Organophosphorus Pesticide Exposure of Urban and Suburban Preschool Children with Organic and Conventional Diets

Cynthia L. Curl, Richard A. Fenske, Kai Elgethun

Department of Environmental Health, School of Public Health and Community Medicine, University of Washington, Seattle, Washington USA

We assessed organophosphorus (OP) pesticide exposure from diet by biological monitoring among Seattle, Washington, preschool children. Parents kept food diaries for 3 days before urine collection, and they distinguished organic and conventional foods based on label information. Children were then classified as having consumed either organic or conventional diets based on analysis of the diary data. Residential pesticide use was also recorded for each home. We collected 24-hr urine samples from 18 children with organic diets and 21 children with conventional diets and analyzed them for five OP pesticide metabolites. We found significantly higher median concentrations of total dimethyl alkylphosphate metabolites than total diethyl alkylphosphate metabolites (0.06 and 0.02 µmol/L, respectively; $p = 0.0001$). The median total dimethyl metabolite concentration was approximately six times higher for children with conventional diets than for children with organic diets (0.17 and 0.03 µmol/L; $p = 0.0003$); mean concentrations differed by a factor of nine (0.34 and 0.04 µmol/L). We calculated dose estimates from urinary dimethyl metabolites and from agricultural pesticide use data, assuming that all exposure came from a single pesticide. The dose estimates suggest that consumption of organic fruits, vegetables, and juice can reduce children's exposure levels from above to below the U.S. Environmental Protection Agency's current guidelines, thereby shifting exposures from a range of uncertain risk to a range of negligible risk. Consumption of organic produce appears to provide a relatively simple way for parents to reduce their children's exposure to OP pesticides. *Key words:* **biological monitoring, dialkylphosphates, diet, organic, organophosphorus pesticides, preschool children, produce.** *Environ Health Perspect* **111:377–382 (2003). doi:10.1289/ehp.5754 available via** *http://dx.doi.org/* **[Online 31 October 2002]**

Reduction of children's risk from pesticides requires an understanding of the pathways by which exposure occurs. Aggregate exposure models that integrate all exposure pathways have been developed by the U.S. Environmental Protection Agency (U.S. EPA) since passage of the Food Quality Protection Act of 1996 (FQPA; 1996). Such models require an understanding of each source, exposure pathway, and exposure route, and they aim, in part, to identify the pathways and routes that are the most significant contributors to children's overall pesticide dose.

Dietary ingestion is one of the pathways by which children are exposed to pesticides (Akland et al. 2000; Berry 1997; ILSI 1999; Thomas et al. 1997). Children eat more food per body mass than adults, and their diets differ from those of adults. These diets are often rich in foods containing higher levels of pesticide residues, such as juices, fresh fruits, and fresh vegetables (National Research Council 1993). Several national programs monitor pesticide levels in the food supply (FDA 1996; USDA 1997), and at least two studies have examined pesticide levels in duplicate diets of children (Fenske et al. 2002; Melnyk et al. 1997). Recent work has indicated that children's diets may contain pesticides at levels above the acute population-adjusted reference dose (Fenske et al. 2002).

Consumption of foods grown organically is often perceived to reduce risk by reducing exposure to pesticide residues (Williams and Hammit 2001). Organic produce is grown without the use of many synthetic agricultural products, including most conventional pesticides (USDA 2001). A recent study of 110 urban and suburban children found measurable levels of organophosphorus (OP) pesticide metabolites in the urine of all children sampled, except for one child whose parents reported buying exclusively organic produce (Lu et al. 2001). This finding suggested that conventionally grown produce might be a primary source of pesticide exposure for urban and suburban children. No studies to date have examined this issue.

Our objective in this study was to compare OP pesticide metabolite levels in the urine of preschool children ages 2–5 years whose diets included either mostly organic or mostly conventional juices, fresh fruits, and fresh vegetables. OP pesticides were selected for analysis because of their widespread use, their reported presence as residues on foods frequently consumed by children, and their acute toxicity (FDA 1996; Fenske et al. 2002; MacIntosh et al. 2001; USDA 1997; WHO 1986).

Methods

Sample population. Subjects were recruited from the entryways of two grocery stores in the Seattle, Washington, metropolitan area: a local consumer cooperative selling a large variety of organic foods and a large retail chain supermarket selling mostly conventional foods. These stores were selected because they tend to serve clientele with similar socioeconomic status (middle to upper-middle class). With permission of the store managers, customers were approached at the store entrances and asked about their interest in the study. Those who had toilet-trained children in the 2–5-year-old age range were asked about their children's diets. Children whose parents stated that their juice, fresh fruit, and fresh vegetable consumption was either nearly all organic or nearly all conventional were eligible for the study. Enrollment was limited to one child per household. On the basis of the population variance and mean urinary dialkylphosphate (DAP) concentrations found in a previous study of pesticide exposure to children in the Seattle metropolitan area (Lu et al. 2001), we calculated that a sample size of 40 would yield a power of 0.80 at a 0.05 significance level.

Subjects agreed to two home visits spaced four days apart. Home visits occurred in June and July 2001. Researchers reiterated the purpose and protocol of the study at the first visit and obtained written consent from each parent and verbal assent from each child. In a few instances, the child was not available during the visit, so the parent obtained the child's assent at a later time. Parents were provided with a detailed study protocol, a food diary form, a urine collection form, and urine collection containers. Urine samples, urine collection forms, and completed food diaries were collected during the second visit, and families were provided

Address correspondence to C.L. Curl, University of Washington, DEH Box 357234, PNASH Center, Health Sciences Building, F-233, 1959 NE Pacific Street, Seattle, WA 98195-7234 USA. Telephone: (206) 616-1958. Fax: (206) 616-2687. E-mail: ccurl@u.washington.edu

We thank C. Lu, J. Yu, and our study participants.

This study was supported primarily by the U.S. Environmental Protection Agency STAR program (R819186). Additional support came from EPA/NIEHS Child Health Center program (R826886/PO1ES09601) and the National Institute for Occupational Safety and Health Agricultural Centers program (U07/CCU012926). Contents are the responsibility of the authors, and do not necessarily represent the official view of these agencies.

Received 9 May 2002; accepted 10 September 2002.

$50 compensation. All procedures were reviewed and approved by the University of Washington Human Subjects Review Committee.

Interviews. Parents were interviewed during the first visit, and information was collected on child age and weight, parental age and occupation, annual family income, home ownership, length of time at the current residence, and housekeeping practices. Parents were also asked about any pesticides used at the current residence. Researchers inquired about residential pesticide use in the home, on the home structure, in the garden, on the lawn, and on pets. Parents were asked how long it had been since the most recent application event in each of these areas and whether the applicator had been someone from the home or a hired professional. Researchers asked to see any products that had been applied and, when available, recorded the product name, U.S. EPA registration number, and date and location of application. Parents were also asked about their child's frequency of thumb sucking, hand washing, and hand-to-mouth activity, as well as the amount of time the child spent outside the home.

Food diaries. Parents were asked to complete a food diary during the two days before and on the day of urine sampling. They recorded type and approximate amount of all food and beverages consumed by their child for breakfast, lunch, dinner, and snacks. They also recorded whether or not each item was organic, determined by the food's label. Parents were instructed to include foods eaten when the child was not in their company (e.g., lunches consumed at day care). Water intake was not recorded.

Juice and fresh produce consumption as recorded by the parents in the food diaries was converted into units of "servings," and number of organic and conventional servings were calculated for each child. The term "produce" here is used to encompass all fresh fruits and vegetables. Servings were calculated according to the U.S. Department of Agriculture's "5 A Day" method for tallying fruit and vegetable intake (USDA 1995). According to this method, fruits usually eaten whole, such as apples, bananas, and peaches, are counted as single servings. For most other produce, raw or cooked, 0.5 cup is counted as one serving. For raw, leafy vegetables, 1 cup constitutes one serving. Servings equal to 0.75 cup are used for vegetable and fruit juices. In the current study, dried, canned, or processed produce was not counted, though these foods are included in the "5 A Day" method. If 75% or more of a child's juice and produce servings were recorded on the food diaries as organic, the child was included in the "Organic" category. If 75% or more of the child's juice and produce servings were recorded as conventional, the child was included in the "Conventional" category. A value of 75% was chosen because preliminary interviews revealed it to be extremely rare for a family to eat 100% organically; alternatively, a cutoff value of 50% might not have resolved the two groups.

Urine collection and analysis. Parents were instructed to collect all urine produced by their child for a 24-hr period, beginning on the morning of the third day following the first visit. Sample collection was not scheduled on days that children spent in day care, and parents were encouraged to practice the urine collection procedure with their child on the preceeding day. To aid in urine collection, parents were provided with a commode specimen collection pan (Baxter Scientific, McGraw Park, IL), nine 250-mL polypropylene bottles (Nalg Nunc International, Rochester, NY), and a large plastic container into which the nine bottles fit (Tupperware, Orlando, FL). Children either urinated into the commode inserts, the contents of which were then poured into a polypropylene bottle, or urinated directly into the bottles. Parents labeled the bottles with the time of the urination event, and each event was captured in an individual bottle. Any missed voids were recorded on the urine collection form.

Urine collection bottles were stored inside the plastic container in the families' refrigerators overnight until researchers retrieved them the following day. Samples were then transported to the University of Washington, where they were processed immediately. Transport time did not exceed 30 min. Individual voids were combined into one 24-hr sample in a 1-L polypropylene container (Nalg Nunc International), and the total volume collected was measured. For each child, we calculated the average volume per void. In instances where parents reported missing samples, we calculated an adjusted total volume by assuming each missed void contained the average volume per void for that child. Samples were aliquoted into three 15-mL test tubes, and all urine was stored at –20°C until analysis.

Urine was analyzed for five DAP metabolites: dimethylphosphate (DMP), dimethylthiophosphate (DMTP), dimethyldithiophosphate (DMDTP), diethylphosphate (DEP), and diethylthiophosphate (DETP), as reported by Moate et al. (1999). The sixth DAP compound, diethyldithiophosphate (DEDTP), was not targeted in this analysis because of analytic difficulties. The limits of detection (LOD) were 1.2 µg/L for DMP and 1.3 µg/L for the other compounds. Urine samples were also analyzed for creatinine concentration. Creatinine concentrations were ascertained using a colorimetric procedure based on the Jaffé reaction (Creatinine Procedure No. 555, Sigma Diagnostics, Dorset, UK). However, because the samples represented full or near 24-hr voids, creatinine adjustment to normalize for hydration was not necessary.

Quality control/quality assurance. Urine samples previously determined to be free of DAP metabolites were taken into the field intermittently during sample collection and were analyzed along with actual samples. Field blanks were not contaminated during transport.

For laboratory quality control and assurance, one blank sample and two spiked samples were analyzed along with six actual samples in each analytic batch. Laboratory duplicates were analyzed for 10% of the samples, and quality control criteria required that there be no more than 15% variation between laboratory duplicates. Calibration curves consisting of a minimum of five fortification levels were run with each batch, and squared correlation coefficients (r^2) were > 0.9999. In addition, the laboratory staff was blinded to the random submission of three blank samples and four duplicate samples. Average variation between the randomly submitted duplicate samples was < 25%.

Data analysis. All samples containing concentrations below the LOD were assumed to have concentrations equal to one-half the LOD. Values were not corrected for recovery efficiency. Total dimethyl molar quantities were calculated according to the formula

$$\begin{aligned}[\text{Dimethyl DAP}] = {} & [\text{DMP}]/125 \\ & + [\text{DMTP}]/141 \\ & + [\text{DMDTP}]/157, \quad [1]\end{aligned}$$

where metabolite concentrations are in units of micrograms per liter and the molecular weights by which they are divided are in units of grams per mole. The distributions of the metabolite levels were not normal, and nonparametric tests including the Wilcoxon matched pairs signed-ranks test for paired samples, Mann-Whitney *U*-test for independent samples, and the binomial probability test for proportions were used to determine significant differences between groups. These analyses were performed using the statistical package STATA (STATA 6, College Station, TX).

Dose estimation. Each child's estimated dimethyl OP pesticide dose was calculated according to the method described by Fenske et al. (2000). Total molar metabolite quantities were multiplied by the adjusted volume of the 24-hr urine sample and the molecular weight of the parent pesticide,

and were divided by the child's body weight according to the formula

$$\text{Dose} = [\text{Dimethyl DAP}] \times \text{Volume} \times \text{MW}_{\text{pesticide}} \times 1/\text{body weight}. \quad [2]$$

Dose units are micrograms per kilograms per day, the metabolite concentrations are in units of micromoles per liter, volume is in liters per day, units for molecular weight are grams per mole, and body weight is measured in kilograms.

Dose estimation using DAP metabolites is complicated by the fact that these metabolites cannot be attributed to specific parent OP pesticides. Because the nearly 40 OP pesticides used in the United States vary widely in toxicity, a meaningful assessment of children's risk cannot be made without reducing the number of OP pesticides considered in the dose estimation. We used three methods to eliminate pesticides unlikely to be responsible for most exposures to this population. First, chemical structures were evaluated, and only pesticides that produced the most commonly occurring metabolite(s) were considered. Second, pesticides not used on fruit and vegetable crops were eliminated. The most and least toxic pesticides fulfilling these two criteria were included in the dose estimation analysis to establish a range of possible doses. Finally, pesticides with the highest use (annual pounds applied) on fruits and vegetables were also included in the dose estimation analysis.

Results

Study participants. Participants originally included 25 children whose parents identified them as eating nearly all organic produce and juice and 18 children identified as eating nearly all conventional produce and juice. However, the food diaries demonstrated that the diets of eight self-identified organic families and one self-identified conventional family were misclassified, at least for this 3-day period. Four of the children had diets reported to be in the organic category, but the food diaries revealed that only 41–65% of the total produce and juice servings consumed were actually organic. These children were not included in further analyses. Four other children had diets that were initially classified as organic, yet < 25% of their total produce and juice servings were organic. These diets were reclassified into the conventional group. Analysis of the food diary of one child whose diet was initially classified as conventional demonstrated that 75% of his produce and juice servings were organic. This child's diet was reclassified into the organic group. Therefore, for the following analyses, 18 diets were considered organic, 21 were considered conventional, and 4 were excluded. Reclassification was completed before receipt of the laboratory results.

Organic and conventional participants did not vary by age or sex: mean ages were 46 and 47 months, respectively; 56% and 57% were male, respectively. Mean body weight for both groups was 17 kg (37 lbs). Families did not differ by home ownership status or by annual income. No differences were found between the two groups regarding child activity and behavior. A similar number of children in each group sucked their thumbs, and comparable frequencies of hand washing and hand-to-mouth activity were reported. Children in the two groups also spent similar amounts of time in and out of the home.

Residential pesticide use. Parents of children with conventional diets were more likely to report some pesticide use while living in their current residence than parents of children with organic diets (86% vs. 56%; binomial probability test, $p < 0.05$), as indicated in Table 1. Parents usually remembered the approximate date of the most recent application event. In most cases, they were also able to recall which product was used, or they had stored the remainder of the product and provided the label information to the researchers. Researchers were then able to determine whether or not the product was an organophosphate. Most of the pesticides reported were not OP pesticides. Frequently reported pesticides included pyrethrins, Round-up (glyphosate), Raid (cyfluthrin), Advantage (imidachloprid), and Frontline (fipronil). Subsequent analysis of residential pesticide use was restricted to products that were either definitely or probably OP pesticides. Seven families with conventional diets and three families with organic diets used OP pesticides, but this difference was not significant (binomial probability test, $p = 0.2$).

Urine collection and analysis. Some parents found it difficult to collect all urine produced by their child over the 24-hr study period. Several of the youngest children wore diapers at night, and even older children had occasional accidents or contaminated the urine samples with feces. Overall, 13 of the parents (33%) collected a full 24-hr sample. Another 15 parents (38%) missed just one void. Six parents (15%) missed two voids, and five parents (13%) missed three voids. On average, children in this study urinated 6.7 times per day, and parents collected an average of 5.7 of these voids. Collection efficiency did not differ by dietary group. After adjustment for missed voids, the average volume collected per child was 570 mL and ranged from 180 to 1,600 mL.

Of the five DAP metabolites targeted for analysis, DMTP was the dominant metabolite (Table 2), found at detectable levels in 87% of all urine samples. Only DETP was found with similar frequency (85%). DMTP concentrations were substantially higher than concentrations of the other four compounds (Wilcoxon matched pairs signed-rank test, $p \leq 0.0001$). Correspondingly, total dimethyl DAP levels were significantly higher than total diethyl DAP levels (medians, 0.06 and 0.02 μmol/L, respectively; Wilcoxon matched pairs signed-rank test, $p < 0.0001$).

Children with organic diets had significantly lower levels of total dimethyl metabolites in their urine than did children with conventional diets (Mann Whitney *U*-test, $p = 0.0003$). Median values differed by a factor

Table 1. Number (%) of families reporting residential pesticide use by time since most recent application and diet status.

Questionnaire item	Home	Structure	Pet	Lawn	Garden	Any use[a]
Reported use of any pesticides						
< 1 month						
Organic[b]	1 (6)	0 (0)	2 (11)	3 (17)	2 (11)	7 (39)
Conventional	3 (14)	1 (5)	2 (10)	3 (14)	6 (29)	10 (48)
> 1 month						
Organic	1 (6)	2 (11)	3 (17)	1 (6)	1 (6)	6 (33)
Conventional	5 (24)	5 (24)	3 (14)	5 (24)	2 (10)	14 (67)
Ever						
Organic	2 (11)	2 (11)	5 (28)	4 (22)	3 (17)	10 (56)*
Conventional	8 (38)	6 (29)	5 (24)	8 (38)	7 (33)	18 (86)*
Reported use of organophosphorus pesticides						
< 1 month						
Organic	1 (6)	0 (0)	0 (0)	0 (0)	0 (0)	1 (6)
Conventional	0 (0)	1 (5)	0 (0)	0 (0)	0 (0)	1 (5)
> 1 month						
Organic	0 (0)	2 (11)	0 (0)	1 (6)	1 (6)	3 (17)
Conventional	2 (10)	4 (19)	0 (0)	0 (0)	0 (0)	6 (29)
Ever						
Organic	1 (6)	2 (11)	0 (0)	1 (6)	1 (6)	3 (17)
Conventional	2 (10)	5 (24)	0 (0)	0 (0)	0 (0)	7 (33)

[a]Number of families reporting any pesticide use; totals do not add across rows because some families used pesticides in more than one area. [b]Organic, $n = 18$; conventional, $n = 21$. *$p < 0.05$ (binomial probability test).

of six (0.03 and 0.17 µmol/L, respectively), and mean values differed by a factor of nine (0.04 and 0.34 µmol/L, respectively). These results were unchanged when participants who reported residential use of OP pesticides were excluded (data not shown). Diethyl metabolite levels were not different across the two groups (Mann Whitney *U*-test, $p = 0.13$).

Dose estimation. Because DMTP was the dominant metabolite found in child urine, dose estimation was limited to OP pesticides producing this metabolite. DMTP is created from the metabolism of OP pesticides containing two methyl esters and one or two thio groups bonded to a central phosphorous atom, and is a metabolic product of 13 of the 36 registered OP pesticides (CDC 2001; U.S. EPA 1999a). These 13 pesticides are applied to a large variety of crops. Table 3 presents these pesticides along with some of the crops on which they are applied (U.S. EPA 1999b, 1999c, 1999d, 1999e, 1999f, 1999g, 2000a, 2000b, 2000c, 2002). Pesticides are listed in approximate decreasing order of annual pounds applied on fresh produce crops in the United States, and crops are listed in approximate decreasing order of annual weight applied per crop. This is not a complete list of crops to which these pesticides are applied; some of these pesticides are used on up to 50 crops. However, six of the pesticides that produce DMTP are used only on such products as cotton, grain, and livestock or in mosquito control; thus they are not likely contributors to the difference in urinary DAP levels of children with organic or conventional produce consumption.

The remaining seven pesticides vary greatly in toxicity and in annual use patterns. Oxydemeton-methyl has the highest chronic toxicity [daily reference dose (RfD) = 0.13 µg/kg/day] (U.S. EPA 1999e) and malathion has the least (RfD = 24 µg/kg/day) (U.S. EPA 2000a). In terms of annual use, more malathion is applied in the United States than any of the other pesticides (1.3×10^7 lbs), but approximately 90% of this use is on cotton crops to control the boll weevil (U.S. EPA 2000c). The remaining 10% of annual malathion use is split among mosquito control, residential application, and grain and produce application. Thus, less than a million pounds (5×10^5 kg) is used on fruits and vegetables each year. Methyl parathion and dimethoate have the next highest annual application rates (4.2×10^6 and 2.5×10^6 lbs, respectively) (U.S. EPA 1999b, 1999d). However, 90% of the annual use of methyl parathion and more than 60% of the annual use of dimethoate are on cotton, corn, wheat, alfalfa, soybeans, rice, and ornamentals. Twenty percent of the annual use of azinphosmethyl is on cotton, and 4% of the annual use of phosmet is on alfalfa. However, these two pesticides are used primarily on fresh produce: More than 1.7×10^6 lbs (8×10^5 kg) of azinphosmethyl and 9.5×10^5 lbs (4×10^5 kg) of phosmet are applied annually on fresh produce crops in the United States (U.S. EPA 1999f, 1999g). These data indicate that of the OP pesticides producing DMTP, azinphosmethyl and phosmet have the highest annual use on fresh fruits and vegetables.

Individual dimethyl OP pesticide doses were calculated assuming that all exposure came either from oxydemeton-methyl, malathion, azinphosmethyl, or phosmet (Table 4). Doses for children with conventional diets were significantly higher than doses for children with organic diets for all four pesticides (Mann Whitney *U*-test, $p = 0.0002$). If all exposure were assumed to be from oxydemeton-methyl, 88% of the children with organic diets and 100% of the children with conventional diets would exceed the U.S. EPA chronic reference dose.

Table 2. Individual dialkylphosphate metabolite concentrations (µg/L) and total molar concentrations (µmol/L) in the urine of children with organic and conventional diets.

	Individual metabolites (µg/L)					Total molar concentrations (µmol/L)	
Dietary classification	DMP	DMTP	DMDTP	DEP	DETP	Dimethyl	Diethyl
Organic ($n = 18$)							
Median	0.6	2.8	0.7	0.7	2.0	0.03*	0.02
Mean	1.1	4.3	0.8	1.0	2.7	0.04	0.02
SD	1.0	4.3	0.5	0.7	2.7	0.03	0.02
Percent detectable	22	78	11	17	83	–	–
Conventional ($n = 21$)							
Median	0.6	14	2.1	0.7	3.0	0.17*	0.02
Mean	1.9	41	4.8	0.8	4.0	0.34	0.03
SD	2.7	48	10	0.5	3.3	0.38	0.02
Percent detectable	43	95	62	14	86	–	–
Total ($n = 39$)							
Median	0.6#	5.8#	0.7#	0.7#	2.7#	0.06**	0.02**
Mean	1.5	24	3.0	0.9	3.4	0.20	0.03
SD	2.1	40	7.7	0.6	3.1	0.32	0.02
Percent detectable	33	87	38	15	85	–	–

*Dimethyl concentration in conventional diets > dimethyl concentration in organic diets; $p = 0.0003$ (Mann Whitney *U*-test). **Total dimethyl > total diethyl; $p < 0.0001$ (Wilcoxon matched pairs signed-rank test). #Total DMTP > other four metabolites; $p \leq 0.0001$ (Wilcoxon matched pairs signed-rank test).

Table 3. Molecular weights (g/mol), chronic daily reference dose (µg/kg/day), annual application (10^6 lb/year), and common crop type for application for the 13 OP pesticides that metabolize into DMTP.

Pesticide	MW	Chronic RfD[a]	Total annual application[b]	Some of the most common crops for application by approximate quantity of use[c]
Pesticides used on fresh fruit and vegetable crops				
Azinphosmethyl	317	1.5	2.2	Apples, cotton, almonds, pears, peaches, walnuts, potatoes
Phosmet	317	11	1.0	Apples, peaches, walnuts, almonds, pears, alfalfa, nectarines
Dimethoate	229	0.5	2.5	Wheat, alfalfa, cotton, corn, soybeans, lettuce, citrus, apples
Malathion	263	24	13	Cotton, corn, wheat, oats, mosquito control, strawberries
Methyl parathion	263	0.2	4.2	Cotton, corn, wheat, soybeans, rice, apples, apricots
Methidation	302	1.5	0.2	Almonds, oranges, plums/prunes, walnuts, grapes, artichokes
Oxydemeton-methyl	246	0.13	0.2	Broccoli, cauliflower, brussels sprouts, wheat, alfalfa, corn
Pesticides not used on fresh fruit and vegetable crops				
Chlorpyrifos methyl	323	1.0	0.08	Wheat, stored grain, livestock
Pirimiphos methyl	305	0.2	0.01	Stored grain, livestock, sorghum
Fenitrothion	277	1.3	NA[d]	Ant and roach baits – not for food
Dicrotophos	237	0.02	0.3	Cotton
Fenthion	278	0.07	0.03	Livestock, mosquito control
Temephos	447	–	0.03	Mosquito larvacide – not for food

[a]Chronic oral reference dose in units of µg/kg/day (U.S. EPA 1999a, 1999b, 1999c, 1999d, 1999e, 1999f, 1999g, 2000a, 2000b, 2000c, 2002). [b]Annual application in the United States (10^6 lbs/yr). [c]A sampling of the most common crops to which the pesticide is applied (U.S. EPA 1999a, 1999b, 1999c, 1999d, 1999e, 1999f, 1999g, 2000a, 2000b, 2000c, 2002); crops are listed in decreasing order of pesticide use. [d]Fenitrothion is used on 26% of wheat gluten consumed in the United States, nearly all of which is imported from Australia; thus, no information is available on annual pounds applied in the United States (U.S. EPA 2000b).

Conversely, if either malathion or phosmet were assumed to be the source of all exposure, no child from either group would exceed the RfD. However, if azinphosmethyl were the only source, one child with an organic diet (6%) and 11 children with conventional diets (52%) would surpass the RfD.

Discussion

This study demonstrates that dietary choice can have a significant effect on children's pesticide exposure. To our knowledge, no other studies have tested this hypothesis. Our finding that children who consume primarily organic produce exhibit lower pesticide metabolite levels in their urine than children who consume conventional produce is consistent with known agricultural practice, because organic foods are grown without pesticides. Consumption of organic produce represents a relatively simple way for parents to reduce their children's pesticide exposure.

Exposure pathways. Diet appears to have been the primary pathway for OP pesticide exposure for this population. One-third of the conventional diet families and one-sixth of the organic diet families reported some use of OP pesticides for residential pest control. However, residential pesticide use did not appear to confound the analysis; the results were unchanged when participants reporting residential OP pesticide use were excluded. Drinking water is another potential source of pesticide exposure. However, virtually all participants in this study reside in the Seattle metropolitan area and receive their water from a municipal water system. Further, a previous study of OP pesticide exposure in Seattle did not detect residues in drinking water (Kedan 1999).

Dose estimation. Very different conclusions regarding risk can be drawn depending on the pesticide to which the dose is attributed. If a more toxic pesticide is chosen, such as oxydemeton-methyl, nearly all of the estimated daily doses are above the U.S. EPA chronic reference dose. Alternatively, if a less toxic pesticide is chosen, such as phosmet or malathion, none of the daily doses are above the RfD. However, if all exposure is attributed to a relatively toxic and commonly applied pesticide, azinphosmethyl, consumption of organic produce and juice can shift most of the doses from above the RfD to below it. It is unlikely that these doses stemmed from azinphosmethyl exposure alone, but this analysis demonstrates that consumption of organic produce and juice may be able to shift children's exposure from a range of uncertain risk to a range of negligible risk within the context of the U.S. EPA's current risk framework.

Comparison with other populations. A recent study of children in the Seattle metropolitan area reported a median dimethyl DAP concentration of 0.11 µmol/L (Lu et al. 2001). This value is approximately midway between the children with primarily organic diets (0.03 µmol/L) and those with conventional diets (0.17 µmol/L). This finding is consistent with the notion that the 110 children in the previous study represented a mixture of organic and conventional diets.

The Centers for Disease Control and Prevention (CDC) have periodically analyzed biologic samples from the National Health and Nutrition Examination Survey (NHANES). In 1999, the NHANES-III was conducted in 12 locations across the country, and CDC analyzed samples to establish national reference ranges for biomarkers of 27 chemicals (CDC 2001). OP pesticide metabolites were among the chemicals investigated. Urine samples collected from over 700 subjects 6–59 years old were analyzed for six DAPs. In the top 50% of these values (50th percentile and higher), DMTP and DMDTP levels in the urine of children with conventional diets were above the levels in the NHANES population, while DMTP and DMDTP levels in the urine of children with organic diets were lower (Table 5). In contrast, DMP levels in the top 50th percentile of the U.S. population exceeded corresponding levels for children with both organic and conventional diets. However, the magnitude of difference in urinary levels between the study children and the NHANES adult population was much greater for DMTP than for DMP. This suggests that while children with conventional diets may have higher dimethyl OP pesticide exposures than the general population, exposures to children with organic diets may be lower. Diethyl findings are less clear (CDC 2001).

The higher levels found in the urine of children with conventional diets are consistent with the 1993 National Research Council report *Pesticides in the Diet of Infants and Children*, which postulated that children receive proportionately higher pesticide exposure through their diet than do adults (National Research Council 1993). The lower levels found in the urine of children with organic diets support another National Research Council hypothesis, that the predominant route of pesticide exposure for most children is the diet (National Research Council 1993). Our current study suggests that consumption of organic foods may be able to reduce children's exposure levels below those of the general adult population.

Limitations. There are several limitations to this work. First, the 43 children who participated in this study were not necessarily representative of children in the Seattle metropolitan area. A true probability sample of a similar population would provide a stronger basis for generalization of these findings.

Table 4. Dose estimates (µg/kg/day) for each of four organophosphorus pesticides based on attribution of all dimethyl metabolites to each pesticide (conventional > organic, $p = 0.001$).

Pesticide (RfD[a])	Mean	Percentiles 25th	50th	75th	90th	Max
Oxydemeton-methyl (0.13)						
Organic	0.3	0.2	0.2	0.4	0.6	1.2
Conventional	2.2	0.4	1.3	3.2	5.2	7.8
Azinphosmethyl (1.5)						
Organic	0.4	0.2	0.3	0.5	0.8	1.6
Conventional	2.8	0.6	1.7	4.1	6.7	10
Phosmet (11)						
Organic	0.4	0.2	0.3	0.5	0.8	1.6
Conventional	2.8	0.6	1.7	4.1	6.7	10
Malathion (24)						
Organic	0.4	0.2	0.2	0.4	0.6	1.3
Conventional	2.3	0.5	1.4	3.4	5.6	8.3

Max, maximum.
[a]Chronic oral reference doses in units of µg/kg/day (U.S. EPA 1999d, 1999e, 1999f, 1999g, 2000a, 2000c).

Table 5. Comparison of urinary DAP concentrations (µg/L) for children eating conventional and organic diets with NHANES-III data for DAP concentrations in the general U.S. population.

Compounds	Percentiles 25th	50th	75th	90th
DMP				
Organic	<LOD[a]	<LOD	<LOD	2.2
Conventional	<LOD	<LOD	2.2	2.8
NHANES[b]	0.8	1.7	3.8	7.4
DMTP				
Organic	2.5	2.8	4.5	8.8
Conventional	5.8	14	61	93
NHANES[b]	0.7	3.8	9.0	23
DMDTP				
Organic	<LOD	<LOD	<LOD	0.9
Conventional	<LOD	2.1	4.4	5.4
NHANES[b]	<LOD	0.6	2.1	5.4
DEP				
Organic	<LOD	<LOD	<LOD	2.4
Conventional	<LOD	<LOD	<LOD	1.4
NHANES[b]	1.1	1.9	4.9	11
DETP				
Organic	1.5	2.0	3.2	4.1
Conventional	2.1	3.0	4.6	6.5
NHANES[b]	0.6	0.7	1.0	1.5

[a]<LOD equals "less than the limit of detection." For the current study, the LOD for DMP was 1.2 µg/L and for DMTP, DMDTP, DEP, and DETP, the LOD was 1.3 µg/L. For the NHANES study, the LOD for DMP was 0.51 µg/L, for DMTP the LOD was 0.18 µg/L, and for DMDTP, the LOD was 0.08 µg/L (CDC, 2001). [b]Data from NHANES-III as reported by CDC (CDC 2001).

Second, residential pesticide use was assessed based on interview data. In some cases, study participants were unable to cite the specific pesticide that they had applied, and in these instances the pesticide was assumed to be an organophosphate. However, some misclassification may have been introduced by relying on subject recall.

A third limitation of this work was that not all of the samples represented full 24-hr voids. Some parents missed as many as three voids during the collection period, and it is difficult to determine the effect of the missing voids on the overall results. In future studies, it would be useful to require the parents to practice the urine collection procedure with their child before the actual sampling. This was suggested to parents in the current study, and those who reported practicing were more likely to collect all of the samples.

Another limitation concerns the model used for dose estimation. This model assumes that 100% of the absorbed dose of dimethyl OP pesticides is expressed as DMP, DMTP, and DMDTP, which likely leads to an underestimate of the true dose (Fenske et al. 2000). For example, an intravenous dosing study of azinphosmethyl using human volunteers demonstrated that only approximately 70% was actually excreted in urine (Feldmann and Maibach 1974).

The final limitation of this study involves dose attribution; analysis for generic DAP metabolites does not allow for definitive calculation of dose from biological monitoring results. Without the collection of duplicate diets, the specific pesticides responsible for exposure cannot be identified, and a cumulative risk approach to dose estimation cannot reasonably be employed. The goal of the dose estimation procedure used in this study was simply to determine whether or not there was a possibility that the measured exposures could have biological relevance. The difference in dose estimates attributed to either malathion or oxydemeton-methyl reflects the large range of toxicities within the organophosphate class. Dose estimates attributed to azinphosmethyl or phosmet are more likely based on pesticide use patterns, yet it is unlikely that any single pesticide is responsible for all of the exposure. Further, the pesticide use information that was the basis for our analysis is from the United States only. Residues on imported foods may also be an important source (FDA 1996).

Conclusion

This study found that children with primarily organic diets had significantly lower organophosphorus pesticide exposure than did children with primarily conventional diets. Dose estimates generated from pesticide metabolite data suggest that organic diets can reduce children's exposure levels from above to below the U.S. EPA's chronic reference doses, thereby shifting exposures from a range of uncertain risk to a range of negligible risk. Consumption of organic produce represents a relatively simple means for parents to reduce their children's exposure to pesticides.

References

Akland GG, Pellizzari DC, Roberds M, Rohrer M, Leckie JO, Berry MR. 2000. Factors influencing total dietary exposures of young children. J Exp Anal Environ Epidemiol 10:710–722.

Berry MR. 1997. Advances in dietary exposure research at the United States Environmental Protection Agency-National Exposure Research Laboratory. J Exp Anal Environ Epidemiol 7(1):17–37.

CDC. 2001. National Report on Human Exposure to Environmental Chemicals. Atlanta, GA:Centers for Disease Control and Prevention.

FDA. 1996. Food and Drug Administration Pesticide Program Residue Monitoring. Washington, DC:United States Food and Drug Administration.

Feldmann RJ, Maibach HI. 1974. Percutaneous absorption of some pesticides and herbicides in man. Toxicol Appl Pharmacol 28:126–132.

Fenske RA, Kedan G, Lu CA, Fisker-Andersen JA, Curl CL. 2002. Assessment of organophosphorus pesticide exposure in the diets of pre-school children in Washington State. J Expo Anal Environ Epidemiol 12:21–28.

Fenske RA, Kissel JC, Lu C, Kalman DA, Simcox NJ, Allen EH, et al. 2000. Biologically based pesticide dose estimates for children in an agricultural community. Environ Health Perspect 108:515–520.

Food Quality Protection Act of 1996. 1996. Public Law 104–170.

ILSI. 1999. A Framework for Cumulative Risk Assessment. Washington, DC:International Life Sciences Institute Press.

Kedan G. 1999. Comparison of Estimated Aggregate Exposure to Organophosphorus Pesticides with Biomonitoring for Urinary Dialkylphosphate Metabolites Among Children. [Master's Thesis]. Seattle, WA:University of Washington.

Lu C, Knutson DE, Fisker-Andersen J, Fenske RA. 2001. Biological monitoring survey of organophosphorus pesticide exposure among preschool children in the Seattle metropolitan area. Environ Health Perspect 109:299–303.

MacIntosh, DL, Kabiru CW, Ryan B. 2001. Longitudinal investigation of dietary exposures to selected pesticides. Environ Health Perspect 109:1–6.

Melnyk LJ, Berry MR, Sheldon LS. 1997. Dietary exposure from pesticide application on farms in the Agricultural Health Pilot Study. J Expo Anal Environ Epidemiol 7(1):61–80.

Moate TF, Lu C, Fenske RA, Hahne RMA, Kalman DA. 1999. Improved cleanup and determination of dialkyl phosphates in the urine of children exposed to organophosphorus insecticides. J Anal Toxicol 23(4):230–236.

National Research Council. 1993. Pesticides in the Diets of Infants and Children. Washington, DC:National Academy Press.

Thomas KW, Sheldon LS, Pellizzari ED, Handy RW, Roberds JM, Berry MR. 1997. Testing duplicate diet sample collection methods for measuring personal dietary exposures to chemical contaminants. J Expo Anal Environ Epidemiol 7(1):17–36.

USDA. 1995. Nutrition and Your Health: Dietary Guidelines for Americans, 4th ed. Home and Garden Bulletin no. 252. Washington, DC:United States Department of Health and Human Services and Department of Agriculture.

———. 1997. Pesticide Data Program Annual Summary Calendar Year 1997. Washington, DC:United States Department of Agriculture.

———. 2001. United States Department of Agriculture National Organic Program Final Rule. Washington, DC:United States Department of Agriculture.

U.S. EPA. 1999a. Organophosphate Pesticides in Food—A Primer on Reassessment of Residue Limits. Available: http://www.epa.gov/oppsrrd1/op/primer.htm [accessed 17 April 2002].

———. 1999b. Overview of Dimethoate. Available: http://www.epa.gov/oppsrrd1/op/dimethoate/overview.htm [accessed 17 April 2002].

———. 1999c. Overview of Fenthion. Available: http://www.epa.gov/oppsrrd1/op/fenthion/fenthionoverview.pdf [accessed 17 April 2002].

———. 1999d. Overview of Methyl Parathion Refined Risk Assessment. Available: http://www.epa.gov/oppsrrd1/op/methyl_parathion/mp_overview.htm [accessed 17 April 2002].

———. 1999e. Overview of Oxydemeton-Methyl (Metasystox-R®) Revised Risk Assessment. Available: http://www.epa.gov/oppsrrd1/op/oxydemeton-methyl/odm_overview.htm [accessed 17 April 2002].

———. 1999f. Quantitative Usage Analysis for Azinphosmethyl. Available: http://www.epa.gov/oppsrrd1/op/azinphos/azinpho9.pdf [accessed 17 April 2002].

———. 1999g. Quantitative Usage Analysis for Phosmet. Available: http://www.epa.gov/oppsrrd1/op/phosmet/usage.pdf [accessed 17 April 2002].

———. 2000a. Malathion: Revised Chronic Dietary Risk Assessment. Available: http://www.epa.gov/pesticides/op/malathion/rev_chronic.pdf [accessed 17 April, 2002].

———. 2000b. Overview of Fenitrothion Revised Risk Assessment. Available: http://www.epa.gov/oppsrrd1/op/fenitrothion/fenoverview.htm [accessed 17 April 2002].

———. 2000c. Overview of Malathion Risk Assessmentt. Available: http://www.epa.gov/oppsrrd1/op/malathion/overview.htm [accessed 17 April 2002].

———. 2002. Organophosphate Pesticide Tolerance Reassessment and Reregistration. Available: http://www.epa.gov/oppsrrd1/op [accessed 17 April 2002].

WHO. 1986. Guidelines for the Study of Dietary Intakes of Chemical Contaminants. No. 87. Geneva:World Health Organization.

Williams PRD, Hammit JK. 2001. Perceived risks of conventional and organic produce: pesticides, pathogens, and natural toxins. Soc Risk Anal 21(2):319–330.