsewhere (Hwang et al., 1993, 2001).

For cumulative lifetime exposure to PCBs from local fish consumption, the Mohawk men were divided into tertiles. For Raquette Point residence, those who lived there at any time during the past 10 years were compared to those who did not. For occupation, those whom the industrial hygienists determined possibly, probably, or definitely worked in a job with PCB exposure were compared with those who did not. The Euclidean distances between the serum and environmental source samples were ranked in ascending order, and the sum of the ranks within each exposure group was computed. The smaller the rank sum, the shorter the Euclidean distances, and, consequently, the greater the similarity between the PCB congener pattern in the serum samples and that in a given environmental source sample. The Kruskal–Wallis and Wilcoxon rank-sum tests were used to assess the statistical significance of differences in mean ranks among the exposure groups.

Results

The ages of the 139 male participants ranged from 15 to 77 years, with a mean age of 36.7 years. Additional demographic characteristics are summarized in an earlier article (Fitzgerald et al., 1996). The arithmetic mean concentration for serum total PCBs was 4.9 ppb (wet weight), with a standard deviation of 5.6 ppb. The geometric mean was 2.8 ppb, and the median was 3.2 ppb. Eighty-three percent of the men had a total PCB concentration above the method detection limit of 1.0 ppb, 13% had a concentration above 10.0 ppb, and the maximum concentration was 31.7 ppb.

Serum total PCB concentrations increased with age ($P < 0.001$) and cumulative lifetime exposure to total PCBs from local fish consumption ($P = 0.011$), and were lower among men who had never married compared to those who were married, divorced, or widowed ($P = 0.005$, Table 1). Cumulative lifetime exposure to PCBs from occupation was also positively associated with serum total PCB concentration ($P = 0.034$), but there was no significant difference according to Raquette Point residence in the last 10 years.

The seven congeners with a geometric mean equal to or greater than their MDL are displayed in Table 2. The

Table 1. Multiple regression model for serum total PCB concentration (log-transformed): Mohawk Men, Akwesasne, 1992–1995 ($N = 139$)

	β	SE	P
Age	0.034	0.007	<0.001
Marital status[a]	−0.663	0.233	0.005
Fish consumption[b]	0.085	0.033	0.011
Occupational exposure[c]	0.052	0.024	0.034
Raquette point residence[d]	−0.057	0.263	0.829

[a]Marital status: Never married (1) vs. other (0).
[b]Log lifetime cumulative PCB exposure from consumption of local fish.
[c]Log lifetime cumulative PCB exposure from occupation.
[d]Ever (1) vs. never lived (0) at Raquette Point in last 10 years.

Table 2. Geometric mean serum PCB concentrations (ppb, wet weight) of leading congeners: Mohawk men, Akwesasne, 1992–1995 ($N = 139$)

Structure	IUPAC no.	Geometric mean
245/4	74	0.028
245/24	99	0.052
245/34	118	0.040
234/245	138	0.266
245/245	153	0.407
2345/245	180	0.196
2356/245 + 2345/246	187 + 181	0.062
Total PCB[a]		2.809

[a]Total PCB = Σ 68 PCB-containing chromatographic peaks.

Table 3. Multiple regression model[a] for serum congener-specific PCB concentrations (log-transformed): Mohawk men, Akwesasne, 1992–1995 ($N = 139$)

	Fish consumption[b]			Occupational exposure[c]			Raquette point residence[d]		
Congener	β	SE	P	β	SE	P	β	SE	P
PCB-74	0.438	0.162	0.008	0.111	0.119	0.356	1.645	1.287	0.203
PCB-99	0.262	0.158	0.100	0.198	0.117	0.093	2.035	1.256	0.107
PCB-118	0.012	0.182	0.948	0.016	0.135	0.905	1.181	1.449	0.416
PCB-138	0.402	0.128	0.002	0.121	0.094	0.201	−0.332	1.016	0.745
PCB-153	0.126	0.070	0.075	0.046	0.052	0.379	−0.834	0.557	0.136
PCB-180	0.0002	0.157	0.999	0.180	0.116	0.124	−0.332	1.248	0.790
PCB-187 + 181	0.301	0.166	0.071	0.202	0.122	0.100	0.345	1.314	0.794

[a]All models adjusted for age and marital status (never married vs. other).
[b]Log lifetime cumulative PCB exposure from consumption of local fish.
[c]Log lifetime cumulative PCB exposure from occupation.
[d]Ever (1) vs. never lived (0) at Raquette Point in last 10 years.

congeners detected in the greatest concentrations were PCB-153, -138, and -180, with geometric means of 0.407, 0.266, and 0.196 ppb, respectively. As shown in Table 3, multiple regression analysis indicated that cumulative lifetime exposure to PCBs from local fish consumption was associated with serum concentrations of PCB-74 and -138 ($p < 0.05$). In contrast, no congener was significantly associated with cumulative lifetime exposure to PCBs from occupation or with Raquette Point residence.

Regarding the "fingerprinting" analysis, the mean ranks of the Euclidean distances between the serum PCB congener patterns of the Mohawk men and those in environmental source samples are presented in Table 4. A significant association was observed for cumulative lifetime exposure to PCBs from local fish consumption when a composite sample of yellow perch caught off-shore from the General Motors facility was used as the environmental source. Specifically, the mean ranks decreased as local fish consumption increased ($P = 0.014$). As a lower rank indicates a closer match between patterns in serum and source, this finding indicates that Mohawk men who had the greatest exposure to PCBs from local fish consumption had a serum PCB congener pattern that more closely resembled that found in local fish than did men who ate less fish.

According to the industrial hygienists, 29 Mohawk men had possible, probable, or definite occupational exposure to PCBs. Most of these men worked in the General Motors and ALCOA facilities or in other manufacturing industries that entailed handling of transformers, capacitors, hydraulic fluids or other PCB-containing materials. Using Aroclor 1248 as the environmental source, the mean rank of their Euclidean distance was 55.8 (Table 4), compared to 73.8 for men without occupational exposure ($P = 0.033$). Only 13 men had ever lived at Raquette Point at any time in the last 10 years. Table 4 shows that their mean rank did not differ significantly from that of men who did live at Raquette Point, using summer air samples from Raquette Point as the source.

Table 4. Mean rank of Euclidean distances between PCB concentration in serum and in environmental source by local fish consumption, occupation, and Raquette point residence: Mohawk men, Akwesasne, 1992–1995 ($N = 139$)

Environmental exposure	N	Mean rank	P
Local fish consumption[a]			
Low	46	83.9	0.014
Medium	46	65.8	
High	47	60.5	
Occupational exposure[b]			
No	110	73.8	0.033
Yes	29	55.8	
Raquette point residence[c]			
No	126	71.0	0.368
Yes	13	60.2	

[a]Tertile of cumulative lifetime exposure to PCBs from local fish consumption. Environmental source was composite sample of yellow perch caught off-shore from General Motors facility.
[b]Possible, probable, or definite occupational exposure to PCBs according to evaluation by industrial hygienists. Environmental source was Aroclor 1248.
[c]Raquette Point residence in last 10 years. Environmental source was outdoor air sampled at Raquette Point.

To compare the pattern in serum with that in outdoor air independent of local fish consumption, differences by Raquette Point residence were examined after stratifying according to cumulative lifetime exposure to PCBs from local fish consumption (Table 5). The results indicated significant differences only among men who had the lowest exposure to PCBs from local fish consumption. That is, men who lived on Raquette Point had a serum PCB congener pattern that more

Table 5. Mean rank of Euclidean distances between PCB concentration in serum and in air sample from Raquette point by Raquette point residence and fish consumption: Mohawk men, Akwesasne, 1992–1995 ($N = 139$)

Fish consumption[a]	Raquette point residence[b]	N	Mean rank	P
Low	No	42	25.0	0.015
	Yes	4	7.8	
Medium	No	43	23.3	0.689
	Yes	3	26.7	
High	No	41	23.3	0.381
	Yes	6	28.7	

[a]Tertile of cumulative lifetime exposure to PCBs from local fish consumption.
[b]Raquette Point residence in last 10 years.

closely matched that found in outdoor air only if they ate relatively little local fish ($P = 0.015$). In addition, none of the four men who had the lowest fish consumption and had lived on Raquette Point in the past 10 years had occupational exposure to PCBs (data not shown).

Discussion

Caution must be exercised when comparing serum PCB levels across studies, given differences in analytical methods, time periods and populations (Longnecker et al., 2003). In general, however, the median concentration of 3.2 ppb for serum PCB among Mohawk men is consistent with the general USA population value of 3.1 ppb noted by Patterson et al. (1994) for the same time period. These relatively low current body burdens are most likely the result of the significant declines in reported fish consumption over time among the Mohawk men (Fitzgerald et al., 1999). The Mohawk values are also similar to the range of 1.4–3.1 ppb for average serum total PCB concentrations reported by Dellinger (2004) for 822 tribal members from several Obijwe and Menominee reservations in Michigan, Minnesota, and Wisconsin from 1993 to 2000. This resemblance in PCB body burden between the Mohawk and the Obijwe and Menominee peoples reflects similarity in their rates of local fish consumption, which currently averaged 21.2 meals per year for the Mohawk men and ranged from 12 to 34 meals per year for the Obijwe and Menominee. Consumption rates for both native groups are greater than the median of 6.5 sport fish meals per year reported for the general population of the Great Lakes states (Tilden et al., 1997). In contrast, much higher serum PCB levels have been observed among the Inuit people, who are much more dependent on local fish and other PCB-contaminated marine food sources than are the Mohawks (Ayotte et al., 1997).

Despite their relatively low average serum total PCB level, 13% of the Mohawk men had a concentration above 10 ppb, a value that is often the upper limit observed in other studies of persons with no unusual exposures to PCBs (ATSDR, 2000). This finding most likely reflects the impact of elevated past rates of fish consumption. Supporting this contention is the result that serum total PCB concentrations were significantly associated with cumulative lifetime exposure to PCBs from local fish consumption. This measure of exposure combined dietary intake with fish PCB concentrations; however, cumulative lifetime exposure to PCBs from local fish consumption was strongly correlated with intake alone ($r = 0.94$), suggesting that intake was the primary factor driving the exposure estimate. It is also important to note that the median total PCB level of 3.2 ppb for the Mohawk men was greater than the median of 1.2 ppb that we observed in our parallel study of Mohawk women who were the wives or other close relatives of men in the current investigation (Fitzgerald et al., 2004). Fish consumption is again the most likely explanation, as on an average the rates of local fish consumption reported by the men were two to three times greater than those for the women.

The three leading congeners in the serum of the Mohawk men were PCB-153, -138, and -180. All three are hexa- or heptachlorobiphenyls that are resistant to metabolism by the P-450 enzyme system (Hansen, 1999). They were also present in the greatest concentrations in our study of Mohawk women, and typically are the most dominant congeners in human tissue worldwide (Hansen, 1998). They are not found in Aroclor 1248 (Frame et al., 1996). As such, they probably do not reflect exposure to PCBs from the local industrial facilities as much as they do more general Lake Ontario and St. Lawrence River exposures (Bush et al., 1985).

On the other hand, PCB-74, -99, and -118 are more lightly chlorinated biphenyls that are present in Aroclor 1248, the commercial mixture used by General Motors, ALCOA, and Reynolds. The fact that they were detected in the serum of Mohawk men suggests some impact of local point sources on body burden. Consistent with this interpretation is the fact that PCB-74 was significantly associated with cumulative lifetime exposure to PCBs from local fish consumption.

In addition, the results confirmed the hypothesis that cumulative lifetime exposure to PCBs from occupation increases serum concentrations, at least for total PCB. The Raquette Point comparison had limited statistical power, as only 13 men had lived at that location at any time in the last 10 years. The lack of association between Raquette Point residence and serum PCB levels, however, does not support the hypothesis that outdoor air elevates body burdens, even for the more lightly chlorinated congeners found in samples obtained at that location (Chiarenzelli et al., 2000). This lack of difference in serum total PCB level by Raquette Point residence was also observed in our study of Mohawk women (Fitzgerald et al., 2004).

In contrast, several German studies (Gabrio et al., 2000; Schwenk et al., 2002; Liebl et al., 2004) have found increased mean serum concentrations for some lower chlorinated PCB congeners among teachers and pupils in schools with indoor air contaminated with PCBs from the use of sealants. Despite the very high concentrations of total PCBs in indoor air (from 690 to 20,800 ng/m^3), all three investigations concluded that the excess body burden was very small compared to that attributable to dietary intake, and in one study, the authors concluded that differences were not discernible below indoor air levels of 1,000 ng/m^3 (Gabrio et al., 2000).

No study has demonstrated a difference in serum PCB concentrations according to levels of PCBs in outdoor air, most likely because the levels in outdoor air are much lower than those indoors, even in the vicinity of PCB-containing hazardous waste sites. For example, the maximum outdoor air PCB level detected in three New Bedford Harbor, MA neighborhoods immediately downwind of hot spot sediment areas that were being dredged was 61 ng/m^3 (Vorhees et al., 1997). Although this air concentration is three times the maximal level at Raquette Point, it is approximately 15 times lower than the threshold cited in the German studies. Consistent with our findings for Mohawk men, epidemiological studies of New Bedford residents have not observed elevated PCB body burdens in the absence of fish consumption or occupational exposure (Miller et al., 1991; Korrick and Altshul, 1998). Similarly, in an exposure survey of families who lived within a half-mile of a factory that produced PCBs in Anniston, AL, 9 of 43 adults (21%) had a serum total PCB concentration that exceeded 10 ppb, but each of these persons reported eating fish, chicken, eggs and other locally produced foodstuffs (Orloff et al., 2003). Such findings, together with the result of this investigation, may help to address community concerns about the whether airborne PCBs from hazardous waste sites and other local point sources affect body burden and their potential to cause adverse health effects.

The matching of congener patterns complemented the statistical analysis of serum concentrations. Instead of examining each congener individually, the pattern matching evaluates all congeners simultaneously and compares the profile in human serum with that in environmental source samples such as local fish or outdoor air. The results of the pattern matching for fish consumption and occupation are consistent with those for the concentration analysis. That is, Mohawk men who had the greatest exposure to PCBs from local fish consumption had serum PCB congener patterns that were significantly more similar to that found in contaminated local fish than were men who ate less local fish. Similarly, men with jobs that were evaluated by industrial hygienists as entailing exposure to PCBs were significantly more likely than men without occupational exposure to have a serum congener pattern that resembled Aroclor 1248, the commercial PCB mixture used at all three local facilities. The association between local fish consumption and serum congener pattern among Mohawk men is consistent with our earlier work that showed nursing Mohawk women who ate the local fish most also showed congener patterns in their breast milk that more closely resembled the pattern in contaminated local fish (Hwang et al., 2001). These findings strengthen the argument that local exposures to PCBs through fish consumption or occupation have resulted in exposure to PCBs among the Mohawk people.

Significant differences in serum congener patterns relative to those in outdoor air were evident according to residence at Raquette Point only when the data were stratified according to fish consumption. Specifically, the pattern in the serum of Raquette Point residents was significantly more likely than non-residents to resemble the congener pattern in outdoor air only among men who ate relatively little local fish. This result suggests that, given the much higher concentrations of PCBs in local fish than in outdoor air, the impact of fish consumption may overwhelm that of outdoor air among persons who are exposed through both pathways. Together with the findings of the concentration analysis, the data indicate, that, although inhalation may be insufficient to result in a detectable increase in body burden at the low levels found in outdoor air, it may alter serum congener profiles, at least in the absence of heavy fish consumption. This contrast between the findings of the pattern matching and concentration analyses implies that the former method may be a more sensitive indicator of the impact of low-level exposures, perhaps because it evaluates all congeners simultaneously and focuses on relative differences in overall pattern, while the concentration analysis emphasizes measurable differences in the absolute level of each congener individually.

Relatively few studies have attempted to quantitatively match PCB congener patterns in human samples to those in environmental source samples. Burse et al. (1994) examined 23 New Bedford residents with elevated serum PCB concentrations and used Jaccard measures of similarity and principal components analysis to identify congener patterns. Their results indicated that the pattern in the human serum samples were similar to those found in local lobsters. Both of the patterns also resembled those found in goats fed Aroclor 1254; however, the human and lobster patterns also contained some of the more lightly chlorinated congeners characteristic of Aroclors 1016 and 1242. As 17 of the 23 persons reported current or past employment in a capacitor plant and 10 stated that they had consumed seafood from the PCB-contaminated New Bedford Harbor, the authors concluded that these findings reflect the impact of both occupation and diet.

In a separate study of 753 Akwesasne residents published recently, DeCaprio et al. (2004) used polyvector analysis (PVA) to determine the number, composition, and relative proportion of independent serum congener patterns. PVA

utilizes principal components analysis as an intermediate data reduction step, followed by rotation of the reduced data matrices. They identified five independent patterns, each characterized by a unique mixture of congeners. For 5% of the study population, the pattern resembled that in air obtained from Raquette Point, leading the investigators to hypothesize that this finding reflected recent inhalation.

In our previous "fingerprinting" articles (Hwang et al., 1993, 2001), we compared the statistical properties of the Euclidean distance measure that we used in this analysis with other possible approaches such as principal components analysis, cluster analysis, and the Jaccard and other similarity coefficients. We concluded that each method has its strengths and weaknesses and that none is uniformly superior. However, unlike Burse et al. (1994) and DeCaprio et al. (2004), the current study directly compares the serum congener patterns of persons with and without specific environmental exposures relative to a source sample, and assesses the statistical significance of any observed differences. Consequently, it is a more definitive test of the hypotheses that diet, occupation, and outdoor air affect PCB congener patterns in humans. In addition, by stratifying according to potential exposure, we were able to differentiate among these pathways.

A limitation of our pattern matching method is the fact that the profile of PCBs in human serum is influenced by biotransformation processes, thereby rendering it more difficult to match that profile with those evident in environmental source samples. However, in our previous work, we weighted the Euclidean distances for each congener by a factor representing its relative half-life, and the results were similar to those without such weighting (Hwang et al., 2001). Another limitation of the study pertains to the accuracy of the self-reported information regarding lifetime fish consumption. Although uncertainty in recall may have resulted in some exposure misclassification, rendering it more difficult to detect associations, the positive correlation between local fish consumption and serum PCB concentrations and profiles helps to validate the dietary histories.

Conclusion

On an average, serum PCB concentrations of the Mohawk men in this study were similar to those of the general population, a finding that appears to be the result of their decreased rates of local fish consumption over time in response to advisories. However, cumulative lifetime exposure to PCBs from local fish consumption was significantly associated with individual serum concentrations of total PCB and of several congeners. In addition, occupational exposure to PCBs was positively associated with serum total PCB concentration, but men who lived at Raquette Point, the only area of the Reserve with elevated outdoor air PCB levels did not have higher serum concentrations of total or congener-specific PCB than men who lived elsewhere. For local fish consumption and occupation, the results of the pattern matching were consistent with those of the serum PCB concentration analysis; men with the greatest exposure from local fish consumption had a congener profile that most closely resembled that in local fish, and men who were occupationally exposed had a congener profile that was most similar to that of Aroclor 1248, the commercial mixture used at local industrial facilities. The congener pattern in the serum of men who lived at Raquette Point was more similar to that detected in outdoor air samples from Raquette Point only for those who ate relatively few local fish. The study confirms that exposures to PCBs from fish consumption and occupation are the major environmental contributors to body burden, and is among the first to link outdoor air to serum PCB congener patterns, at least in the absence of heavy fish consumption. The study also illustrates the sensitivity of pattern matching in detecting the impact of low-level PCB exposures, even when absolute serum concentrations of PCBs are not elevated.

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