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Historical Changes in Serum PCB and DDT Levels in an Environmentally-Exposed Cohort

Mary E. Hovinga*[1], MaryFran Sowers**, and Harold E. B. Humphrey†

*Department of Epidemiology, School of Public Health, University of Alabama at Birmingham, Birmingham, Alabama 35294, USA; **Department of Epidemiology, School of Public Health, University of Michigan, Ann Arbor, Michigan 48109, USA and †Michigan Department of Public Health, Lansing, Michigan 48960, USA

Abstract. A previously characterized cohort of 115 Great Lakes fisheaters and 95 non-fisheating controls was re-examined in 1989 to evaluate changes that had occurred in serum PCB and DDT levels since the 1982 study. Substantial and significant decreases in mean serum DDT levels had occurred in both fisheaters (25.8 ppb vs 15.6 ppb) and controls (9.6 ppb vs 6.8 ppb)[2] over this time period. In contrast, only a slight decrease in serum PCB levels was observed, and in fisheaters only. No association between individual changes in serum PCB or DDT levels and self-reported changes in Great Lakes fish consumption was observed. The findings from this longitudinal examination of serum PCB and DDT levels confirm earlier cross-sectional surveys of western populations, and demonstrate that the prohibition of DDT has been successful in reducing the level of DDT contamination in human populations.

Widespread and increasing use of polychlorinated biphenyls (PCBs) and DDT from the 1940's through the 1960's resulted in extensive environmental contamination. These organochlorine compounds are not only exceptionally stable and persistent in the physical environment, but, because of their lipophilic nature, have the ability to biomagnify in aquatic and terrestrial foodchains (Risebrough *et al.* 1968). Examination of a variety of wildlife has clearly demonstrated that extensive contamination of fish, bird, and mammalian species by PCBs and DDT has occurred (Risebrough *et al.* 1968; Dustman and Stickel 1969; Horn *et al.* 1979; Veith *et al.* 1981; Foley *et al.* 1988).

Contamination has also been demonstrated in humans. Measurable levels of PCBs and DDT have been found in human adipose tissue, blood, and breast milk throughout the world (Quimby *et al.* 1965; Zavon *et al.* 1969; Mes *et al.* 1982; Frank *et al.* 1988; Skaare *et al.* 1989; Kutz *et al.* 1991). A primary route of human exposure has been the consumption of contaminated foods. In the Great Lakes region, consumption of contaminated fish has been identified as an important exposure route (Humphrey 1983a; Schwartz *et al.* 1983; Fiore *et al.* 1989). In a 1982 study by the Michigan Department of Public Health (Humphrey 1983b), individuals who consumed 24 or more pounds of sport-caught Great Lakes fish had a mean serum PCB level three times greater than that of the non-fisheating controls. The mean serum DDT level for the fisheaters was more than twice that of the control group. Further analysis of this study population demonstrated that fish consumption was a major determinant of the elevated PCB and DDT levels in the fisheater group.

The environmental persistence and biomagnification of PCBs and DDT, coupled with evidence of serious adverse health effects in wildlife populations, prompted a reduction in the use of DDT and PCBs in the United States. The use of DDT was banned in 1972, and PCB production was halted in 1977. The effects of these prohibitions have become apparent in the environment. In the Great Lakes region, sampling data suggest that the degree of DDT and PCB contamination in fish declined sharply in the 1970's, and has plateaued more recently (Schmitt *et al.* 1985; D'Itri 1988; Schmitt *et al.* 1990). Surveys of dairy milk in Canada have suggested a similar pattern (Frank and Braun 1989).

The current study examined whether the observed declines in environmental DDT and PCB levels were also detectable in human populations. Surveys monitoring contaminant levels in human adipose tissue, blood, and breast milk in the United States (Kutz *et al.* 1991), Canada (Frank *et al.* 1988), and Norway (Skaare *et al.* 1989), suggest that DDT levels have been declining since the early 1970s while PCB levels have remained stable. However, these studies have been cross-sectional, and did not allow longitudinal follow-up of individuals, or identification of the relevant sources of exposure. Re-contact of the 1982 Michigan Department of Public Health study population provided an opportunity for the current study to evaluate historical changes in serum DDT and PCB levels within individuals who had a previously identified route of environmental exposure.

[1] Address correspondence to Dr. Mary E. Hovinga.

[2] ppb = ng/g

Table 1. Comparison of mean baseline characteristics of Entire Cohort and Southern Region Fisheaters and Controls

	1982 Fisheaters		1982 Controls	
	Entire Cohort	Southern Region	Entire Cohort	Southern Region
N	572	197	419	162
1982 age (yrs)	45.9	45.6	44.1	42.3
% male	65.0	63.5	43.2	49.4
1982 Quetelet Index	2.61	2.56	2.49	2.47
1982 annual fish meals	58.6	55.7	NR	NR
1982 serum PCB (ppb)	21.1	19.9	7.2	6.8
1982 serum total DDT (ppb)	28.8	24.5*	10.6	9.7

*$p < 0.05$
NR = not recorded in 1982 dataset
Natural log transformation used for mean and signif. testing

Table 2. Comparison of mean baseline characteristics of Southern Region and Full Participant Fisheaters and Controls

	Fisheaters		Controls	
	Southern Region	1989 Full Participants	Southern Region	1989 Full Participants
N	197	115	162	95
1982 age (yrs)	45.6	46.0	42.3	44.3
% male	63.5	64.3	49.4	46.3
1982 Quetelet Index	2.56	2.60	2.47	2.48
1982 annual fish meals	55.7	53.5	NR	NR
1982 serum PCB (ppb)	19.9	20.5	6.8	6.6
1982 serum total DDT (ppb)	24.5	25.8	9.7	9.6

NR = not recorded in 1982 dataset
Natural log transformation used for mean and signif. testing

Methods

Study Population

The 1982 study by the Michigan Department of Public Health (MDPH) identified and enrolled 572 fisheaters and 419 controls within eleven communities along the Lake Michigan shoreline. Fisheaters were defined as individuals who typically consumed 24 or more pounds of sport-caught Great Lakes fish annually. These individuals were identified and recruited through MDPH staff visits to area marinas, piers, bait shops, sporting goods stores, and fishing clubs, as well as referrals through other participants. Controls were defined as individuals whose self-reported annual consumption of sport-caught Great Lakes fish was less than 6 pounds. Approximately 1,000 households were contacted by random digit dialing to obtain 419 age- and region-matched controls.

Resource limitations restricted the 1989 follow-up study to the Southern Region of the 1982 MDPH study. This region contained 36.2% of the entire 1982 cohort, and included 197 fisheaters (34.4% of all fisheaters) and 162 controls (38.7% of all controls). A comparison of 1982 baseline characteristics is presented in Table 1. The Southern Region eligible population was demographically comparable to the Entire Cohort population. Although mean serum PCB and DDT levels were slightly lower for the Southern Region groups, only the difference in mean serum DDT levels between fisheaters was statistically significant. This difference was not viewed as a biologically important difference.

Letters were sent to the 1982 Southern Region subjects which described the current study and invited continued participation. MDPH staff members conducted personal interviews and collected blood specimens from participating subjects. The questionnaire used in the 1989 personal interview was similar to the 1982 MDPH questionnaire. Information was obtained on the frequency, amount, and changes in sport-caught Great Lakes fish consumption, possible sources of occupational exposures, and lifestyles and demographic characteristics. Study participation was voluntary, without compensation, and was accompanied by the signing of an informed consent statement approved by both Human Subjects Review Committees of The University of Michigan and the Michigan Department of Public Health.

Contact was made with 169 fisheaters (85.8%) and 127 controls (78.4%). Of these eligible participants, 115 fisheaters (68.1%) and 95 controls (74.8%) were full participants—individuals who completed the personal interview and provided a blood specimen. Twenty-six fisheaters (15.4%) and 21 controls (16.5%) declined further participation in the study. The remaining 28 fisheaters and 16 controls agreed to complete the questionnaire but were unable or unwilling to provide a blood specimen. Table 2 presents the 1982 baseline characteristics of the Southern Region cohort and the 1989 Full Participant sample. No significant differences between the regional cohort and the full participant sample were observed, for either fisheaters or controls.

Laboratory Methods

Serum PCB and DDT analyses were performed by the MDPH Environmental Laboratory using the modifications of the Webb–McCall packed-column gas chromatography methodology developed for the 1982 fisheater study (Webb and McCall 1973; Needham *et al.* 1981; Humphrey 1983b). Peaks were identified by relative retention times and quantified by mean weight percent factors (Sawyer 1978), using Aroclor® 1260 as the reference standard. The total serum DDT value was obtained by multiplying the serum *p,p'*DDE content by 1.114 and adding this value to the serum *p,p'*DDT content. The detection limits for PCB and total DDT analyses were 3 ppb and 1 ppb, respectively. Samples with serum PCB levels below the detection limit ($n = 7$) were set to 2.0 ppb in subsequent analyses. All samples had total serum DDT levels above the detection limit.

Testing of randomly selected duplicates representing 10% of serum samples demonstrated good reliability of laboratory analysis. The technical error (Kahn and Sempos 1989) for PCB measurement was 1.4, which represented 8.1% of the total variation among individuals. The technical error for total DDT measurement was 0.9 and represented 6.3% of the total variation among individuals.

Data Analysis

Paired 1982 and 1989 serum PCB and DDT measurements were available for 111 fisheaters and 90 controls. The difference between the two time point measurements was calculated for each subject. For descriptive purposes, these intra-individual changes over time in serum PCB and DDT levels were treated as categorical variables. Each value was categorized as increased, decreased, or no change. In order to diminish the influence of trivial differences, the "no change" category was broadened to include historical changes which were small relative to the 1982 fisheater or control values.

For analytic purposes, the intra-individual changes over time in serum PCB and DDT levels were treated as continuous variables. The means of these intra-individual differences were calculated separately

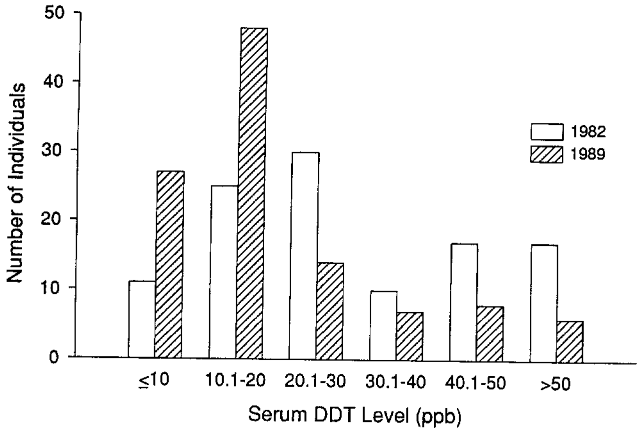

Fig. 1. Distribution of serum DDT levels of fisheaters in 1982 and 1989

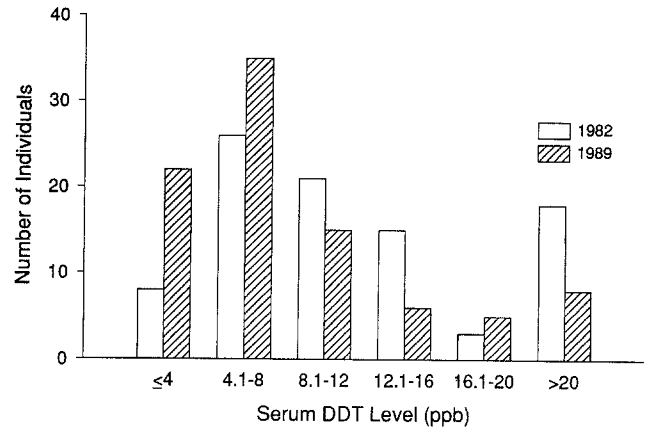

Fig. 2. Distribution of serum DDT levels in non-fisheating controls in 1982 and 1989

for fisheaters and controls, and paired t-tests were performed to determine whether a statistically significant within-group change had occurred between 1982 and 1989. Additionally, the means of the intra-individual changes in serum PCB and DDT levels were compared across the fisheater and control groups using two-sided t-tests. Because the 1982 baseline serum PCB and DDT levels were substantially higher in the fisheater group than in the control group, the intra-individual changes were examined as both the absolute change in serum PCB and DDT levels, as well as the relative change, expressed as percent change from the 1982 level. An alpha of 0.05 was used for all tests of statistical significance.

Changes in fish consumption were determined from questionnaire data. An individual assessment of change in Great Lakes fish consumption since the 1982 study was self-reported in the 1989 questionnaire as increased, decreased, or remained the same. The associations between intra-individual changes in PCB and DDT levels and changes in fish consumption were evaluated using multiple linear regression. Models were constructed which contained the individual difference in serum PCB or DDT level from 1982 to 1989 as the dependent variable. The primary independent variable of interest in these models was the categorical change in Great Lakes fish consumption. Age, sex, and the baseline 1982 serum PCB or DDT level were also included as control variables in the regression models. All statistical analyses were conducted using programs available through SAS (SAS Institute 1985).

Table 3. Distribution of serum level change categories for PCB and DDT in fisheaters and controls

	Serum PCB		Serum DDT	
	Fisheaters	Controls	Fisheaters	Controls
N	111	90	111	90
% increased	21.6 (24)	31.1 (28)	6.3 (7)	7.8 (7)
% no change	43.2 (48)	36.7 (33)	28.8 (32)	28.9 (26)
% decreased	35.1 (39)	32.2 (29)	64.9 (72)	63.3 (57)

Number of individuals in parentheses

Table 4. Mean serum PCB and DDT levels in fisheaters and controls, 1982 vs 1989

	Fisheaters			Controls		
	1982	1989	p-Value*	1982	1989	p-Value*
Serum PCB (ppb)	20.5	19.0	0.026	6.6	6.8	0.79
Serum DDT (ppb)	25.8	15.6	0.0001	9.6	6.8	0.0002

Values represent 111 fisheaters and 90 controls
*p-values for paired t-test of mean differences

Results

The comparisons of the 1982 and 1989 serum DDT distributions are shown in Figures 1 and 2 for the fisheater and control groups, respectively. Since the 1982 survey, there has been an apparent downward shift of the DDT contamination level in both fisheaters and controls. Over the same time period, no changes were seen in the serum PCB distributions in either the fisheater or the control group.

Qualitatively, these same results were observed when the serum PCB and DDT level changes were treated categorically. The data presented in Table 3 demonstrate that over 60% of both fisheaters and controls experienced a decrease in serum DDT levels from 1982 to 1989, while only 7% (14/201) of the entire group exhibited an increase. In contrast, no apparent trends in serum PCB changes were seen in either fisheaters or controls.

The population mean serum PCB and DDT levels for 1982 and 1989 are presented in Table 4, in conjunction with the results from the paired t-test analysis of the mean intra-individual historic changes. A substantial decrease in the overall population mean serum DDT level was apparent in both the fisheater and control groups. The paired t-test analysis revealed that the mean intra-individual decreases in serum DDT levels from 1982 to 1989 were statistically significant for both fisheater and control groups. In contrast, only small intra-individual decreases in serum PCB levels from 1982 to 1989 were observed, and only the mean intra-individual decline seen in the fisheater group was statistically significant.

Further comparisons of the mean intra-individual differences in serum PCB and DDT levels were made across the fisheater and control strata. For serum PCB levels, the mean intra-individual decrease seen in the fisheater group (−2.1 ppb) was not significantly different from that observed in the control group (−0.1 ppb). For serum DDT levels, the mean intra-individual decrease for the fisheater group (−13.8 ppb) was significantly

Table 5. Distribution of self-reported changes in fish consumption for fisheaters and controls

	Fisheaters	Controls
% increased	5.2 (6)	9.5 (9)
% no change	37.3 (43)	66.3 (63)
% decreased	57.4 (66)	24.2 (23)

Number of individuals in parentheses

greater than that observed in the control group (−3.1 ppb). However, when the relative magnitude of the serum DDT change was examined by expressing the intra-individual difference as the percent change from the 1982 level, there was no statistically significant mean difference between fisheaters and controls (−29.7% vs. −26.3%, respectively).

A substantial decrease was observed in the amount of Great Lakes fish consumed by the fisheater group, relative to the 1982 study. Questionnaire data indicated that this decrease resulted from a reduction in the amount of fish caught, and was not due to concern over toxins in the fish. The distributions of the self-reported changes in fish consumption are presented in Table 5. Despite these changes, the mean annual Great Lakes fish consumption of the fisheater group remained significantly higher than that of the control group (21.6 pounds vs. 1.6 pounds).

To determine whether the intra-individual historic changes in serum PCB and DDT levels were associated with changes in fish consumption, multiple linear regression analyses were performed. After controlling for the secondary independent variables of age, sex, and the baseline 1982 contaminant level, no statistically significant associations between either increased or decreased fish consumption and the observed changes in serum PCB and DDT levels were found. This lack of association persisted whether the outcome variable was expressed as either the absolute difference between the 1982 and 1989 contaminant levels, or as the percent change from the 1982 baseline level. The findings of no association between changes in fish consumption and changes in serum PCB or DDT levels were consistent in both fisheater and control groups.

Discussion

The 1989 re-examination of the 1982 MDPH fisheater study population provided a unique opportunity to evaluate historical changes in serum PCB and DDT levels within individuals. Previous studies have generally consisted of cross-sectional surveys examining biological specimens obtained from either autopsy or self-referred populations. This study was able to repeat serum PCB and DDT measurements, using identical analytic methods, in individuals with previously demonstrated contamination from a continuing low-level environmental exposure.

Earlier studies have suggested that DDT levels in western populations have been declining since the 1970's. The results from this study confirm those findings, and support the interpretation that the decline reflects the overall reduction in environmental DDT contamination (Skaare *et al.* 1989; Kutz *et al.* 1991). Since the banning of DDT use in the United States in 1972, a documented decrease in environmental and wildlife DDT contamination has occurred. In this study, the intra-individual reductions in serum DDT levels were not associated with concurrent decreases in the frequency of the exposure—the consumption of sport-caught Great Lakes fish. This suggests that the observed lower levels may have been due to a decreased intensity of exposure, *i.e.*, lower levels of DDT in both the fish and the environment in general. This interpretation is supported by the observation that when the historic changes were expressed in terms of relative magnitude (percent change from 1982 levels), the decrease in DDT contamination was virtually the same for both the exposed fisheater group and the control group. The greater absolute loss in serum DDT experienced by the fisheaters was reflective of their higher 1982 baseline levels. These findings suggest that the gradual environmental improvement resulting from the banning of DDT has extended to human populations as well.

In contrast, although environmental and wildlife PCB levels have declined in the Great Lakes region, no consistent, comparable decline was evident in either the fisheaters or the controls. This finding agrees with earlier cross-sectional surveys which have observed stable PCB levels over time periods during which DDT levels declined dramatically.

Although the novel use of PCBs was restricted in the United States in 1974, and PCB production was halted altogether in 1977, very large quantities remain in industrial use. Environmental contamination continues to occur, as do human exposures, from a variety of sources. The more recent and less complete restrictions on PCBs, in conjunction with the long half-lifes typical of most PCB mixtures, may explain the findings of this and other studies, that the restrictions on PCBs have not as yet been as effective as the restrictions on DDT in reducing the levels of contamination in human populations.

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