Journal of Exposure Analysis and Environmental Epidemiology (2000) 10, 662–671

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Strategies for assessing children's organophosphorus pesticide exposures in agricultural communities

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Children can be exposed to pesticides from multiple sources and through multiple pathways. In addition to the standard pathways of diet, drinking water and residential pesticide use, children in agricultural communities can be exposed to pesticides used in agricultural production. A research program on children and pesticides was established at the University of Washington (UW) in 1991 and has focused on two major exposure pathway issues: residential proximity to pesticide-treated farmland and transfer of pesticides from the workplace to the home (paraoccupational or take-home exposure). The UW program selected preschool children of agricultural producers and farm workers in the tree fruit region of Washington state as a population that was likely to have elevated exposures from these pathways. The organophosphorus (OP) pesticides were selected as a common class of chemicals for analysis so that issues of aggregate exposure and cumulative risk could be addressed. This paper provides an overview of key findings of our research group over the past 8 years and describes current studies in this field. Soil and housedust concentrations of OP pesticides were elevated in homes of agricultural families (household members engaged in agricultural production) when compared to non-agricultural reference homes in the same community. Dialkyl phosphate metabolites of OP pesticides measured in children's urine were also elevated for agricultural children when compared to reference children and when compared to children in the Seattle metropolitan area. Proximity to farmland was associated with increased OP pesticide concentrations in housedust and OP pesticide metabolites in urine. Current studies include a community-based intervention to reduce parental transfer of pesticides from the workplace, and a systematic investigation of the role of agricultural spray drift in children's exposure to pesticides. *Journal of Exposure Analysis and Environmental Epidemiology* (2000) **10,** 662–671.

Keywords: *agriculture, children, exposure assessment, housedust, organophosphorus pesticides, urinary metabolites.*

Introduction

The potential health risks associated with exposure of children to pesticides have received increased attention with the passage of the Food Quality Protection Act of 1996 and with new federal emphasis on children's health (U.S. Environmental Protection Agency, 1997). Current efforts to characterize such exposures within a risk assessment framework have focused primarily on exposures of the general population. Definitions of specific subpopulations are currently restricted to age categories (e.g., children and adults) and occupation (e.g., pesticide handlers, agricultural reentry workers). However, children in farming communities can also be viewed as a definable subpopulation because it is known that pesticide use patterns in such communities differ from those in metropolitan and other rural areas. The U.S. Environmental Protection Agency (EPA) recognizes that these children are likely to have a different exposure profile than those in the general population, and has devoted resources to promote research on such populations, including the studies reported here (U.S. Environmental Protection Agency, 1999). There is a clear need to develop appropriate methods to evaluate exposures in these children.

Research on children and pesticides began at the University of Washington (UW) in 1991. The UW program was developed within a public health research model that employs epidemiological and surveillance approaches to risk characterization. The UW program has been guided by four principles: (1) focus research on high-risk populations; (2) evaluate exposure to a common class of chemicals; (3) measure multiple exposure pathways; and (4) identify opportunities for community-based intervention.

Abbreviations: DEP, diethyl phosphate; DETP, diethylthio phosphate; DEDTP, diethyldithio phosphate; DMP, dimethyl phosphate; DMTP, dimethylthio phosphate; DMDTP, dimethyldithio phosphate; EPA, U.S. Environmental Protection Agency; GPS, global positioning system; LIDAR, light detection and ranging; OP, organophosphorus; UW, University of Washington; WIC, Women, Infants, and Children program; g, gram ; l, liter; ml, milliliter; ng, nanogram; μg, microgram

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Received 3 December 1999; accepted 17 July 2000.

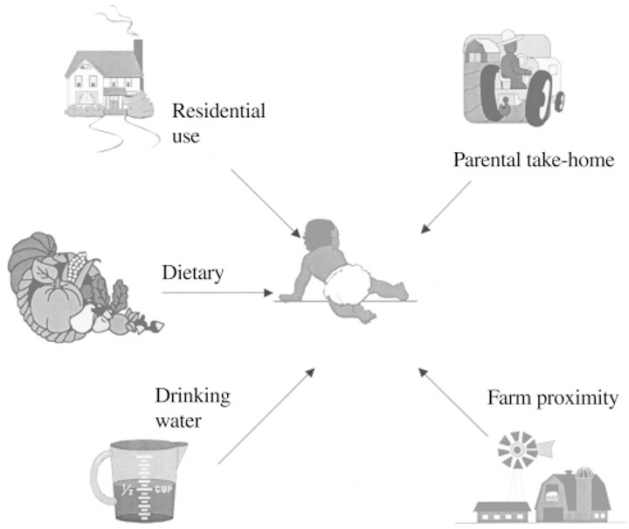

Figure 1. Pesticide exposure pathways for children in agricultural communities. The three traditional pathways of drinking water, diet, and residential use are shown on the left of the figure. Two additional pathways relevant to farm children — farm proximity and parental take-home — are shown on the right.

High-risk populations can be defined as groups which are either more highly exposed to an environmental agent or more susceptible to its effects (Ashford et al., 1990). Preschool children of agricultural producers and farm workers appear to meet both of these criteria; children are considered potentially vulnerable to environmental agents due to developing organ systems, and children in farm communities are likely to receive greater pesticide exposures than other children.

The organophosphorus (OP) pesticides were selected as an important class of chemicals that could be evaluated simultaneously. The integration of such exposures *via* common biomarkers is also possible. They have since been designated as a class of compounds that act by a common mechanism (Mileson et al., 1998), and have been selected by EPA for cumulative risk evaluation (International Life Sciences Institute, 1999; U.S. Environmental Protection Agency, 1999).

The OP pesticides are widely used in agriculture, but are also used in residential settings for pest control. In outdoor settings, OP pesticides are relatively non-persistent as they are degraded by natural and microbiological actions. However, when used indoors or as a part of structural treatments, these compounds can remain stable for extended periods of time (i.e., months to years). EPA currently considers children's exposure to be characterized by three pathways: diet, drinking water, and residential use. In our studies, we have hypothesized that children in agricultural communities receive additional exposures from living near agricultural pesticide use and because of their parents' occupation. We have designated these additional exposure sources as the "farm proximity pathway" and the "parental take-home pathway" (Figure 1). Thus, children in agricultural communities have a more complex aggregate exposure profile than other children, as well as the potential for exposure to multiple OP compounds.

Methods

Sampling Frame — Study Design

A major challenge in the conduct of population-based exposure assessment studies is the definition of a sampling frame. Most sampling frames are geographical and are often based on existing database definitions; e.g., census data or political jurisdictions such as states or counties. Ideally, a probabilistic sample can be drawn from a well-defined sampling frame so that results can be generalized to the entire population within the frame. The current National Human Exposure Assessment Survey is a good example of such an approach (Callahan et al., 1995). However, the definition of "agricultural communities" is more problematic. Such communities are widely dispersed and may not conform to census or political boundaries. Also, traditional methods of access to families may not be feasible in such communities. Multiple families may live in residences designed for a single family, and telephone-based sampling methods may miss a significant fraction of the population. In Washington state's agricultural regions, the primary language is Spanish, so bilingual capabilities are essential. Finally, age is an important consideration for a sampling frame directed toward children. Recruitment of children within a relatively narrow age range (e.g., preschool) can

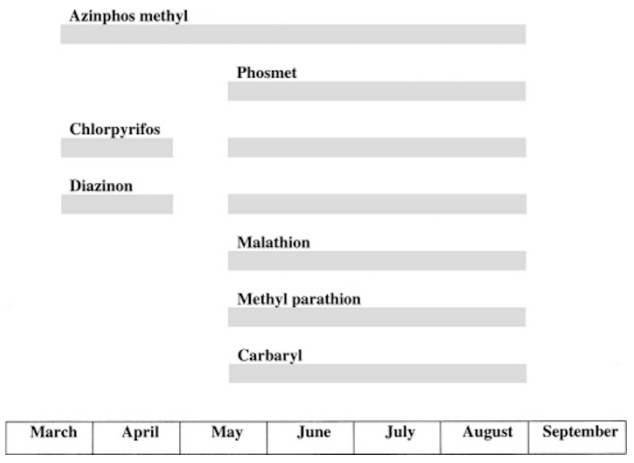

Figure 2. Pesticide use patterns in Washington state apple orchards in 1998. EPA placed new restrictions on azinphos methyl and methyl parathion use in 1999. Carbaryl, a carbamate insecticide (cholinesterase inhibitor), is used as a chemical thinning agent.

be daunting with traditional methods; i.e., the fraction of the population with young children may be relatively small, requiring initial screening of a large sample.

The study area selected for our studies centered around the city of Wenatchee, Washington, considered the heart of apple cultivation in the region. The region consists of an urban zone along the Columbia River, with orchards extending into the surrounding mountain canyons as well as upriver, and newer residential development interspersed with farmland. This entire region — some 150 square miles — was considered the "agricultural community" for this study. Orchard management in the area includes periodic application of several OP pesticides, along with numerous other crop protection chemicals. Figure 2 illustrates the pattern of OP pesticide use in the region's apple orchards across the growing season. Azinphos methyl, chlorpyrifos, and diazinon are commonly used in the early spring and throughout most of the season. Phosmet, malathion, methyl parathion, and carbaryl (a carbamate cholinesterase inhibitor) are used from mid-May through August.

Subject recruitment took place through community organizations, including social service agencies and producer-operated cooperatives. This approach allowed us to quickly identify families with young children. In our 1998 studies, we attempted probability-based sampling based on census tract data, but this approach required a randomized door-to-door contact because most of the population did not have telephone service. We also found that families were

Table 1. Organophosphate pesticides registered in Washington state in 1998[a].

Active ingredient	Alkyl ester structure[b]	Dialkyl phosphate metabolites	Specific OP metabolites
Acephate	dimethyl (S)	–[c]	
Azinphos methyl	dimethyl	DMP, DMTP, DMDTP	
Bensulide	di-2-propyl	–	
Chlorpyrifos	diethyl	DEP, DETP	3,5,6-trichloropyridinol
Coumaphos	diethyl	DEP, DETP	
Diazinon	diethyl	DEP, DETP	under development[d]
Dichlorvos	dimethyl	DMP	
Dicrotophos	dimethyl	DMP	
Dimethoate	dimethyl	DMP, DMTP, DMDTP	
Disulfoton	diethyl	DEP, DETP, DEDTP	
Ethion	diethyl	DEP, DETP, DEDTP	
Ethoprop	dipropyl (S,S)	–	
Ethyl parathion[e]	diethyl	DEP, DETP	*p*-nitrophenol
Fenamiphos	ethyl, 2-propyl (NH)	–	
Fenthion	dimethyl	DMP, DMTP	
Fonofos	ethyl, (ethylphosphono)	–	
Isofenphos	ethyl, 2-propyl (NH)	–	
Malathion	dimethyl	DMP, DMTP, DMDTP	under development
Methamidophos	dimethyl (S)	–	
Methidathion	dimethyl	DMP, DMTP, DMDTP	
Methyl parathion	dimethyl	DMP, DMTP	*p*-nitrophenol
Naled	dimethyl	DMP	
Phorate	diethyl	DEP, DETP, DEDTP	
Phosmet	dimethyl	DMP, DMTP, DMDTP	
Propetamphos	ethyl, methyl (NH)	–	
Sulfotepp	diethyl	DEP, DETP	
Temephos	dimethyl	DMP, DMTP	
Terbufos	diethyl	DEP, DETP, DEDTP	
Tetrachlorvinphos	dimethyl	DMP	
Trichlorfon	methyl (C)	–	

[a]Source: Pesticide Information Center On-Line Databases, Washington State University, updated January 1999 E-mail: {http://picol.cahe.wsu.edu/~plirs/pl-logscreen.html}.
[b](S) means a sulfur substitution for oxygen in the ester; (NH) means amino substitution for oxygen in the ester; (C) means carbon in lieu of ester.
[c]Compound would not be detected in normal dialkyl phosphate analysis.
[d]Under development at Centers for Disease Control and Prevention (D. Barr, personal communication).
[e]No longer registered for use in Washington state, but included as an analyte in WA studies.

wary of strangers approaching their doors and were often unreceptive to our request for participation. This method was ultimately abandoned due to prohibitive cost. Instead, we chose to work with the local WIC (Women, Infants, and Children) clinic and recruited from its clients. This approach assured us access to families with young children and provided a non-threatening means of enrolling participants.

The 1992 and 1995 studies divided households into two groups based on proximity to farmland and parental occupation. "Agricultural" families were defined as households that included at least one adult working on a farm. Adult workers were further classified as pesticide applicators and farm workers in the 1995 study. None of the pesticide applicators in these studies conducted this activity full time; i.e., they were not commercial applicators. Rather, they were responsible for periodic treatment of crops as part of farm management. A smaller "reference" family population was also recruited. These families had no household members working on a farm and lived more than one quarter of a mile (about 400 m) from the farmland. Airblast applications, which are common in tree fruit orchards, are known to produce measurable drift up to a distance of 200 ft or 60 m (Fox et al., 1993).

Children up to 6 years of age were recruited from these families. Often, more than one child per family would participate in the study. Samples from all participants were analyzed, but for statistical purposes only, a single "focus" child from each household was used for most data analyses to remove within-household dependence. The focus child for a household was selected randomly from children with complete urine samples and creatinine measurements.

Environmental Sampling of OP Pesticides

In 1998, 30 OP pesticides were registered for use in Washington state (Table 1). The need to measure multiple OP pesticides in environmental media required the development of new analytical methods by our laboratory. While some laboratories offer screens for a broad panel of pesticides, the accuracy and the precision of such analyses are usually limited for specific compounds. When we began this work in 1991, there were no laboratories prepared to conduct multiple OP residue analysis in media other than food, and even acquiring appropriate standards was problematic. Our 1992 and 1995 studies focused on four OP pesticides used in Washington state orchards — azinphos methyl, phosmet, chlorpyrifos, and ethyl parathion — and included soil and housedust sampling (Simcox et al., 1995; Loewenherz et al., 1997). The 1998 studies expanded the list of target compounds to include diazinon, dichlorvos, malathion, methyl parathion, methidathion, mevinphos, ethoprop, phorat, dimethoate, and terbufos, and sample media were expanded to include 24-h indoor air, indoor and outdoor surface wipes, and drinking water (Table 2). Duplicate 1-day diet samples were analyzed by the Food and Environmental Quality Laboratory at Washington State University. As Table 1 indicates, however, more than half of the OP pesticides registered in Washington State still fell outside these analytical capabilities.

Dialkyl Phosphate Metabolite Analysis

The challenge of evaluating exposure to multiple OP compounds extends to biological monitoring. Of the 30 pesticides listed in Table 1, only five have urinary metabolites that can be considered compound-specific

Table 2. Analytes and sample matrices for 1992, 1995, and 1998 studies.

	House dust	Outdoor soil	Indoor 24-h air	Child hand wipe	Toy wipe	24-h food	Child urine
Azinphos methyl	1992, 1995, 1998	1992, 1998	1998	1998	1998	1998	
Chlorpyrifos	1992, 1995, 1998	1992, 1998	1998	1998	1998	1998	
Diazinon	1998	1998	1998	1998	1998	1998	
Dichlorvos	1998	1998	1998	1998	1998	1998	
Dimethoate						1998	
Ethoprop						1998	
Ethyl parathion	1992, 1995	1992				1998	
Malathion						1998	
Methyl parathion						1998	
Methidathion						1998	
Mevinphos						1998	
Phorat						1998	
Phosmet	1992, 1995, 1998	1992, 1998	1998	1998	1998	1998	
Terbufos						1998	
Dialkyl phosphates						1998	1995, 1998

(D. Barr, Centers for Disease Control, personal communication). The lack of specific metabolites for OP pesticides has made the use of the more generic dialkyl phosphate analysis attractive. The dialkyl phosphate method was first developed for occupational exposure assessments (Shafik et al., 1973) and allowed resolution of dimethyl and diethyl compounds. Six metabolic products are normally measured by gas chromatography following derivatization: dimethyl phosphate (DMP), dimethylthio phosphate (DMTP), dimethyldithio phosphate (DMDTP), diethyl phosphate (DEP), diethylthio phosphate (DETP), and diethyldithio phosphate (DEDTP). Figure 3 illustrates the possible metabolic breakdown products for OP pesticides. OP compounds with a sulfur atom (thio) at the double bond position or linked to the leaving group can appear in urine as either a non-sulfonated metabolite (DMP or DEP) or as a single sulfonated metabolite (DMTP or DETP). OP compounds with sulfur atoms in both positions can produce all three of the dialkyl phosphate metabolites. Not pictured in Figure 3 are the non-sulfonated OP compounds that can produce only DMP or DEP.

It is important to note, however, that even this more generic assay does not necessarily capture all OP compounds. As indicated in Table 1, 8 of 30 OP pesticides have unusual alkyl ester structures, and in the case of trichlorfon, a single carbon is present in lieu of an alkyl ester. Metabolites from these compounds will therefore differ from the six dialkyl phosphates mentioned above. Two laboratories have published methods for the dialkyl phosphate assay recently (Aprea et al., 1996; Moate et al., 1999), and population surveys of these

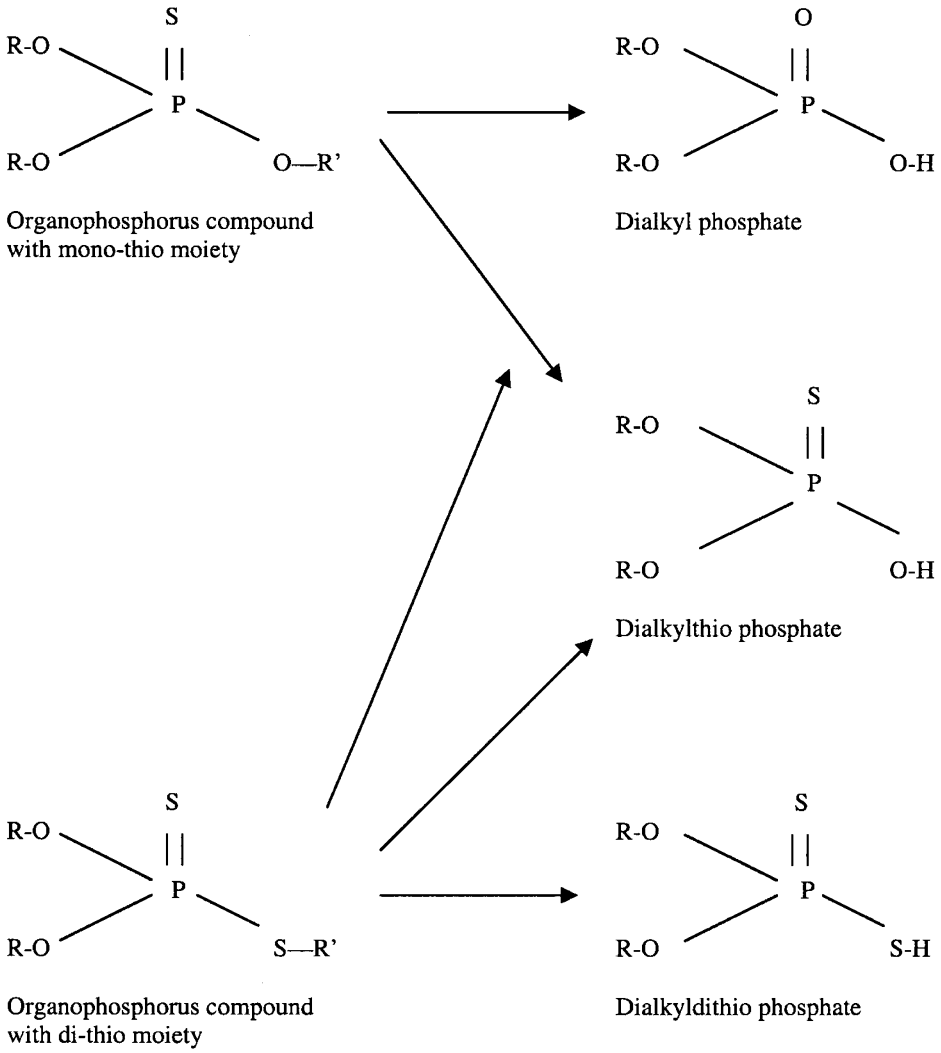

Figure 3. Generic chemical structures of OP pesticides and dialkyl phosphate metabolites. Monothio compounds can produce the first two metabolites. Dithio compounds can produce all three metabolites.

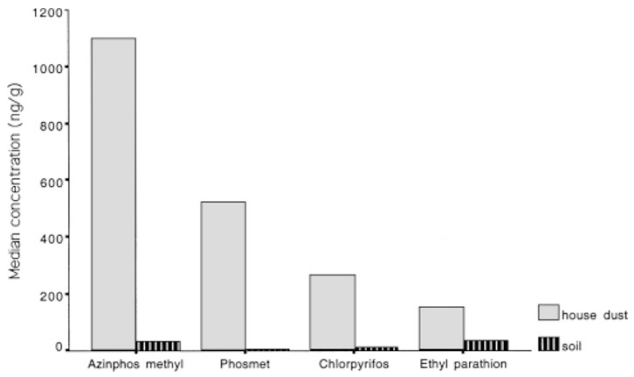

Figure 4. Comparison of median OP pesticide concentrations (ng/g) in housedust and outdoor soil. Samples were collected from homes of 48 agricultural families living in an agricultural community in central Washington state. Data are from Simcox et al. (1995).

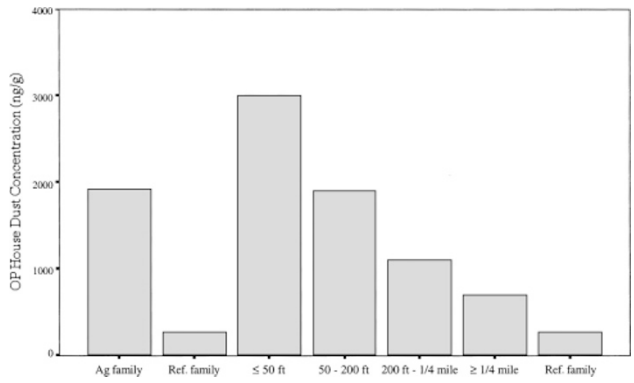

Figure 6. Median dimethyl OP pesticide concentrations (ng/g) in housedust of 62 agricultural and 14 reference families; grouped by proximity to pesticide-treated farmland. Data are from Lu et al. (2000).

metabolites are underway in some countries (Aprea et al., 1996). The limits of detection for the dialkyl phosphates are now in the range of 1–10 μg/l (1–10 ppb), and these methods demonstrate good accuracy and precision. The method described by Moate et al. (1999) has been used since 1995 for our studies.

Results

The 1992 studies included soil and housedust sampling of 48 agricultural families and 11 reference families (Simcox et al., 1995). Figure 4 provides median values for four OP pesticides in housedust and soil. These data indicated that housedust concentrations were significantly higher than soil concentrations for all compounds, and that azinphos methyl and phosmet, both dimethyl compounds, were found at the highest concentrations in housedust. These findings, coupled with knowledge that these children spent most of their time indoors, led to the conclusion that housedust concentration was the most useful indicator of exposure potential for this population. Figure 5 compares the OP pesticide housedust concentrations for agricultural and reference families, demonstrating that children in agricultural households had higher exposure potential than did children in reference families for all four OP compounds measured. These findings confirmed the primary hypothesis of the study and led to further studies that incorporated biological monitoring.

The 1995 studies included housedust sampling in 76 homes and collection of urine samples from 109 children child urine sampling (Lu et al., 2000). An initial report of this study focused on 48 applicator families and 14 reference families and presented DMTP concentrations for children in these households (Loewenherz et al., 1997). Azinphos methyl and phosmet were combined to

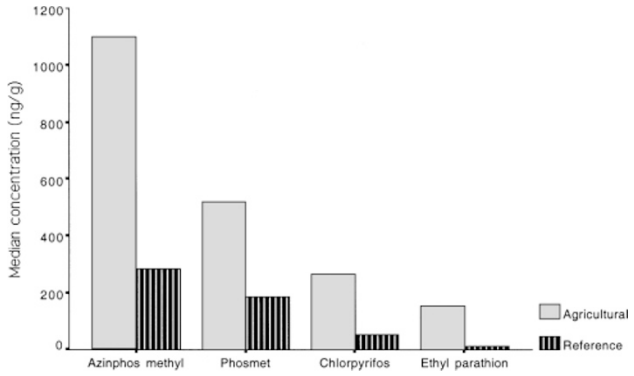

Figure 5. Comparison of median OP pesticide concentrations (ng/g) in housedust between 48 agricultural and 14 reference families in an agricultural community in central Washington state. Data are from Simcox et al. (1995).

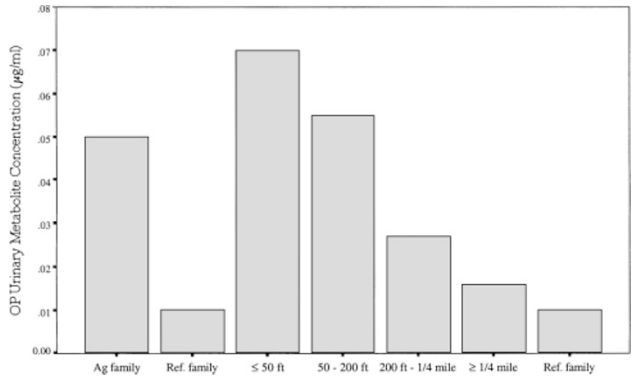

Figure 7. Median dimethyl OP pesticide metabolite levels (μg/ml) in urine of 62 agricultural and 14 reference children; grouped by proximity to pesticide-treated farmland. Data are from Lu et al. (2000).

produce a single dimethyl OP pesticide metric for evaluation of housedust concentrations. Figure 6 indicates a fivefold difference in housedust concentrations for agricultural and reference families. This graph also illustrates the association of housedust concentrations with proximity to farmland (Lu et al., 2000). Figure 7 displays median values for OP urinary metabolites (sum of DMTP and DMDTP). The patterns for metabolite concentrations were very similar to those for housedust concentrations. The difference between children from agricultural and reference families was about four- to fivefold, and metabolite concentration decreased with increasing distance from farmland (Lu et al., 2000). Although not readily discernible in Figures 6 and 7, concentrations for the agricultural population living more than 1/4 mile from farmland were higher than those of the reference population for both housedust and urine samples, indicating a contribution from parental take-home exposure.

The 1998 studies included biweekly urine sample collection from 44 Wenatchee children for 1 year, cross-sectional biomonitoring studies among 96 children in two Seattle metropolitan area communities, and a pilot multipathway exposure analysis in 13 homes. Preliminary results demonstrate that OP pesticide exposure continues year round for most children in the agricultural community, and that there is significant temporal variation in metabolite concentrations; i.e., levels were higher during the spring spraying season. We have also compared the DMTP concentrations reported in our 1995 studies (Loewenherz et al., 1997) with those measured in Seattle (Figure 8) and found that concentrations from Seattle children appear to be similar to those of the Wenatchee reference population.

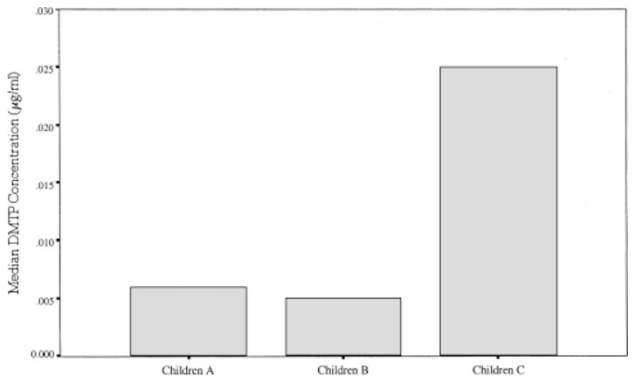

Figure 8. Comparison of median DMTP levels in urine (μg/ml) of 96 children from the Seattle metropolitan area (children A), non-agricultural (children B), and agricultural (children C) families living in an agricultural community in central Washington state. Data for children A are from Knutson (1998). Data for children B and C are from Lu et al. (2000).

The studies reported here have also spawned an attempt to estimate children's doses to OP pesticides. Current risk assessment methods in regulatory agencies such as EPA do not often use data from biological monitoring. Instead, environmental concentration data are linked to behavioral data and route-specific absorption factors to produce estimates of internal dose (U.S. Environmental Protection Agency, 1998). Biologically based dose estimates can be generated from urinary metabolite data if several assumptions related to pharmacokinetics are adopted. Our initial attempt to generate such estimates indicated that a substantial fraction of the children in this study exceeds current EPA reference doses (RfDs) and World Health Organization acceptable daily intake (ADI) values (Fenske et al., 2000). We have also used the soil and housedust data in traditional exposure models to predict urinary metabolite levels and have found that these models underpredict the concentrations observed in these children (Kissel et al., 1999).

Discussion

Study Design Considerations

Field study design provides the framework for sampling strategies, data analysis, and hypothesis testing. As in epidemiologic studies, field studies must adapt to existing characteristics of the study population and environment. In the case of pesticide exposures in agricultural communities, study designs must be modified to account for regional pesticide use patterns, workforce and labor hiring patterns, seasonal factors (e.g., weather, length of growing season), and population characteristics (e.g., accessibility *via* telephone, language, parenting practices).

Several design features in these studies proved helpful in drawing meaningful conclusions from our data. First, the inclusion of a well-defined reference population allowed useful comparisons across groups. Our two criteria for the reference population — no adult household members working in field agricultural production and residence distant from treated farmland — were tied explicitly to the hypothesized exposure pathways: take-home exposure and spray drift. Although sample sizes in these studies were relatively small and exposure measurements variable, we were still able to find significant differences across these groups, indicating that these pathways are important components of children's exposures in agricultural communities. Second, the choice of a "reference" population (a comparison population within the same rural community) rather than a traditional "control" population (e.g., children from the Seattle metropolitan area) allowed examination of pathways specific to crop production rather than a broader

urban–rural comparison. We have subsequently measured urinary metabolites in urban environments, as indicated in Figure 8.

Third, detailed documentation of residential proximity to treated farmland allowed creation of four proximity categories in these studies. Had we used only two distance categories, our findings would have been less striking. Proximity in these studies was determined by self-reports of participants and observations by research staff. In current studies, we are using global positioning system (GPS) technology to document these distances. This more objective measure of distance should decrease misclassification. Still, an accurate definition of "treated farmland" can require extensive investigation. Farm workers may not know the spraying schedules on nearby property, so it may be necessary to interview farm owners or local cooperative extension agents to document pesticide use patterns.

Environmental Concentration Measurements

Soil measurements provided little information on potential OP pesticide exposures for children in these environments, but housedust measurements proved to serve as an index of indoor environmental contamination of agricultural pesticides. The findings of these studies confirm the theory that relatively non-persistent chemicals such as the OP pesticides can be stable in residences. Since the children in these studies also spent most of their waking hours indoors, the pesticides in housedust also represent a potential exposure source. We were unable, however, to demonstrate a strong relationship between housedust concentrations and biological levels in this population. This finding is probably due to several factors. First, the complexity inherent in children's exposures — intermittent contact with surfaces, variable hand-to-mouth behaviors — would tend to decrease an association of this kind. Also, there is relatively high variability in the biologic measures employed (spot urine sampling). Finally, the instrument used for dust sampling (HVS-3) tends to remove particles from deep carpet as well as from surfaces. The concentrations found may not represent chemical available to children during normal residential activity. On the other hand, the HVS-3 does provide a systematic and reproducible method for dust collection. Had we simply collected vacuum cleaner bags from families, as has been proposed recently for some studies, it is unlikely that we would have observed a strong association between concentrations and distance from treated farmland. Housedust sampling methods should conform to standard scientific criteria such as accuracy, precision, and systematic, protocol-based procedures.

Biological Measurements

The use of the generic dialkyl phosphate metabolites for children's exposure has both strengths and limitations. This method captures most OP pesticide exposures and allows source and pathway identification for dimethyl and diethyl compounds. This distinction can be very useful if it is known, for example, that a family uses diethyl chemicals for residential pest control. Also, it is important to recognize that unique metabolites have not been identified for most OP pesticides, so a multi-metabolite screen (analogous to a multiresidue analysis in food) is not currently feasible. The generic assay overcomes this problem.

The primary limitation of this method, of course, is a lack of specificity. New compound-specific assays have been developed by CDC researchers for such OP pesticides as malathion and diazinon, and samples from our current studies will be analyzed for both unique metabolites and dialkyl phosphate metabolites. Biological measures in populations such as the one discussed in this paper can provide important baseline information for evaluating the impact of new policies associated with pesticide use reduction.

Recent Studies of OP Pesticide Exposure

Two papers have been published recently that have examined children's exposure to pesticides in Latin America. The first, an ecological study of Yaqui Indian children in Mexico, found physiological and neurological deficits in preschool children who were presumably exposed to pesticides (Guillette et al., 1998). The study design did not include measurements of pesticide concentrations in the children's environment, nor did it include biological monitoring, so the attribution of the observed effects to pesticides remains speculative. A carefully conducted exposure assessment in conjunction with health outcome testing in this population would clarify the etiology of these effects.

The second study, conducted in rural El Salvador, evaluated OP pesticide exposure in children 8–17 years old (Azaroff, 1999). The study employed a dialkyl phosphate assay that yielded qualitative data, resulting in a classification scheme of no, low, or high metabolite concentrations. These categorical data were compared to self-reported occupational activities and residential pesticide use through logistic regression analysis. The study found a significant association between adult family member and children OP pesticide metabolite concentrations, but the other statistical analysis were confounded by the pooling of adult and child data. These data were clearly not independent, and so should have been separated for these analyses.

Ongoing Studies of OP Pesticide Exposure

Several other OP pesticide exposure studies have been initiated that include children in agricultural communities (Table 3). The most common target pesticides are

Table 3. Current biological monitoring studies of children's OP pesticide exposure studies in the US.

Institution	Location	Population	Target OP pesticides	Data available (years)
University of Minnesota	Minneapolis–St. Paul and rural counties	Urban–rural comparison of 3–12-year-old children	malathion, chlorpyrifos	1–2
University of Minnesota	Minneapolis	SES comparison of K-5 school children	malathion, chlorpyrifos	2–3
University of Arizona	Yuma County, AZ	Farm worker children	Chlorpyrifos, diazinon	1–2
University of Washington	Chelan-Douglas and King Counties, WA	Clinic-based urban–rural comparison	OP pesticides (dialkyl phosphates)	1–2
University of Washington	Yakima County, WA	Children in proximity to farmland	OP pesticides (dialkyl phosphates)	3–5
University of Washington	Yakima County, WA	Farm worker children in 28 communities	OP pesticides (dialkyl phosphates)	3–5
University of California, Berkeley	Monterey County, CA	Clinic-based enrollment during prenatal care	OP pesticides (dialkyl phosphates)	3–5
Oregon Health Sciences University	Oregon	Farm worker children	OP pesticides (dialkyl phosphates)	3–5
National Cancer Institute	Iowa, North Carolina	Subpopulation of farm families from Ag Health Study	Extensive pesticide screen	3–5
ATSDR	Six states	Intervention design+cohort investigation (children)	Methyl parathion	3–5
ATSDR	Texas border area	Epidemiological study of neural tube defects	Methyl parathion, chlorpyrifos, malathion	3–5
ATSDR	US–Mexico border	Comparison of high and low potential exposure (children)	OP pesticides (dialkyl phosphates)	3–5
EPA/ORD	California and North Carolina	Clinic-based high-risk pediatric population	OP pesticides (dialkyl phosphates)	3–5

chlorpyrifos and diazinon, although in some cases, OP pesticides as a class are under investigation, and a dialkyl phosphate metabolite method is proposed. Several of these studies hope to link biologic measures to near-term outcomes such as cholinesterase inhibition. It remains to be seen whether the exposure levels currently detected in child populations are sufficiently high to produce measurable changes in such enzymes or in other biomarkers of effect. Perhaps the most ambitious among these studies is the University of California's prospective evaluation of a group of women and their offspring in an agricultural community. Women are being enrolled at time of pregnancy and their children followed through age 2 (Eskenazi et al., 1999).

The UW studies reviewed here have provided some new insights into the extent of OP pesticide exposure in agricultural communities. It seems clear that children who live near treated farmland or with parents working in agriculture can have higher exposures than other children in the same community, and therefore constitute a high-risk population based on the definition provided at the outset of this paper. The two additional exposure pathways for these agricultural children — farmland proximity and parental take-home — are the focus of evaluation and intervention studies within the UW program. The relationship between pesticide drift and children's exposure is being assessed with novel technologies. Light detection and ranging (LIDAR) technology is being adapted to characterize both sources and downwind features of spray drift. Data from this system should provide a spatial–temporal exposure profile that can be linked with child activity. Child activity, in turn, will be monitored through adaptation of existing GPS technology, documenting the movement of children over time. Biological monitoring will be used to evaluate the accuracy of exposure models derived from these technologies.

In the case of parental transfer of pesticides from workplace to home, the UW program is working with researchers at the Fred Hutchinson Cancer Research Center to develop a community-based intervention to break the take-home exposure pathway. Twenty-four communities in the lower Yakima Valley of Washington state have been enrolled in this study. Adult and child urine samples, as well as housedust and vehicle dust samples, were collected from about 200 households in 1999 to provide baseline data for the intervention. Community-based intervention activities are being conducted for 2 years, followed by another round of biological and environmental sampling. This study design provides the opportunity to evaluate the effectiveness of the intervention with objective measures of exposure.

Further studies that employ both environmental sampling and biological monitoring as measures of OP pesticide exposure are needed to characterize potential health risks for children in agricultural communities. Improved cost-effective methods for the analysis of environmental and biological samples are an important component of such

studies. Risk assessments aimed at children and pesticides need to account for the additional pathways that exist in agricultural communities. One or more well-defined prospective community-based studies of children and pesticides would provide the most meaningful new information in this area.

Acknowledgments

This work was supported by funding from the U.S. Environmental Protection Agency (cooperative agreement no. R819186-01), the Association of Schools of Public Health (cooperative agreement no. S147-14/16), the U.S. Environmental Protection Agency STAR grant program (grant no. 916001537), and the National Institute for Occupational Safety and Health (Pacific Northwest Agricultural Safety and Health Center cooperative agreement no. U07/CCU012926). The authors thank Kathy Yuknavage, I-Chwen Lee, Garland Bellamy, and David Kalman for their assistance in this work.

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