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Determinants of polychlorinated biphenyls in dust from homes in California, USA

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Abstract

Polychlorinated biphenyl (PCB) production ceased in the U.S. over 30 years ago, but these persistent chemicals remain ubiquitous contaminants. Here, we evaluate potential determinants of PCB levels in dust from California homes including characteristics of the residence as well as the residents' habits and occupations. Dust was collected from 415 households as part of a large case-control study (the Northern California Childhood Leukaemia Study), using a high-volume small surface sampler. Dust concentrations of 6 PCBs (PCB-105, PCB-118, PCB-138, PCB-153, PCB-170, and PCB-180) were measured using gas chromatography-mass spectrometry. Individual PCB detection rates ranged from 9% to 54% with PCB concentrations ranging from below detection (1 or 2 ng/g) to 270 ng/g and PCB loadings ranging from below detection to 960 ng/m^2. Multivariable linear and logistic regression models were used to identify potential determinants of residential PCB contamination based on in-home interviews and residential geographic locations. We observed that residences built prior to 1980 had higher odds of PCB detection and higher PCB loadings than more recently constructed homes. Households where residents typically did not remove their shoes had higher PCB dust loadings than households where residents did. PCBs were less likely to be detected in carpet dust from households that had frequently vacuumed or replaced carpets compared to other households. Since we used a cross-sectional dust sampling protocol and report significant, but modest, effects of these determinants on levels of PCBs in residential dust, our results should be interpreted with caution. Longitudinal studies to determine optimal strategies for reducing PCBs in homes are warranted.

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†Electronic Supplementary Information (ESI) available: [Table S1 shows results from multivariable linear regression of PCB concentrations in residential dust. Table S2 shows the percentages of residences with detectable concentrations of each PCB stratified by categories of each potential PCB determinant]. See DOI: 10.1039/b000000x/

Introduction

Polychlorinated biphenyls (PCBs) are lipophilic chemicals that are resistant to degradation and therefore extremely persistent in the environment.[1] In the U.S., the Toxic Substances Control Act halted the production and distribution of PCBs in 1979.[2] Still, despite more than 30 years of regulation, PCBs remain ubiquitous residential contaminants – with recently reported maximum dust concentrations of major PCB congeners as high as 35 μg/g in one U.S. home.[3] Indeed, in 2005, it was estimated that 13–17% of the PCBs that have been produced globally were still in use.[4] Inhalation and accidental ingestion of dust is one important route of exposure to PCBs, especially for small children.[5] While the potential health impact of PCB exposure via dust inhalation or ingestion has not been fully characterized, elevated levels of PCBs measured in residential dust have been associated with increased risk of non-Hodgkin lymphoma[6] and childhood leukaemia.[7] Moreover, prenatal and early childhood exposures to PCBs have been associated with adverse immunological[8] and neurological[9] effects, including diminished IQ.[10]

To limit human exposure to PCBs it is useful to understand the sources of these residential contaminants. PCBs may have primary and secondary sources located both within and outside of the home. Primary indoor sources of PCBs include consumer products and construction materials.[11, 12] Primary sources of PCB found outside the home include transformers, large capacitors and other electrical equipment used for industrial or utilities applications.[12] Any of these PCB-containing items can subsequently contaminate environmental media indoors (*e.g.*, carpet dust, air) or outdoors (*e.g.*, soil, sediment, water, air), creating secondary sources of PCBs.

In small investigations of a few highly-contaminated residences, researchers have identified specific indoor PCB sources, including a contaminated wood floor finish and a contaminated carpet pad.[3, 13] However, investigators have had less success using questionnaires or interviews to identify common sources of PCBs that determine concentrations of PCBs in typical households.[14, 15] Self-reported or interview-conducted inventories of household items that may contain PCBs lack specificity, because PCBs have been used inconsistently in consumer goods and construction materials.[16] Moreover, PCB-containing consumer goods that were manufactured prior to 1980 have likely been replaced by products without PCBs in many homes.[17] Thus, even the most accurate residential inventory of PCB-contaminated items would not necessarily be a sensitive representation of historic sources of PCBs in a home.

While it may be difficult to identify specific sources of PCB, one surrogate for the historic presence of PCB-contaminated materials in a home is the age of a residence. Residences constructed after 1979 would be expected to be free of PCB-contaminated construction materials. On the contrary, homes built before 1980 would be likely to contain PCB-contaminated construction materials and would have been equipped (at least initially) with consumer products that may have contained PCBs. Thus, homes built before 1980 have a greater potential for historic PCB contamination via indoor primary sources than more recently constructed residences. Indeed, investigators have observed elevated PCB concentrations in dust from older residences[6] and in dust from older floor surfaces.[14, 18]

Since outdoor sources of PCBs may also contribute to residential PCB contamination, it would be useful to understand factors that influence PCB transport into the home from outdoors. Some residents may inadvertently convey PCBs from the workplace into the home via contaminated shoes or clothing.[14] Likewise, residents that live near a single strong PCB source (*e.g.,* a contaminated brownfield) or many weak PCB sources (*e.g.,* leaky transformers) may carry PCB-contaminated dust and soil inside their homes. Residents that do not remove their shoes upon entering their home or those that have cats and dogs may introduce additional outdoor soil inside.[19, 20]

Here, we measure concentrations of 6 PCBs in residential dust from 415 households in California. We evaluate potential indoor and outdoor determinants of PCB levels in residential dust using multivariable logistic and linear regression.

Methods

Dust sample collection

We collected dust samples from 415 households who participated in the Northern California Childhood Leukaemia Study (NCCLS) from 2001–2006.[7] Dust samples were collected using a high-volume surface (HVS3) sampler. Investigators generally collected dust from an area (~2 m^2) of a carpet or rug in the family or living room, as previously described.[21] Investigators recorded the size of the dust collection area so that we were able to characterize levels of PCB contamination as concentrations (ng of PCB per g of dust collected) or loadings (ng of PCB per m^2 of dust collection area). In 2 residences, the size of the dust collection area was not recorded; therefore we were unable to calculate PCB loadings for these residences. We obtained written informed consent in accordance with the institutional review boards' requirements at the University of California, Berkeley, the National Cancer Institute of the National Institutes of Health, and all other participating institutions.

Chemical analysis

A multi-residue analysis scheme was used to analyse 65 different neutral chemicals, from several compound classes (*e.g.*, PCBs, polycyclic aromatic hydrocarbons, insecticides, and herbicides), including six PCB congeners considered antiestrogenic, immunotoxic, or enzyme-inducing[22] (PCB-105, PCB-118, PCB-138, PCB-153, PCB-170, PCB-180), as previously described.[21] Briefly, a 0.5-g aliquot of each dust sample was spiked with 250 ng of each of 13 different compound class-specific surrogate recovery standards, including $^{13}C_{12}$ PCB-138, to provide sample-by-sample method performance data for each compound class. Samples were extracted by ultrasonication in 1:1 hexane:acetone solution, solvent exchanged into hexane, purified by solid-phase extraction, concentrated to 1mL, and spiked with an internal standard of p,p′-dibromophenyl prior to analysis using gas chromatography-mass spectrometry (GC-MS) in the multiple ion detection mode. The GC separation used an RTx-5 MS column (30 m, 0.25-mm i.d., 0.25-μm film) that was programmed from 130$^{\circ C}$ to 220$^{\circ C}$ at 2$^{\circ C}$ per min, and then from 220$^{\circ C}$ to 300$^{\circ C}$ at 10$^{\circ C}$ per min. Each batch contained 12 participants' samples, a method blank, a duplicate sample, and a duplicate sample spiked (prior to extraction) with 250 ng of each PCB. No PCBs were detected in any of the 49 method blanks and PCB recoveries in spiked samples indicated that the analytical protocol was valid (average recovery ± standard deviation = 86±15, 86±15, 88±16, 88±16, 86±16, 88±16 for PCBs 105, 118, 138, 153, 170, and 180, respectively).

Household characteristics

In-home interviews were conducted to ascertain information pertinent to childhood leukaemia and this analysis utilized selected questions to identify potential determinants of residential PCB contamination. Parents, primarily the biological mother (97%), were asked to identify the construction date of their residence as one of 8 categories (built since 1990, 1985–1989, 1980–1984, 1970–1979, 1960–1969, 1950–1959, 1940–1949, or built prior to 1940). Using this information, we divided the population into residences constructed prior to 1980, which had the potential for historic PCB contamination via indoor primary sources, and residences constructed since 1980, which were not likely contaminated with PCBs via indoor primary sources.

We asked participants about remodelling activities undertaken in their home since they moved in (*e.g.*, floor and roof replacement), about any remodelling activities that occurred between the date of the child's diagnosis (or reference date for controls) and the date of dust collection in the room from which dust was sampled, and about the timing of the most recent carpet replacement in the room from which dust was sampled, as these activities may have affected PCB dust levels. We also asked participants how frequently they used their vacuum cleaners.

To assess the influence of outdoor PCB sources on PCB dust levels, we asked participants about their occupations, including jobs with potential PCB exposure (*e.g.*, employment as an electrician, lineman, or cable puller; and employment in manufacturing, assembly, or industrial operations), as well as pet ownership (*i.e.*, whether a cat or dog lived or slept in the home) and shoe removal habits (*i.e.*, whether all of the people who lived in the home usually took off their shoes when entering the home). We used a global positioning device to locate each residence and we linked each location to the corresponding U.S. census block.[23] We used block-level population density as a surrogate for the density of outdoor PCB sources (*e.g.*, transformers or PCB-contaminated construction materials), since previous investigators have observed higher ambient concentrations of PCBs in urban compared to rural locations.[24–26]

Some parents were unable or unwilling to complete certain aspects of the questionnaires. In regression analyses, each missing questionnaire response was replaced by the population average from non-missing households (*e.g.*, for 54 respondents that did not know their residence's construction date, residence constructed prior to 1980 was set to a value of 0.55, since 55% of the study residences were built prior to 1980). This conservative imputation strategy may slightly attenuate true associations between PCB levels and questionnaire determinants. Aside from residence construction date, no other covariate had more than 10 missing values imputed.

Statistical analysis

Depending upon the particular PCB congener, between 46 and 91% of PCB measurements were below analytical limits of detection (Table 1). Since the proportions of non-detects were high for several congeners, we used PCB detection as an outcome variable in bivariate comparisons and in multivariable logistic regression models. Using the Logistic Procedure from SAS (v. 9.2, Cary, NC), we fit a multivariable logistic regression model for each of 6 PCBs. We modelled the probability of PCB detection in residential dust based on the household characteristics obtained from interview responses and residential geographic locations. Logistic regression results are presented as odds ratios (*e.g.*, the ratio of the odds of PCB detection when the explanatory variable equals 1 to the odds of PCB detection when the explanatory variable equals 0). Logistic regression model fit was estimated using the generalized coefficient of determination, max-rescaled r^2.[27]

For all observations above detection limits, we used multivariable linear regression to evaluate whether any household characteristics were associated with PCB loadings or concentrations in residential dust. Here, we present results from the PCB loading models only; results from the PCB concentration models can be found in the Electronic Supplementary Information (Table S1). Since the PCB congeners had approximate log-normal distributions, natural log transformations of the PCB loadings were used for linear regression. Using the Reg Procedure from SAS (v. 9.2, Cary, NC), we fit a multivariable linear regression model for each PCB congener. Linear regression results are presented as proportional increases (*i.e.*, the ratio of the loading of PCB when the explanatory variable equals 1 to the loading of PCB when the explanatory variable equals 0). Linear regression results were reported for PCB-118 (N = 133), PCB-138 (N = 221), PCB-153 (N = 216), and PCB-180 (N = 161).

Results

Concentrations of individual PCB congeners ranged from below detection (1 or 2 ng/g) to a maximum of 270 ng/g (Table 1). Loadings of individual PCB congeners ranged from below detection to a maximum of 960 ng/m^2. PCB-138 and PCB-153 predominated in residential dust with higher median concentrations and loadings than the other four PCB congeners. Residences that were built before 1980 were more likely to have detectable levels of PCBs than those constructed after 1980 (Table 2). For example, PCB-153 was detected in 71% of residences built before 1980, but in only 32% of homes constructed more recently. Likewise, homes built before 1980 had higher median, 75th percentile, and 95th percentile PCB loadings than more recently constructed homes (Table 2).

The percentages of residences with detectable concentrations of each PCB are shown stratified by categories of each potential PCB determinant in the Electronic Supplementary Information (Table S2). Results from multivariable logistic models for detection of each PCB are shown in Table 3. Residences built prior to 1980 had significantly higher odds of detection of PCB-118, PCB-138, PCB-153, PCB-170, and PCB-180 than more recently constructed homes [odds ratio, OR (95% confidence interval, 95% CI) = 4.3 (2.5, 7.2); 3.5 (2.1, 5.6); 6.0 (3.6, 10); 3.4 (1.4, 8.0); and 4.9 (2.9, 8.1), respectively]. Households that reported having replaced the sampled carpet within the past 5 years had significantly lower odds of detection of PCB-105, PCB-153, and PCB-180 than homes with older carpets [OR (95% CI) = 0.5 (0.3, 0.9); 0.6 (0.4, 0.9); 0.6 (0.4, 1.0), respectively] and households that reported frequent vacuum cleaning had significantly lower odds of detection of PCB-118 and PCB-153 than homes with less frequent vacuuming [OR (95% CI) = 0.5 (0.3, 0.9) and 0.4 (0.2, 0.7), respectively]. In contrast, households that reported floor replacement had significantly higher odds of detection of PCB-138 and PCB-153 than homes where the floors were not replaced [OR (95% CI) = 1.9 (1.0, 3.6) and 2.3 (1.2, 4.5), respectively]. Households with a resident employed in manufacturing, assembly, or industrial operations (N = 25) had significantly higher odds of PCB-138 detection than households with no resident employed in these occupations [OR (95% CI) = 2.9 (1.1, 7.9)]. Households with a cat or dog had significantly lower odds of detection of PCB-105, PCB-138, and PCB-153 than homes without pets [OR (95% CI) = 0.4 (0.2, 0.8); 0.6 (0.4, 1.0); and 0.5 (0.3, 0.9), respectively]. In general, the multivariable logistic models in Table 3 were only moderately effective at predicting PCB detection (model max-rescaled r^2 ranged from 0.07 to 0.24 for the 6 PCB models).

Multivariable linear models of PCB loadings among residences with detectable levels of the respective PCBs are shown in Table 4. Residences built prior to 1980 had significantly higher loadings of PCB-118, PCB-138, and PCB-153 compared to newer homes [proportional increase (95% CI) = 2.8 (1.4, 5.9); 1.7 (1.0, 2.8); and 2.3 (1.4, 4.0), respectively]. Carpet replacement was consistently associated with lower PCB loadings, but the results were not statistically significant. Floor replacement was associated with lower PCB loadings and results were significant for PCB-180 [proportional increase (95% CI) = 0.5 (0.2, 1.0)]. Households in more densely populated census blocks had higher PCB-118 loadings [proportional increase (95% CI) = 1.2 (1.0, 1.5), per 2000 person/km2 increase in population density]. Households in which residents did not regularly remove their shoes upon entering the home had significantly higher loadings of PCB-118, PCB-138, and PCB-153 [proportional increase (95% CI) = 2.1 (1.1, 4.1); 2.3 (1.4, 3.7); 2.1 (1.3, 3.4), respectively]. Households with a resident employed as an electrician, lineman, or cable puller (N = 12) had significantly higher PCB-105 loadings in their residential dust than households with no resident employed in these occupations [proportional increase (95% CI) = 12 (2.0, 73)]. Pet ownership was consistently associated with lower PCB loadings, but the effect was not statistically significant. The multivariable linear models in Table 4 were only moderately effective at predicting PCB loadings (model r^2 ranged from 0.10 to 0.21 for the 4 PCBs).

Discussion

Compared to previous studies that collected residential dust from homes in California from 2003–2005, from homes in Texas in 2006, and from homes in Wisconsin in 2008, we report comparable, but slightly lower PCB concentrations [*e.g.*, median PCB-138 concentration of 2 ng/g in our study compared to median of 5 ng/g from Whitehead *et al.*[28], median of 7 ng/g from Harrad *et al.*[5], and geometric mean of 7 ng/g (combined PCB-138/PCB-163) from Knobeloch *et al.*[29]]. Several factors associated with PCB levels in our study have been suggested as potential determinants of residential-dust PCB levels by previous investigators, including residence and carpet age,[6, 14, 18, 29] occupational PCB exposures,[14] resident shoe removal,[30] and pet ownership.[18] We also identified the frequency of vacuum cleaning and neighbourhood population density as two additional determinants of PCB levels in residential dust.

Investigators have observed elevated PCB concentrations in dust from older residences.[6, 29] Likewise, we found that residential construction date (pre- or post-1980) was the strongest predictor of PCB contamination in the residential dust samples from the NCCLS. Since U.S. regulations ended the production and distribution of PCBs in 1979,[2] homes built before 1980 have a greater potential for historic PCB contamination via indoor primary sources than more recently constructed residences. The first step in reducing residential exposure to PCBs would be to identify and remove primary sources of PCB emissions in the home. While we did not identify specific items as PCB sources in this study, potential sources of PCBs in homes built before 1980 include PCB-contaminated consumer products, such as fluorescent light ballasts, refrigerators, televisions, carpet pads, and air conditioners.[11–13, 31] Based on the average lifetime of these products[17] (*e.g.* 20-year lifetime for a refrigerator), pre-1980 consumer items were likely removed from most homes prior to dust collection (2001-2006). However, PCB-contaminated construction materials, such as paint, ceiling tiles, insulation, building joint caulk, floor finish, and roofing material may still be present in homes built before 1980.[3, 16, 32] Moreover, any of these PCB-containing items could contaminate dust in carpets or on household surfaces, creating long-lasting secondary sources of PCBs. As such, in addition to the identification and removal of primary PCB sources, a complete remediation strategy for homes containing PCBs would include the removal of secondary sources of PCBs as well.

Investigators have found that concentrations of PCBs in dust are correlated with floor and carpet age,[14, 18] suggesting that PCBs can accumulate on these surfaces over time. We observed modest, yet statistically significant, reductions in the probability of PCB detection associated with recent carpet replacement and non-significant reductions in PCB loadings associated with carpet replacement. These results suggest that it may be possible to reduce PCB contamination in the home by removing surfaces that collect dust (*e.g.*, an old carpet).

While households reporting recent carpet replacement were less likely to have detectable PCBs and were likely to have lower PCB loadings, many households that reported recent carpet replacement still had detectable levels of PCBs in carpet dust (*e.g.*, PCB-153 was detected in 49% of homes with a recent carpet replacement). Seemingly, in many instances, when an old carpet was removed, its replacement became contaminated with PCBs. Indeed, previous investigators have reported that to remediate homes contaminated by the pesticide methyl parathion, it was necessary to remove not only the surfaces treated by the pesticide, but draperies, furniture, baseboards, dry wall, and ceilings as well.[33] Likewise, semi-volatile chemicals can equilibrate between many household surfaces including draperies, furniture, or walls[33, 34] and PCBs from these surfaces may contaminate new carpets. Hence, complete PCB removal may require the removal of primary PCB sources and the simultaneous replacement of several indoor surfaces.

Investigators have reported reductions of 50% or more in dust and lead loadings measured on window sills and in carpets following a vigorous dust clean-up intervention in which floors and carpets were vacuumed with a high-efficiency particle accumulating vacuum cleaner and walls, horizontal surfaces, and uncarpeted areas of floor were wet-wiped or mopped with detergent solution.[35] We observed modest, yet statistically significant, reductions in the probability of PCB detection associated with frequent vacuum cleaning. However, it should be noted that while frequent vacuum cleaning may reduce PCB levels in carpet dust, vacuum cleaning may disperse dust particles and increase dust exposures for the vacuum operator,[36] thus, increasing exposure to PCB-contaminated dust.

Rudel *et al.*[3] reported that certain wood floor finishes from the 1950s and 1960s can be important sources of PCB contamination in homes, particularly if these floors are subsequently sanded or refinished, releasing floor particles to the environment. We observed that residents who reported floor replacement had an increased likelihood of PCB-138 and PCB-153 detection, but we also observed that floor replacement was associated with lower PCB-180 loadings.

Occupational contaminants, including pesticides[37] and lead[38], have been shown to enter the residential environment via dusty skin, clothing, and shoes. In their analyses of dust from 34 homes, Vorhees *et al.*[14] noted that the two highest PCB concentrations were found in homes with residents reporting previous occupational exposure to PCBs. Similarly, we observed that a resident's employment in manufacturing, assembly, or industrial operations conferred an increased risk for residential PCB-138 detection, and that employment as an electrician, lineman, or cable puller was associated with higher PCB-118 loadings. In consideration of the small number of residents employed in these occupations in our study population (12 residents employed as an electrician, lineman, or cable puller and 25 employed in manufacturing, assembly, or industrial operations), the uncertainty associated with inferring PCB exposures based on broad job categories, and the fact that occupational associations were not consistent across PCB congeners, we interpret these associations with caution.

Chuang *et al.*[30] reported strong positive correlations between PCB concentrations in house dust and entryway dust from 8 homes, suggesting that PCB-contaminated dust can be tracked inside from the outdoor environment. Previous investigators have reported that pesticide applicators (either professionals or home owners) who removed work[39] or outdoor[40] shoes outside of their home and stored work shoes outside of their home[41] had lower pesticide loadings in their residential dust than their counterparts who wore shoes indoors. Likewise, we observed that residents who usually removed their shoes upon entering the home had lower PCB loadings than residents who did not usually remove their shoes upon entering the home. Since shoes can transport dust[19] and persistent chemicals[42] into the home, shoe removal is one simple strategy to reduce residential PCB contamination.

Investigators reported that dogs transported residues of 2,4-D[40] and diazinon[20] into homes after pesticide lawn applications via their paws and fur, resulting in increased floor pesticide loadings in dust. In contrast, we found that residents owning a dog or cat that slept or lived inside were less likely to have detectable levels of PCBs and likely to have lower PCB loadings. Lee *et al.* also reported that dog ownership was associated with lower PCB levels in residential dust.[18] It has been suggested that animals may constitute an important "sink" for higher chlorinated PCBs in industrialized environments.[43] Since pets are frequently in contact with carpets and floors, they are more likely to be in contact with dust than their human counterparts. Thus, PCBs may be taken up by household pets and may remain stored in their tissues.[44]

Previous investigators have observed higher ambient concentrations of PCBs in urban locations compared to rural ones.[24–26] Population density may be a surrogate for the density of outdoor PCB sources (*e.g.*, transformers) or it may be a surrogate for the density of PCB-contaminated consumer products and construction materials in a neighbourhood (*e.g.*, building joint caulk). We observed that homes in more densely populated census blocks had higher PCB-118 loadings, suggesting that PCB sources outside of the home can be important contributors to PCB contamination in residential dust.

The PCB dust concentrations in the NCCLS residences were all below the 1 ppm action level for PCB remediation in bulk materials (*e.g.*, contaminated soil) required by the U.S. Environmental Protection Agency.[45] However, this reference level was not intended for residential dust and it may not be an appropriate standard, especially in homes with young children. Since young children tend to ingest more dust than adults, they are particularly vulnerable to dust contaminated with PCBs.[5] Indeed, background-level PCB exposures have been associated with increased risk of childhood leukaemia in the NCCLS[7] as well as adverse immunological effects[8] and diminished IQ[10] in young children.

Since the primary focus of the NCCLS is to identify risk factors for childhood leukaemia, our questionnaire and sampling protocol were not designed specifically to identify sources of PCBs or to evaluate the effectiveness of PCB remediation strategies. Our ability to identify factors that impact PCB levels in residential dust was limited by the lack of a detailed survey of household items that may have contained PCB, the lack of outdoor soil samples, and the collection of dust from a single room during a single home visit (*i.e.*, cross-sectional dust sampling protocol).

Future studies should evaluate potential PCB determinants using a longitudinal sampling protocol so that the utility of possible PCB-remediation strategies can be assessed directly. In this way, investigators could observe changes in PCB levels in each residence over time in response to specific activities that occurred between visits (*e.g.*, carpet replacement). It would also be useful to test the effectiveness of PCB removal via the simultaneous replacement of carpets, furniture, and draperies as well as the thorough cleaning of household surfaces (*e.g.*, floors, walls, and ceilings) using test homes that were incidentally contaminated with PCBs.

Our findings must be interpreted with caution, since the potential PCB determinants that we identified had only small effects on the low levels of PCBs found in residential dust in our population. Future studies of PCB determinants could focus on populations with elevated PCB contamination or could improve analytical sensitivity by using a method optimized specifically for PCBs. Finally, a variety of mechanistic experiments should be performed to verify our cross-sectional observations, for example, a future study could measure PCB levels in lint taken from the work clothing of potentially occupationally-exposed individuals.

Conclusions

In summary, we measured levels of 6 PCBs in residential dust collected from 415 California residences from 2001-2006. We observed that residences constructed prior to 1980 had higher residential-dust PCB levels than more recently constructed homes, that outdoor and occupational sources of PCBs may contribute to indoor levels of PCB, and that shoe removal prior to entry may reduce residential PCB levels. Interestingly, we found that households reporting recent carpet removal had lower, but often detectable, levels of PCBs, suggesting that carpet replacement alone may not remove PCB entirely from residential dust. Our ability to identify determinants of residential-dust PCB levels was limited by our cross-sectional dust sampling protocol and lack of a detailed survey of household items that may have contained PCB. Given these limitations and in light of the potential health effects for children exposed to PCB-contaminated dust, additional studies to determine optimal strategies for reducing PCBs in homes are warranted.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Notes and references

1. Beyer A, Biziuk M. Rev Environ Contam Toxicol. 2009; 201:137–158. [PubMed: 19484591]
2. Koppe, G.; Keys, J. The Precautionary Principle in the 20th Century: Late Lessons from Early Warnings. Harremoes, P.; Gee, D.; MacGarvin, M.; Stirling, A.; Keys, J.; Wynne, B.; Guedes Vaz, S., editors. Earthscan Publications Ltd; London: 2002. p. 64-78.
3. Rudel RA, Seryak LM, Brody JG. Environ Health. 2008; 7:2. [PubMed: 18201376]
4. Breivik K, Sweetman A, Pacyna JM, Jones KC. Sci Total Environ. 2007; 377:296–307. [PubMed: 17395248]
5. Harrad S, Ibarra C, Robson M, Melymuk L, Zhang X, Diamond M, Douwes J. Chemosphere. 2009; 76:232–238. [PubMed: 19356786]
6. Colt JS, Severson RK, Lubin J, Rothman N, Camann D, Davis S, Cerhan JR, Cozen W, Hartge P. Epidemiology. 2005; 16:516–525. [PubMed: 15951670]
7. Ward MH, Colt JS, Metayer C, Gunier RB, Lubin J, Crouse V, Nishioka MG, Reynolds P, Buffler PA. Environ Health Perspect. 2009; 117:1007–1013. [PubMed: 19590698]
8. Weisglas-Kuperus N, Patandin S, Berbers GA, Sas TC, Mulder PG, Sauer PJ, Hooijkaas H. Environ Health Perspect. 2000; 108:1203–1207. [PubMed: 11133402]
9. Faroon O, Jones D, de Rosa C. Toxicol Ind Health. 2000; 16:305–333. [PubMed: 11693948]
10. Stewart PW, Lonky E, Reihman J, Pagano J, Gump BB, Darvill T. Environ Health Perspect. 2008; 116:1416–1422. [PubMed: 18941588]
11. U.S. Environmental Protection Agency. Use Authorization for, and Distribution in Commerce of, Non-liquid Polychlorinated Biphenyls (Proposed Rule). 1999; 64(237)
12. Agency for Toxic Substances and Disease Registry (ATSDR). Toxilogical Profile for Polychlorinated Biphenyls. U.S. Department of Health and Human Services, Public Health Service; Atlanta, GA: 2001.
13. Franzblau A, Zwica L, Knutson K, Chen Q, Lee SY, Hong B, Adriaems P, Demond A, Garabrant D, Gillespie B, Lepkowski J, Luksemburg W, Maier M, Towey T. J Occup Environ Hyg. 2009; 6:188–199. [PubMed: 19152164]
14. Vorhees D, Cullen AC, Altshul LM. Environ Sci Technol. 1999; 33:2151–2156.
15. Tan J, Cheng SM, Loganath A, Chong YS, Obbard JP. Chemosphere. 2007; 68:1675–1682. [PubMed: 17490710]

16. Kopp, T. PCBs in the United States: Industrial Use and Environmental Distribution. U.S. Environmental Protection Agency, Office of Toxic Substances; Washington D.C.: 1976. EPA 560/6-76-005
17. Appliance Recycling Information Center. Info Bulletin #5: Major Appliances and PCB Small Capacitors. Appliance Recycling Information Center; Washington, D.C.: 2001.
18. Lee, SY.; Zwica, L.; Knutson, K.; Hong, B.; Chen, Q.; Towey, T.; Gillespe, BW.; Demond, A.; Adriaens, P.; Lepkowski, J.; Franzblau, A.; Garabrat, D. Linear Regression Modeling to Predict Household Dust PCB Congener Concentrations; Dioxin 2007: International Symposium on Halogenated Persistent Organic Pollutants; Tokyo, Japan. 2007. (Abstract)
19. Hunt A, Johnson DL, Griffith DA. Sci Total Environ. 2006; 370:360–371. [PubMed: 16962161]
20. Morgan MK, Stout DM, Jones PA, Barr DB. Environ Res. 2008; 107:336–342. [PubMed: 18448091]
21. Colt JS, Gunier RB, Metayer C, Nishioka MG, Bell EM, Reynolds P, Buffler PA, Ward MH. Environ Health. 2008; 7:6. [PubMed: 18291036]
22. Wolff MS, Camann D, Gammon M, Stellman SD. Environ Health Perspect. 1997; 105:13–14. [PubMed: 9074863]
23. U.S. Census Bureau. 2000 Census of Population and Housing. U.S. Department of Commerce, Economics and Statistics Administration;
24. Harner T, Shoeib M, Diamond M, Stern G, Rosenberg B. Environ Sci Technol. 2004; 38:4474–4483. [PubMed: 15461152]
25. Pozo K, Harner T, Wania F, Muir DC, Jones KC, Barrie LA. Environ Sci Technol. 2006; 40:4867–4873. [PubMed: 16955879]
26. Schuster JK, Gioia R, Sweetman AJ, Jones KC. Environ Sci Technol. 2010; 44:8068–8074. [PubMed: 20883016]
27. Nagelkerke N. Biometrika. 1991; 78:691–2.
28. Whitehead TP, Nuckols JR, Ward MH, Rappaport SM. Emerg Themes Epidemiol. 2012; 9:2. [PubMed: 22439752]
29. Knobeloch L, Turyk M, Imm P, Anderson H. Chemosphere. 2012; 86:735–740. [PubMed: 22104335]
30. Chuang, JC.; Callahan, PJ.; Katona, V.; Gordon, SM. Development and Evaluation of Monitoring Methods for Polycyclic Aromatic Hydrocarbons in House Dust and Track-In Soil. U.S. Environmental Protection Agency; Research Triangle Park, NC: 1994. EPA/600/SR-94/189
31. Seidel U, Schweizer E, Schweinsberg F, Wodarz R, Rettenmeier AW. Environ Health Perspect. 1996; 104:1172–1179. [PubMed: 8959406]
32. Herrick RF, McClean MD, Meeker JD, Baxter LK, Weymouth GA. Environ Health Perspect. 2004; 112:1051–1053. [PubMed: 15238275]
33. Clark JM, Bing-Canar J, Renninger S, Dollhopf R, El-Zein J, Star D, Zimmerman D, Anisuzzaman A, Boylan K, Tomaszewski T, Pearce K, Yacovac R, Erlwein B, Ward J. Environ Health Perspect. 2002; 110(Suppl 6):1061–1070. [PubMed: 12634141]
34. Petrick L, Destaillats H, Zouev I, Sabach S, Dubowski Y. Phys Chem Chem Phys. 2010; 12:10356–10364. [PubMed: 20582338]
35. Rhoads GG, Ettinger AS, Weisel CP, Buckley TJ, Goldman KD, Adgate J, Lioy PJ. Pediatrics. 1999; 103:551–555. [PubMed: 10049955]
36. Knibbs LD, He C, Duchaine C, Morawska L. Environ Sci Technol. 2012; 46:534–542. [PubMed: 22084932]
37. Curl CL, Fenske RA, Kissel JC, Shirai JH, Moate TF, Griffith W, Coronado G, Thompson B. Environ Health Perspect. 2002; 110:A787–92. [PubMed: 12460819]
38. Czachur M, Stanbury M, Gerwel B, Gochfeld M, Rhoads GG, Wartenberg D. Am J Ind Med. 1995; 28:289–293. [PubMed: 8585525]
39. Lozier MJ, Curwin B, Nishioka MG, Sanderson W. J Occup Environ Hyg. 2012; 9:289–297. [PubMed: 22506545]
40. Nishioka MG, Lewis RG, Brinkman MC, Burkholder HM, Hines CE, Menkedick JR. Environ Health Perspect. 2001; 109:1185–1191. [PubMed: 11713005]

41. Harnly ME, Bradman A, Nishioka M, McKone TE, Smith D, McLaughlin R, Kavanagh-Baird G, Castorina R, Eskenazi B. Environ Sci Technol. 2009; 43:8767–8774. [PubMed: 19943644]
42. Fenske RA, Lu C, Barr D, Needham L. Environ Health Perspect. 2002; 110:549–553. [PubMed: 12003762]
43. Harrad SJ, Sewart AP, Alcock R, Boumphrey R, Burnett V, Duarte-Davidson R, Halsall C, Sanders G, Waterhouse K, Wild SR, Jones KC. Environ Pollut. 1994; 85:131–146. [PubMed: 15091669]
44. Storelli MM, Storelli A, Barone G, Franchini D. Sci Total Environ. 2009; 408:64–68. [PubMed: 19836059]
45. U.S. Environmental Protection Agency. Polychlorinated Biphenyl (PCB) Site Revitalization Guidance Under the Toxic Substances Control Act (TSCA). 2005 OPPT/2004/0123.

Table 1

Summary statistics for 6 PCBs measured in residential dust collected from 415 households participating in the Northern California Childhood Leukaemia Study from 2001–2006.

Congener	Detected, N	Detected, %	Concentration, ng/g					Loading, ng/m^2			
			Detection Limit	Median	75^{th} Percentile	95^{th} Percentile	Maximum	Median	75^{th} Percentile	95^{th} Percentile	Maximum
PCB-105	51	12	1	<1	<1	10	68	< LOD[a]	< LOD	11	530
PCB-118	133	32	1	<1	4.1	18	100	< LOD	1.6	35	960
PCB-138[b]	222	54	1	2.2	6.7	31	200	0.7	6.5	58	620
PCB-153	217	52	1	1.3	5.5	21	270	0.3	4.9	52	760
PCB-170	38	9.2	2	<2	<2	7.3	93	< LOD	< LOD	7.4	240
PCB-180	161	39	2	<2	3.9	13	150	< LOD	3.1	39	480

[a]LOD = Limit of detection;

[b]*N* = 414 for PCB-138 due to chemical interference during GC-MS analysis.

Table 2

Summary statistics for 6 PCBs measured in residential dust collected from 415 households participating in the Northern California Childhood Leukaemia Study from 2001–2006, by residence construction date.

Congener	Residence built prior to 1980					Residence built since 1980				
	Residences with PCB detected, N	Residences with PCB detected, %	Loading ng/m^2			Residences with PCB detected, N	Residences with PCB detected, %	Loading ng/m^2		
			Median	75th Percentile	95th Percentile			Median	75th Percentile	95th Percentile
PCB-105	26	13	<LOD[a]	<LOD	14	15	9.1	<LOD	<LOD	4.4
PCB-118	91	46	<LOD	6.3	96	30	18	<LOD	<LOD	5.3
PCB-138[b]	133	68	2.7	13	150	61	37	<LOD	2.4	16
PCB-153	139	71	2.8	12	94	52	32	<LOD	0.9	14
PCB-170	26	13	<LOD	<LOD	14	7.0	4.3	<LOD	<LOD	<LOD
PCB-180	109	55	1.0	5.0	62	33	20	<LOD	<LOD	15

[a] LOD = Limit of detection;

[b] *N* = 414 for PCB-138 due to chemical interference during GC-MS analysis.

Table 3

Multivariable logistic regression results for potential determinants of the odds of PCB detection in 415 Northern California Childhood Leukaemia Study residences (2001–2006).

Determinant	Logistic regression odds ratio (95% C.I.)					
	PCB-105	**PCB-118**	**PCB-138**	**PCB-153**	**PCB-170**	**PCB-180**
Residence built prior to 1980	1.7 (0.8, 3.3)	4.3 (2.5, 7.2)*	3.5 (2.1, 5.6)*	6.0 (3.6, 10)*	3.4 (1.4, 8.0)*	4.9 (2.9, 8.1)*
Replaced carpet within the past 5 years	0.5 (0.3, 0.9)*	0.8 (0.5, 1.3)	0.7 (0.4, 1.1)	0.6 (0.4, 0.9)*	1.0 (0.5, 2.1)	0.6 (0.4, 1.0)*
Replaced flooring in home	1.0 (0.4, 2.6)	1.5 (0.8, 2.8)	1.9 (1.0, 3.6)*	2.3 (1.2, 4.5)*	1.0 (0.3, 2.6)	1.7 (0.9, 3.1)
Replaced roof in home	0.5 (0.1, 2.0)	0.9 (0.4, 1.9)	0.7 (0.3, 1.7)	0.6 (0.3, 1.4)	0.6 (0.2, 2.4)	0.7 (0.3, 1.6)
Remodelled sampled room	0.9 (0.5, 1.7)	1.0 (0.6, 1.6)	1.0 (0.7, 1.6)	1.1 (0.7, 1.7)	1.3 (0.7, 2.7)	0.9 (0.5, 1.3)
Regularly vacuum at least once a week	0.7 (0.4, 1.5)	0.5 (0.3, 0.9)*	0.7 (0.4, 1.2)	0.4 (0.2, 0.7)*	0.9 (0.4, 2.0)	0.6 (0.4, 1.1)
Population density[a], persons/km^2	1.0 (0.8, 1.2)	0.9 (0.8, 1.1)	1.1 (0.9, 1.3)	1.0 (0.9, 1.1)	1.0 (0.9, 1.2)	1.1 (0.9, 1.2)
Resident employed as electrician[b]	2.9 (0.7, 12)	0.8 (0.2, 2.9)	0.5 (0.1, 1.7)	0.7 (0.2, 2.6)	1.9 (0.4, 9.4)	1.0 (0.3, 3.3)
Resident employed in industrial operation[c]	1.0 (0.3, 3.8)	0.9 (0.4, 2.3)	2.9 (1.1, 7.9)*	1.1 (0.5, 2.7)	1.9 (0.6, 6.0)	1.0 (0.4, 2.4)
Residents do not remove their shoes	1.5 (0.8, 3.0)	1.5 (0.9, 2.5)	1.0 (0.6, 1.6)	1.0 (0.6, 1.6)	0.9 (0.4, 1.9)	1.3 (0.8, 2.2)
Resident has cat or dog in home	0.4 (0.2, 0.8)*	0.7 (0.4, 1.1)	0.6 (0.4, 1.0)*	0.5 (0.3, 0.9)*	0.8 (0.4, 1.6)	0.8 (0.5, 1.3)

*Indicates logistic regression coefficient *p*-value < 0.05; Model max-rescaled r^2 was 0.07, 0.15, 0.16, 0.24, 0.07, and 0.18 for PCBs 105, 118, 138, 153, 170, and 180, respectively;

[a]Odds ratio for an increase in population density of 2000 persons/km^2;

[b]Includes any resident employed as an electrician, lineman, or cable puller;

[c]Includes any resident employed in manufacturing, assembly, or industrial operation.

Table 4

Multivariable linear regression results for loadings (ng/m^2) of specific PCBs in Northern California Childhood Leukaemia Study residences (2001–2006) with detectable levels of PCB.

Determinant	**Proportional increase (95% C.I.)**			
	PCB-118, *N* = 133	**PCB-138, *N* = 221**	**PCB-153, *N* = 216**	**PCB-180, *N* = 161**
Residence built prior to 1980	2.8 (1.4, 5.9)*	1.7 (1.0, 2.8)*	2.3 (1.4, 4.0)*	1.3 (0.7, 2.5)
Replaced carpet within the past 5 years	0.8 (0.4, 1.4)	0.8 (0.5, 1.2)	0.7 (0.5, 1.2)	0.7 (0.4, 1.2)
Replaced flooring in home	0.8 (0.3, 1.6)	0.8 (0.4, 1.4)	0.8 (0.4, 1.4)	0.5 (0.2, 1.0)*
Replaced roof in home	0.9 (0.3, 2.5)	0.9 (0.4, 2.0)	0.8 (0.4, 1.8)	1.2 (0.5, 3.1)
Remodelled sampled room	0.8 (0.4, 1.5)	0.9 (0.6, 1.4)	0.9 (0.6, 1.4)	1.6 (0.9, 2.8)
Regularly vacuum at least once a week	1.3 (0.7, 2.4)	0.9 (0.6, 1.5)	0.9 (0.5, 1.4)	0.8 (0.5, 1.5)
Population density[a], persons/km^2	1.2 (1.0, 1.5)*	1.0 (0.9, 1.1)	1.0 (0.9, 1.1)	1.0 (0.9, 1.1)
Resident employed as electrician[b]	12 (2.0, 73)*	1.2 (0.3, 5.1)	1.7 (0.4, 6.6)	3.1 (0.7, 14)
Resident employed in industrial operation[c]	0.7 (0.2, 2.4)	1.0 (0.5, 2.2)	0.9 (0.4, 2.3)	0.9 (0.3, 2.5)
Residents do not remove their shoes	2.1 (1.1, 4.1)*	2.3 (1.4, 3.7)*	2.1 (1.3, 3.4)*	1.2 (0.7, 2.1)
Resident has cat or dog in home	0.6 (0.3, 1.1)	0.8 (0.5, 1.2)	0.7 (0.4, 1.2)	0.7 (0.4, 1.3)

[*] Indicates linear regression coefficient *p*-value < 0.05; Model r^2 was 0.21, 0.10, 0.11, and 0.10 for PCBs 118, 138, 153, and 180, respectively;

[a] Proportional increase per each increase in population density of 2000 persons/km^2;

[b] Includes any resident employed as an electrician, lineman, or cable puller;

[c] Includes any resident employed in manufacturing, assembly, or industrial operation.