

Community-based intervention to reduce pesticide exposure to farmworkers and potential take-home exposure to their families

ASA BRADMAN^a, ALICIA L. SALVATORE^a, MARK BOENIGER^b, ROSEMARY CASTORINA^a, JOHN SNYDER^c, DANA B. BARR^d, NICHOLAS P. JEWELL^a, GERI KAVANAGH-BAIRD^e, CYNTHIA STRILEY^b, AND BRENDA ESKENAZI^a

^aCenter for Children's Environmental Health Research, School of Public Health, University of California, Berkeley, California, USA

^bDivision of Surveillance, Hazard Evaluations and Field Studies, National Institute for Occupational Health and Safety, Cincinnati, Ohio, USA

^cDepartment of Horticulture, University of Kentucky, Lexington, Kentucky, USA

^dNational Center for Environmental Health, Centers for Disease Control and Prevention, Atlanta, Georgia, USA

^eCenter for the Health Assessment of Mothers and Children of Salinas (CHAMACOS), Clinica de Salud del Valle Salinas, Salinas, California, USA

The US EPA Worker Protection Standard requires pesticide safety training for farmworkers. Combined with re-entry intervals, these regulations are designed to reduce pesticide exposure. Little research has been conducted on whether additional steps may reduce farmworker exposure and the potential for take-home exposure to their families. We conducted an intervention with 44 strawberry harvesters (15 control and 29 intervention group members) to determine whether education, encouragement of handwashing, and the use of gloves and removable coveralls reduced exposure. Post-intervention, we collected foliage and urine samples, as well as hand rinse, lower-leg skin patch, and clothing patch samples. Post-intervention loading of malathion on hands was lower among workers who wore gloves compared to those who did not (median = 8.2 vs. 777.2 µg per pair, respectively ($P < 0.001$)); similarly, median MDA levels in urine were lower among workers who wore gloves (45.3 vs. 131.2 µg/g creatinine, $P < 0.05$). Malathion was detected on clothing (median = 0.13 µg/cm²), but not on skin. Workers who ate strawberries had higher malathion dicarboxylic acid levels in urine (median = 114.5 vs. 39.4 µg/g creatinine, $P < 0.01$). These findings suggest that wearing gloves reduces pesticide exposure to workers contacting strawberry foliage containing dislodgeable residues. Additionally, wearing gloves and removing work clothes before returning home could reduce transport of pesticides to worker homes. Behavioral interventions are needed to reduce consumption of strawberries in the field.

Journal of Exposure Science and Environmental Epidemiology (2009) 19, 79–89; doi:10.1038/jes.2008.18; published online 26 March 2008

Keywords: pesticides, malathion, farmworkers, agriculture, transfer coefficients, biomarkers.

Introduction

The US EPA Worker Protection Standard (WPS) provides pesticide safety information to farmworkers (US EPA 1992, 2005). Combined with re-entry intervals after pesticide applications, these regulations are designed to reduce pesticide exposure and protect farmworker health. However, the WPS does not directly address the potential for occupational “take-home” exposure, where workers transport pesticide residues on their skin or clothing to their homes, potentially exposing family members. Agricultural pesticides have been detected on farmworkers’ skin, clothing, and work shoes, and also in dust from farmworkers’ vehicles and homes, suggesting the

potential for take-home exposure (McCurdy et al., 1994; Bradman et al., 1997; Krieger and Dinoff, 2000; Lu et al., 2000; Curl et al., 2002; Coronado et al., 2006).

The use of protective clothing, gloves, and handwashing are known to reduce pesticide exposure to workers. For example, studies of pesticide mixers, loaders, and applicators (MLAs) demonstrate the effectiveness of protective clothing in reducing worker dermal loading by 50–95% (Keifer, 2000). Factors influencing exposure included the type of weave, fabric (e.g., synthetics vs. cotton), and fabric finishes (water repellants and starch) (Nigg et al., 1986; Fenske, 1988; Obendorf et al., 1991; Lander and Hinke, 1992; Csiszar et al., 1998; Racz et al., 1998; Saleh et al., 1998; Gomes et al., 1999; Boeniger and Lushniak, 2000; Kissel and Fenske, 2000; Krieger and Dinoff, 2000). Gloves have also been found to reduce pesticide dermal loading among MLAs (Putnam et al., 1983; Nigg et al., 1986; Lander and Hinke, 1992). A few studies of field farmworkers have also confirmed that protective clothing (McCurdy et al., 1994; Krieger and Dinoff, 2000) and glove use (Gomes et al., 1999) can reduce the amount of pesticides reaching farmworkers’ skin. Several studies also demonstrate that handwashing can

1. Address all correspondence to: Dr Asa Bradman, Center for Children's Environmental Health Research, School of Public Health, University of California, Berkeley, 2150 Shattuck Avenue, Suite 600, Berkeley, CA 94720-7380, USA.

Tel: +510 643 3023. Fax: +510 642 9083.

E-mail: abradman@socrates.berkeley.edu

Received 2 August 2007; accepted 15 February 2008; published online 26 March 2008

reduce worker exposure to chemicals, including pesticides (Boeniger and Lushniak, 2000; Marquart et al., 2002; Curwin et al., 2003). Overall, the literature on worker pesticide exposure prevention has several implications on the potential for take-home exposure: (1) if dislodgeable pesticides are present in the fields it has been shown that they accumulate on farmworkers' hands, other skin, clothing, and shoes; and, (2) if not removed either by changing clothes or washing, pesticides may be carried home where they can contaminate homes and/or directly expose family members.

In this study, we conducted an intervention to reduce malathion exposure to strawberry harvesters and the potential for take-home exposure to their families. The intervention components included provision of (1) warm water and hand cleansers to encourage handwashing; (2) disposable gloves; (3) removable outer clothing (coveralls) to prevent contamination of clothes and skin; (4) laundering of coveralls; (5) laundry bags and shoe bins for storage of work clothing and shoes in their car and home, and (6) 6 weekly in-field health and pesticide education presentations. In this paper, we compare levels of malathion urinary metabolite measurements in the control and intervention groups, and evaluate the efficacy of the intervention in preventing worker exposure and reducing the potential for take-home exposure to their families.

Methods

Study Population and Design

This community-based research study was conducted between July and October 2003 by the Center for Children's Environmental Health Research, a community-university partnership including the University of California, Berkeley, state and federal agencies, other educational and research institutions, and several community agencies in Monterey County (Israel et al., 2005). Community partners for this study include Clínica de Salud del Valle de Salinas, California Rural Legal Assistance, and the Grower-Shipper Association of Central California. The Center's Community Advisory Board (CAB) and Farmworker Council (FC) participated in the development of this intervention study. The CAB is composed of representatives from the agricultural industry, county environmental and health agencies, local elected representatives, advocacy groups, farmworkers, and other community members. The FC is composed of eight long-term farmworkers from the Salinas Valley.

We focused on strawberry harvesters for two reasons: (1) to standardize the tasks performed by study participants, and (2) because malathion, which is measurable in environmental and personal samples and in urine (as a metabolite), is used on this crop. We enrolled workers from a farm where malathion was expected to be used for insect control. Workers were eligible to participate if they were 18 years or

older, spoke English or Spanish, and were planning to work at the farm until the season ended. In October 2003, 44 strawberry workers provided samples for this study, of which 29 were randomly assigned to the intervention group (intervention group = 29; control group $n = 15$). More information on study methods is presented elsewhere (Salvatore et al., submitted). Written informed consent was obtained from all participants. All procedures were approved by the University of California, Berkeley Committee for the Protection of Human Subjects.

Strawberry Production

California produces 80% of the fresh market and processed strawberries grown in the United States, with harvests exceeding 1.5 billion pounds annually (USDA, 2006). The Watsonville/Salinas region includes over 13,000 planted acres, about one-third of the State's total (USDA, 2006). Raised-bed plasticulture is the primary production method. In this system, individual beds (~38 cm high $\times$ 61 cm wide with 25 cm between rows) with subsurface drip irrigation tapes are covered with plastic and planted annually with day-neutral berries. Day-neutral berries produce continuously, so harvests continue the entire growing season until cold weather sets in. Approximately 200 compounds are approved to control pests on strawberries; however, relatively few are used in large volume. Several million pounds of pesticides are used annually on strawberries in the Watsonville/Salinas region, primarily pre-planting soil fumigants (DPR, 2003). Common post-planting applications include fungicides (sulfur, captan, thiram) and insecticides (malathion, naled, methomyl). Pest pressures determine the frequency of post-planting insecticide applications and vary widely depending on insect life cycles, weather, natural enemies, and so on. Malathion was applied for lygus bug (*Lygus hesperus*) control twice during the growing season on the farm we studied, once in July, and once in October, just before the post-intervention sampling. Berries are harvested by hand with most workers paid on a piece-rate basis. The crews working in the fields we studied were hired directly by the farmer and worked only in fields managed by him. They worked exclusively in strawberries for the entire summer.

Personal and Demographic Data Collection

Two weeks prior to implementation of the intervention, farmworkers were interviewed in Spanish by bilingual interviewers using a standardized questionnaire. Interviews were conducted during breaks in a private location away from other workers. Information obtained focused on personal and demographic information, use of protective clothing and gloves, personal and dietary behaviors related to pesticide exposure, number of household members, household members' occupations, and home pesticide use. This instrument was reviewed by staff (many of whom had been farmworkers) and community partners, and pretested with the FC.

Intervention Components

Each workday for 6 weeks before completion of the post-intervention sampling, intervention group participants were provided with lightweight removable coveralls (cotton/polyester) to wear over their normal work clothing (Sweet Manufacturing, Dallas, TX, USA). Used coveralls were picked up every 7 days and washed by a professional laundry service. Farmworkers in the intervention group were also provided with disposable non-latex gloves and containers for storing work shoes and clothes separately from family clothes. Warm water and soaps were provided to encourage handwashing. Five field-based educational sessions were conducted with intervention group participants throughout the study period. These sessions aimed to educate workers about pesticide exposure and protective behaviors, and to troubleshoot barriers to adopting the behaviors promoted in the intervention. Information about the participatory research methods used to select coveralls, soaps, gloves, and the provision of warm water will be presented in a separate paper.

At the end of the intervention study, control group members were provided with two pairs of coveralls, storage containers, a supply of disposable non-latex gloves, and an educational workshop that covered the information given to intervention participants.

Evaluation of the Intervention: Biological, Environmental, and Personal Sample Collection

To confirm the potential for workers' exposure to malathion, we measured dislodgeable foliar residues (DFRs) and levels of malathion metabolites in workers' urine specimens, as well as malathion in hand rinse, clothing patch, and skin patch samples. The goal of this cross-sectional sampling campaign was to assess the efficacy of specific components of the intervention. Details of collection and measurements are provided below.

Dislodgeable Foliar Residue To determine the potential for dermal exposure and accumulation on clothes, we measured malathion in DFR samples collected from the fields that participants worked in. To collect the DFR samples, we first divided the fields into five equal sized plots. We recorded the lengths and number of rows in each plot. Plants from each plot were randomly selected and three to four leaf punches were taken from each plant. A total of 40 punches 1 inch in diameter were collected for each DFR sample. The DFR samples were immediately placed on ice packs in a cooler and transferred to the field laboratory, where the samples were placed in a beaker with 300 ml of 0.1% Sur-Ten solution and mixed on a shaker table for 20 min. The rinseate was decanted into sample jars and frozen at -80°C until shipment on dry ice to the University of Kentucky, Department of Horticulture research laboratory in

Lexington, KY, for analysis. Quality control procedures included the use of field spikes and blanks.

Prior to analysis, samples were thawed at room temperature and sample weight was determined gravimetrically. The sample was transferred to a separatory funnel, and then partitioned against ethyl acetate. The organic fractions were pooled, the volume reduced to 1–2 ml, transferred to a small vial and blown to just dryness with nitrogen. The sample was then vortex mixed with 2 ml of ethyl acetate. One μl aliquots were injected into a gas chromatograph (GC; Hewlett-Packard 5890) at 250°C with a nitrogen phosphorous detector at 280°C . A DB-5 column was used with helium as the carrier gas (6 ml/min), with a retention time of 2.4 min. Determinations were made in triplicate. The limit of detection (LOD) was 0.03 ng. To determine the concentration of malathion in the samples, external standards were used (0.00033, 0.00333, or 0.0333 g/ μl). An external standard was shot twice per day (in triplicate). Concentrations of malathion in the experimental samples were calculated by the use of proportions, based on the external standard. After calculation of malathion concentration in the experimental sample, mean concentration and its standard deviation were then calculated and expressed as μg malathion/g of original sample. No malathion residue was measured in field blank samples ($n=3$) indicating that no contamination occurred in the field during processing or handling. The low ($n=2$ at 2 μg), medium ($n=2$ at 20 μg), and high ($n=3$ at 200 μg) spike recoveries were on average 223%, 121%, and 117% of the spiked concentrations, respectively.

Urine Collection and Malathion Metabolite Measurements We evaluated workers' exposure to malathion post-intervention by measuring metabolites in spot urine samples. Urine sampling was timed to occur on the same day harvesters entered fields after expiration of the 72 h pre-harvest interval for malathion on strawberries. The post-intervention sampling was conducted with one intervention crew ($n=29$) and one control crew ($n=15$). Spot urine samples were collected following procedures outlined by CDC (CDC, 2003). Participants voided into a sterile collection cup in a field rest room. Samples were kept on ice packs until transport to the field office for aliquoting and storage at -80°C . For quality control purposes, frozen field blanks and spikes, prepared earlier by CDC, were defrosted, repackaged in the field in a manner identical to collection procedures for actual samples, and then shipped blinded to CDC.

Urine samples were analyzed by the Division of Laboratory Services, Centers for Disease Control and Prevention, Atlanta, GA, USA. Malathion dicarboxylic acid (MDA) and six non-specific dialkyl phosphate (DAP) metabolites were measured: dimethylphosphate; dimethyldithiophosphate; dimethylthiophosphate; diethylphosphate; diethyldithiophosphate; and diethylthiophosphate. Urine specimens

were lyophilized to remove water; then the residue was redissolved in acetonitrile/diethyl ether (1:1). The DAPs were derivatized to their chloropropyl phosphate esters and then analyzed by isotope dilution gas chromatography-tandem mass spectrometry (GC-MS/MS) (Bravo et al., 2004). The specific metabolite of malathion, MDA, was measured as the intact metabolite using high performance liquid chromatography (HPLC)-atmospheric pressure chemical ionization-tandem mass spectrometry (Olsson et al., 2004). Creatinine concentrations in urine were determined using a commercially available diagnostic enzyme method (Vitros CREA slides, Ortho Clinical Diagnostics, Raritan, NJ, USA). We adjusted metabolite levels for creatinine, which is standard practice in occupational studies of adult populations (Lauwerys and Hoet, 1993). We calculated the molar sum of the MDA and total dimethyl alkylphosphate (DMAP) urinary metabolites to estimate the fraction of total DMAP urinary metabolites that could be attributed to malathion exposure. Given that there are many potential sources of DAP exposure (e.g., diet (Lu et al., 2005)) and our focus on malathion in field and personal measurements, we report data analyses results for MDA only.

Laboratory quality control included repeat analysis of three in-house urine pools enriched with known amounts of pesticide residues whose target values and confidence limits were previously determined. The validity of each analytical run was determined using the Westgard rules for quality control (Westgard, 2003). The LOD for the MDA analysis was $0.3 \mu\text{g/l}$. We assigned an imputed value of the $\text{LOD}/\sqrt{2}$ to field sample results that were below the detection limit (Hornung and Reed, 1990; Barr et al., 2004). Of 14 field blanks, no MDA metabolites were detected indicating that virtually no contamination occurred in the field during processing and handling. The MDA recoveries for 10 low ($20 \mu\text{g/l}$) and 10 high ($60 \mu\text{g/l}$) field spikes averaged 96% and 105%, respectively.

Clothing and Skin Patch Samples To assess the potential for dermal exposure under worker clothing and the accumulation of malathion on clothing, we collected skin patch ($n=38$) and clothing ($n=41$) samples post-intervention from both intervention and control groups. To collect the samples, we placed square first-aid cotton gauze into a cardboard frame with a 10 cm diameter circle cut out. This ensured that all patch samples had the same area of exposed material. Clothing patches were applied externally to the lower leg of either coveralls worn by participants in the intervention group or to the regular work pants worn by participants in the control group. For skin patch samples, the cardboard frame was taped directly to the skin on the lower leg. The patches were randomly offset, so the skin and clothing patch samples were never aligned directly on top of each other.

Malathion on clothing and skin patch samples was measured by DataChem Laboratories Inc. in Salt Lake City, UT, USA. Samples were extracted in 30 ml of isopropanol for 1 h. GC-mass spectrometry analyses were performed in single-ion monitoring mode. A volume of $1 \mu\text{l}$ was injected, splitless for 0.5 min, at 280°C , on a DB-5 column with $30 \text{ m} \times 0.32 \text{ mm i.d.} \times 0.5 \mu\text{m}$. The LOD and limit of quantification (LOQ) for malathion were 0.02 and $0.06 \mu\text{g}/\text{cm}^2$, respectively. Field quality control samples included 25 blank, spike, and duplicate patch samples. Malathion residues were not detected in blank samples indicating no measurable contamination occurred in the field during processing or handling. Levels of malathion in five field blanks spiked at $0.02 \mu\text{g}/\text{cm}^2$ were below the LOD. Recoveries for five medium ($0.13 \mu\text{g}/\text{cm}^2$) and five high ($1.3 \mu\text{g}/\text{cm}^2$) field spikes averaged 88 and 72%, respectively.

Hand Rinse Samples To assess dermal exposure on hands, we collected hand rinse samples from 42 workers post-intervention from both intervention and control groups. To collect the samples, 500 ml of water with 0.1% Sur-Ten (dioctyl sulfosuccinate sodium salt (CAS no. 577-11-7)) was placed in a clean plastic bag supported by a plastic cylinder. Participants washed their hands in the solution for 60 s. Nailbrushes precleaned in isopropanol were provided to remove surface dirt and brush fingernails. After washing, the solution was transferred to collection jars, transported on ice to the field office, and transferred to a -80°C freezer for storage until shipment on dry ice to the laboratory for analysis.

Hand rinse samples were analyzed by the National Institute of Occupational Safety and Health in Cincinnati, Oh, USA. A 10-ml aliquot was vortex mixed followed by cleanup with a solid phase extraction C18 cartridge. The sample was then washed with 5 ml water and eluted with 3 ml of acetonitrile. Water was added to bring the aliquot concentration to 65% acetonitrile:35% water. Chromatographic analysis using an Agilent 1100 HPLC System (Palo Alto, CA, USA) with UV detection at 210 nm was achieved by the injection of a $100 \mu\text{l}$ sample onto a Zorbax C18-RX column followed by elution at a rate of 1.0 ml/min . An LOD of 10 ppb and LOQ of 30 ppb were based on average values of instrumental baseline noise and the lowest standard that could be reliably measured. We assigned an imputed value of the $\text{LOD}/\sqrt{2}$ to levels below the detection limit. We conducted a recovery study of spiked handwash samples (six each) at 10, 50, 250, 500, 1000, 5100, and 10,200. Average recovery for each spiking level ranged from 96 to 109%, with overall recovery of $100.4 \pm 4.2\%$.

We conducted two additional quality assurance studies to evaluate the reliability of the hand rinse measurements. First, because the hand rinse solutions were likely to contain bacteria, fungi, soil, plant extracts, and other materials, we conducted an experiment to determine whether malathion

degrades in the rinseate during the time, typically 1–2 h, between sample collection and freezing. To accomplish this, we prepared three sets of hand rinse solutions. Group 1 consisted of the clean Sur-Ten rinsing solution. For Group 2, a staff member wore nitrile gloves for 3 h (creating the conditions for a bacterial bloom, mimicking conditions for workers who wore gloves); he then removed the gloves and followed the hand rinse protocol. For Group 3, a staff member went to a (unsprayed) strawberry field and rubbed his hands over the plants and soil to mimic the material that accumulates on worker hands during harvesting. He then followed the hand rinse protocol. For each group, the solution was aliquoted to nine samples, each spiked with 200 ng of malathion. Within each set of nine samples, we froze three samples immediately, let three samples sit at room temperature for 1 h before freezing, and, finally, let three samples sit at room temperature for 2 h before freezing. Recoveries for all groups ranged from 82 to 108%. The results of this quality assurance evaluation suggest that recoveries for field samples were acceptable. Final results were not adjusted for any degradation during transit.

Second, to assess the efficacy of the hand rinse protocol, a subset of 14 intervention participants provided three sequential hand rinses that were analyzed separately. Rinse no. 1 removed an average of 59% (range, SD = 31–74%, 13%) of the total malathion measured in three sequential rinses. Combining rinse no. 1 and rinse no. 2 increased the recovery to 85% (range, SD = 72–92%, 7%), indicating that the initial rinse removed most, but not all, of the recoverable pesticide on the hands of field workers (Table 1).

Data Analysis

Data analysis focused on evaluating the association of specific field intervention components (glove use and coveralls) and worker exposure among the 29 intervention participants and 15 controls. To accomplish this objective, we compared post-intervention median urinary metabolite levels of the intervention ($n = 29$) and control ($n = 15$) groups using either the Mann–Whitney U -test or Kruskal–Wallis test. We also compared these urinary metabolite levels between the intervention and control groups stratified by potential exposure risk factors, including age and number of strawberry boxes picked as continuous variables and gender, smoking status, glove use, and strawberry consumption while working as categorical yes/no variables.

We evaluated these exposure risk factors to assess additional confounding that was not accounted for in the study design, and the significance of compliance with intervention protocols. Among the 29 intervention group participants, all wore coveralls and 27 complied with the glove use requirement; among the 15 controls, 6 wore gloves on a routine basis, including on the day of sampling. As glove use appeared to be a primary determinant of exposure, we conducted additional analyses based on reported glove

Table 1. Proportion of total malathion removed from hands by sequential rinses ($n = 14$ participants, three rinses each)^a.

Rinse no.	Portion (%) of total malathion detected in sequential rinses		
	Mean	SD	Range
1	59	13	(31–74)
1 and 2	85	7	(72–92)
1–3	100	—	—

^aWash time = 60 s; a brush was used to remove surface dirt.

use independently of intervention or control group assignment. Finally, to assess the independent contribution of not wearing gloves to worker exposure, we constructed a multivariate regression model with log (base e) transformed MDA metabolite levels as the dependent variable and glove use, home pesticide use, and eating strawberries in the field (all coded as yes/no) and time worked in the field on the day of sample collection (continuous), as independent variables.

We also compared malathion levels on lower-leg skin with clothing patches and residues on worker hands stratified by reported glove use. On the basis of DFR data and hand rinse malathion levels, we calculated agricultural transfer coefficients (TCs) for these workers (US EPA, 2000; Korpalski et al., 2005). Finally, we used quantile regression to compare MDA levels among the post-intervention strawberry workers with levels reported for Mexican American adults participating in the National Health and Nutrition Examination Survey (NHANES) (CDC, 2003). All data analyses were performed with Stata Version 10 (StataCorp LP, College Station, TX, USA).

Results

Demographic Characteristics

All 44 study participants were born in Mexico; 80% were male, 80% spoke only Spanish, and 82% had attended school through the 6th grade or less. The mean age of study participants was 31 (SD = 10) years and 68% lived at or below the federal poverty level (US Census Bureau, 2003). Fifty-five percent of participants lived with six or more people in their home and 93% percent lived with at least one other agricultural worker. Twenty-five percent of farmworkers lived with their children, 11% had children under 6-years; 23% smoked.

Urinary Metabolites

Table 2 presents the farmworkers' creatinine-adjusted post-intervention urinary MDA metabolite levels. After implementation of the intervention, MDA metabolite levels were essentially the same among workers in the intervention group compared to the control group (median = 56.3 vs. 56.9 $\mu\text{g/g}$).

Table 2. MDA metabolite and creatinine levels in farmworkers' urine samples post-intervention.

Farmworker subgroups	MDA levels ($\mu\text{g/g}$)			
	DF (%)	Median	IQR (25th, 75th)	Range
<i>Post-intervention</i> ^{a,b}				
Control group ($n = 15$)	100	56.9	27.1, 321.0	16.1–444.6
Intervention group ($n = 29$)	97	56.3	34.7, 90.0	0.2–921.3
Total ($n = 44$)	98	56.8	33.6, 142.6	0.2–921.3
Total creatinine (mg/dl) ($n = 44$)	100	105.6	85.2, 144.2	45.0–274.2

Abbreviations: DF, detection frequency; IQR, interquartile range; MDA, malathion dicarboxylic acid.

^aIntervention group members were provided with gloves and coveralls (100% of workers complied with the coverall use protocol, and 93% complied with the glove use protocol).

^bUrine samples were collected post-intervention from workers on the same day they picked strawberries from the sprayed fields.

However, six of the control group members wore gloves, a key component of the intervention. Among controls, median MDA metabolite levels were significantly lower among the six workers who wore gloves ($26.9 \mu\text{g/g}$) compared to the nine who did not ($154.0 \mu\text{g/g}$) (Mann–Whitney U -test $P = 0.003$). Thus, in the analyses presented below, we report data by exposure factors independent of post-intervention group assignment.

Table 3 presents post-intervention MDA metabolite levels by potential exposure factors. Wearing gloves was associated with lower metabolite levels (median MDA metabolite levels were $131.2 \mu\text{g/g}$ among the 11 workers who did not wear gloves *vs.* $45.3 \mu\text{g/g}$ among the 33 workers who did; Mann–Whitney U -test $P < 0.05$). The 14 workers who reported working more than 6 h in the field on the day of sample collection had significantly higher median MDA metabolite levels ($71.7 \mu\text{g/g}$) compared to workers who worked less than 6 h ($43.6 \mu\text{g/g}$) ($P < 0.05$). Workers' age, sex, smoking status, wearing coveralls over work clothes, and number of strawberry boxes picked were not associated with metabolite levels.

Many workers (48%) reported eating strawberries, which may have contained malathion residues, while working in the field. Median MDA metabolite levels were significantly higher among workers who ate strawberries in the field ($114.5 \mu\text{g/g}$) *vs.* those workers who did not ($39.4 \mu\text{g/g}$) (Mann–Whitney U -test $P < 0.01$). Among workers who did eat strawberries, the intervention ($n = 12$) and control ($n = 9$) groups' MDA metabolite levels were very similar (123.5 and $114.5 \mu\text{g/g}$, respectively). Among workers who did not eat strawberries, the intervention group's ($n = 17$) median MDA metabolite levels ($39.1 \mu\text{g/g}$) were lower than the control group's ($n = 6$) median MDA metabolite levels ($56.8 \mu\text{g/g}$); however, this difference was not statistically significant ($P = 0.5$).

We constructed a multivariate regression model with log transformed MDA metabolite levels as the dependent variable and glove use, eating strawberries in the field and

Table 3. Farmworker MDA ($\mu\text{g/g}$) levels by potential exposure factors (control and intervention groups, $n = 44$).

	<i>n</i> (%)	50th	IQR	(25th, 75th)
<i>Age (mean = 30 years)</i>				
18–24	15	34	56.6	32.5, 163.1
25–34	14	32	46.2	35.7, 89.1
35–58	15	34	77.3	31.8, 321.0
<i>Gender</i>				
Male	35	80	56.9	35.7, 157.9
Female	9	20	34.7	26.8, 64.2
<i>Smoking status</i>				
No	34	77	62.7	35.7, 154.0
Yes	10	23	37.6	31.8, 77.3
<i>Number of hours worked in the field today</i>				
≤ 6	30	68	43.6	27.1, 90.0
> 6	14	32	71.7 ^a	53.0, 321.0
<i>Eat unwashed strawberries in the field today</i>				
No	23	52	39.4	31.5, 66.1
Yes	21	48	114.5*	45.3, 217.7
<i>Number of strawberries eaten today</i>				
None	23	52	39.4	31.5, 66.1
1–10	18	41	85.3	41.6, 321.0
> 10	3	7	207.4*	163.1, 217.7
<i>Wear gloves today</i>				
No	11	25	131.2*	56.9, 359.4
Yes	33	75	45.3	31.5, 81.4
<i>Wear coveralls today</i>				
No	15	34	56.9	27.1, 321.0
Yes	29	66	56.3	34.7, 90.0
<i>Boxes of strawberries picked</i>				
2–15	9	21	64.2	31.5, 114.5
16–19	17	40	56.3	39.1, 163.1
20–25	17	40	61.2	35.7, 131.2

*Mann–Whitney U -test or Kruskal–Wallis P -value < 0.05 .

Table 4. Malathion levels on farmworker clothing patch, skin patch, hand rinse (glove wearers *vs.* non-glove wearers) and dislodgeable foliage samples.

	Malathion concentrations					
	<i>n</i>	DF (%)	Mean (SD)	p50	IQR (25th, 75th)	Min–Max
Clothing patch ($\mu\text{g}/\text{cm}^2$)	41	76	0.17 (0.15)	0.13	0.07, 0.22	0–0.70
Skin patch ($\mu\text{g}/\text{cm}^2$)	38	3	0.006 (0.03)	0	0, 0	0–0.21
Hand rinse total (μg per pair of hands)	42	83	206.0 (422.6)	12.1	5.8, 102.1	3.5–1,936.4
Hand rinse (gloves worn)	32	78	25.0 (77.6)	8.2 ^a	5.5, 13.8	3.5–445.7
Hand rinse (gloves not worn)	10	100	785.2 (551.0)	777.2 ^a	382.2, 1,037.6	102.1–1,936.4
Dislodgeable foliage ($\mu\text{g}/\text{cm}^2$)	8	100	1.0 (0.2)	1.0	0.9, 1.1	0.6–1.4

Abbreviations: DF, detection frequency; SD, standard deviation.

^aGlove use *vs.* non-glove use (*P*-value (Mann–Whitney *U*-test)) = 0.0001.

hours worked in the field as independent variables. Results indicate that glove use was inversely associated with MDA metabolites levels ($\beta = -1.2$ (95% CI: $-2.0, -0.5$)) even when controlling for strawberry consumption and hours worked in the field (R^2 (for model) = 0.43). Strawberry consumption also remained significantly associated with MDA metabolite levels ($\beta = 1.1$ (95% CI: $0.4, 1.7$)). Converted to an arithmetic scale, the adjusted coefficients indicate that predicted MDA metabolite levels are 3.4 times higher among workers not wearing gloves compared to workers who wore gloves, and 2.9 times higher among workers eating unwashed strawberries in the field compared to workers who did not.

Finally, we calculated the molar sum of the MDA and total DMAP urinary metabolites — to estimate the fraction of total DMAP urinary metabolites that could be attributable to malathion exposure. On the basis of this comparison, we found that on average approximately 36% of total farmworker DMAP metabolites likely came from malathion *vs.* other sources.

Post-intervention urinary MDA concentrations were also significantly higher by two orders of magnitude among the strawberry harvesters ($n = 44$) (median = $56.8 \mu\text{g}/\text{g}$) compared to Mexican American adults sampled by NHANES ($n = 680$) (median = $0.2 \mu\text{g}/\text{g}$ ($< \text{LOD}$)) ($P < 0.001$) (CDC, 2003; Barr et al., 2005). As our study took place in October, which is late in the strawberry harvest season when yields are lower, workers spent an average of 5.6 h (SD = 0.5) in the field on the day of sample collection. If these harvesters had been in the field 8 or more hours, we would expect malathion exposure levels to have been higher.

Clothing and Skin Patch Samples

Of the 44 post-intervention study participants, 41 provided clothing patch samples and 38 provided skin patch samples. Table 4 presents malathion levels found on the post-intervention farmworkers' clothing patch and skin patch samples. Participants wore the patch samples for an average of 5.5 h (SD = 0.8 h). Malathion was detected on

76% (31 of 41) of clothing patch samples, with a median of $0.13 \mu\text{g}/\text{cm}^2$. Levels among control ($n = 12$) and intervention ($n = 29$) group participants were similar (median = 0.10 and $0.14 \mu\text{g}/\text{cm}^2$, respectively; $P = 0.23$). Malathion was detected on only 3% (1 of 38) of skin patch samples, indicating that even a single layer of clothing protects the skin from dermal exposure.

To assess the potential for bias due to behavioral differences between the participants that could affect exposure, we performed additional analyses of our clothing patch data. Malathion levels measured on the workers' clothing samples were essentially the same between the workers who wore gloves and those who did not (medians = $10.1 \mu\text{g}/\text{cm}^2$ *vs.* $10.0 \mu\text{g}/\text{cm}^2$, respectively), suggesting that the exposure potential (contact with malathion) was similar between the two groups. In addition, the malathion levels measured on the clothes of intervention group members were slightly, but not statistically, higher than the control group (medians = 11.0 *vs.* $7.7 \mu\text{g}/\text{cm}^2$, respectively). Given these two findings, it is unlikely that there were any substantial behavioral differences between the groups that would affect exposure.

Hand Rinse Samples

Of the 44 post-intervention study participants, 42 provided hand rinse samples. Table 4 indicates that median malathion levels were significantly lower on the hands of farmworkers who wore gloves *vs.* those who did not (8.2 *vs.* $777.2 \mu\text{g}$ per pair of hands, Mann–Whitney *U*-test $P < 0.001$), independent of post-intervention group participation. On the basis of quality assurance evaluation of the hand rinse sample collection efficacy described in the Methods section, it is likely that our measurements of dermal loading, which are based on the first rinse, underestimate total dermal exposure.

DFR

During the post-intervention sampling period, we collected DFR samples from a recently sprayed field and analyzed them for malathion. Mean $\pm$ SD malathion levels for the

Table 5. Calculated transfer coefficients (TC) for accumulation of malathion on the hands of strawberry harvesters.

	<i>n</i>	Mean hours in the field (SD)	Transfer coefficient (cm ² /h) ^a		
			GM (95% CI)	50th	Min–Max
All workers ^b	42	5.6 (0.5)	4.7 (2.5, 8.9)	2.2	0.6–413.3
Workers who wore gloves ^b	32	5.7 (0.5)	1.8 (1.2, 2.5)	1.6	0.6–73.4
Workers who did not wear gloves ^b	10	5.5 (0.5)	110.1 (55.9, 216.8)	148.9	20.7–413.3
Provided three hand rinse samples and did not wear gloves ^c	7	5.3 (0.3)	195.7 (86.2, 444.6)	242.9	35.3–584.4

^aFor TC calculations, workers' malathion exposure are based on hand rinse samples (see Eq. (1)).

^bTC calculations were based on first hand rinse sample only (see Results and Discussion for additional information).

^cTC calculations were based on three sequential hand rinse samples.

eight DFR samples were Mean $\pm$ SD = 1.0 $\pm$ 0.2 μ g/cm² (Table 4).

Transfer Coefficient

On the basis of DFR data and the workers' hand rinse malathion levels, we calculated agricultural TCs for malathion accumulation on worker hands using the following equation (Korpalski et al., 2005):

$$\text{TC (cm}^2\text{/h)} = \frac{\text{Exposure } (\mu\text{g of malathion/h)}}{\text{DFR } (\mu\text{g malathion/cm}^2\text{ leaf surface)}} \quad (1)$$

TCs are the ratio of the exposure, determined usually by passive dosimetry on workers that re-enter fields treated with pesticides, to the concurrent DFR samples collected in that crop. For these calculations we used the geometric mean of the DFR malathion levels (0.97 μ g/cm²; *n* = 8). Table 5 presents the TC results for 42 harvesters. The TC levels for all harvesters ranged from 0.6 to 413.3 cm²/h. The TC levels for workers who wore gloves ranged from 0.6 to 73.4 cm²/h, and from 20.7 to 413.3 cm²/h for those who did not wear gloves. Median TC levels among workers who wore gloves (1.6 cm²/h) were nearly an order of magnitude lower than workers who did not wear gloves (148.9 cm²/h). For workers that provided three sequential hand rinses and who did not wear gloves, the TCs ranged from 35.3 to 584.4 cm²/h (median TC = 242.9 cm²/h) (Table 5). When the arithmetic mean of the DFR malathion levels is used instead of the geometric mean for these calculations, the resulting TC values are approximately 3% lower.

Discussion

To assess farmworker exposure and the efficacy of this intervention, we measured malathion in DFR, hand rinse, and clothing patch samples, and MDA metabolites in urine from strawberry harvesters working in fields recently sprayed with malathion. We found that post-intervention loading of malathion on hands was lower among workers who wore gloves compared to those who did not (median = 8.2 *vs.*

777.2 μ g per pair, respectively (*P* < 0.001)); similarly, median MDA levels in urine were lower among workers who wore gloves (45.3 *vs.* 131.2 μ g/g, *P* < 0.05). Additionally, we detected malathion on clothing (median = 0.13 μ g/cm²), but not on skin. Overall, these findings suggest that the intervention was successful in reducing pesticide exposure among strawberry harvesters.

On a cross-sectional basis, the post-intervention median MDA metabolite levels were similar in the intervention (56.3 μ g/g) and control groups (56.9 μ g/g). However, six (of 15) workers in the control group wore gloves on a routine basis, while three workers in the intervention group did not wear gloves; thus, we also analyzed the data stratified by glove use. Malathion levels on worker hands and MDA urinary metabolites were significantly lower in workers wearing gloves compared to workers who did not wear gloves. We detected negligible levels of malathion on skin samples whether or not workers were wearing one pant layer or an extra coverall as part of the intervention. We found much higher levels on clothing patch samples, with similar levels among control and intervention group participants. These findings indicate that wearing gloves resulted in lower levels of malathion on worker's hands, and absorbed dose, and that, while malathion accumulated on worker's clothing, it was not breaking through to the skin. These findings are consistent with studies reporting reduced pesticide exposure among farmworkers wearing protective clothing and gloves (Gomes et al., 1999; Keifer, 2000; Krieger and Dinoff, 2000). The data also suggest that wearing protective gloves and removing work clothes before returning home could reduce pesticide loading on skin and worker clothing, and, therefore, reduce transport of pesticides to worker homes.

Urinary MDA metabolite levels were significantly higher among workers who reported eating strawberries in the field on the day of sample collection compared to those who did not, suggesting that strawberry consumption could confound the association between glove use and exposure; however, strawberry consumption was evenly distributed between glove wearers and non-glove wearers. Furthermore, the

significant inverse association of glove use and MDA metabolite levels remained consistent in multivariate models when controlling for strawberry consumption. On the basis of coefficients resulting from this regression model, urinary MDA metabolite levels were 3.4 times higher among workers not wearing gloves compared to workers who wore gloves, and 2.9 times higher among workers eating unwashed strawberries in the field compared to those who did not. In this model, glove use, strawberry consumption and time worked in the field on the day of sample collection explained over 40% of the variation in MDA urinary metabolite levels (R^2 (for model) = 0.43).

Given our result that strawberry consumption among harvesters working in a recently sprayed field was associated with significantly higher urinary MDA levels, US EPA should further evaluate the potential for malathion exposure to pregnant women, other adults, and children at U-Pick farms.

The malathion DFR levels we observed (mean = $1.0 \pm 0.24 \mu\text{g}/\text{cm}^2$) on samples collected within 72 h of treatment were slightly higher than those reported in the literature. For example, Hernandez et al. (2002) reported mean malathion DFR levels of $0.39 \pm 0.16 \mu\text{g}/\text{cm}^2$ on 10 strawberry samples collected after expiration of the restricted entry interval of 12 h (Hernandez et al., 2002). Zhang (2005), found mean leaf punch DFR levels ranging from 0.22 ± 0.047 to $0.014 \pm 0.007 \mu\text{g}/\text{cm}^2$ in samples collected 1–10 days after application (Zhang, 2005). Hernandez et al. (1997) reported mean malathion DFR from 28 samples during the strawberry harvest of $0.074 \pm 0.088 \mu\text{g}/\text{cm}^2$, although they did not report how long after the application the samples were collected.

The maximum TC ($584.4 \text{ cm}^2/\text{h}$) we calculated is comparable to the assigned TC values (400 and $1500 \text{ cm}^2/\text{h}$) published for strawberry harvesting by the US EPA (US EPA, 2000). If we assume that transfer to bare hands is rapidly saturable, and equilibrium is reached over a 1- to 2-h exposure, as has been suggested in other studies (Spencer et al., 1995; Brouwer et al., 1999), the workers' maximum TC would increase 2.5-fold to $1417.2 \text{ cm}^2/\text{h}$. The dermal exposure measure (hand rinse sampling data) we used to calculate the TCs, however, reflects exposure only to the workers' hands, not the whole body. As these harvesters likely experienced dermal exposure via their faces and necks as well as their hands, we expect that our TC calculations are an underestimate. We found no other published agricultural TC data for comparison.

This study has several limitations. The cross-sectional relationship we found between glove use and decreased urinary metabolite levels must be interpreted with caution due to the inherent differences in individuals who, for example, would tend to comply with the intervention components and those who would not. However, malathion levels on clothing patch samples did not vary by intervention

group or glove use, suggesting no substantial differences in exposure-prone behavior between the groups that would bias this finding. Also, as a cross-sectional study, we had no means of measuring changes in longitudinal exposure. Additionally, our study design did not allow us to directly test the efficacy of handwashing on pesticide loading on worker hands or metabolite levels. As intervention participants wore gloves, leaving minimal residues on the hands to be washed away, we could not assess whether additional handwashing would have reduced dermal loading. However, these results should not be interpreted to suggest that handwashing is not important for reducing farmworker exposure. The hand rinse data confirm that dislodgeable malathion residues were present on worker hands, indicating that efforts to increase handwashing among farmworkers should be encouraged. In a separate paper, we will analyze the efficacy of the intervention in changing knowledge, attitudes, and exposure-related behaviors, including handwashing frequency.

Our quality assurance evaluation of the efficacy of the hand rinse sample collection procedures indicate that, on average, only 59% of the material removed by three sequential rinses was recovered in the first rinse, suggesting that our hand loading estimates significantly underestimate total hand pesticide loading and dermal exposure. This finding is consistent with studies showing that hand rinse methods may underestimate total dermal pesticide exposure by two- to fivefold (Fenske and Lu, 1994). In our study, poor efficacy of the sampling method did not affect our ability to observe significant differences in hand pesticide loading related to glove use. However, as noted by Fenske and Lu (1994), for studies focusing on dermal exposure as the primary outcome, "...efficiency studies should be conducted prior to field investigations."

Finally, we focused on malathion exposure and strawberry harvesters; thus, the measured pesticide exposure may not be generalizable to other farmworker populations. However, a strength of the study is that our findings are the result of both biomonitoring and environmental sampling and are potentially relevant to strawberry harvesters elsewhere in the country. For intervention participants, we did not collect clothing patch samples from the pants that workers wore under their coveralls. For this reason, we did not directly measure potential breakthrough through the coveralls onto intervention participants' clothing. However, the very low levels of malathion measured on participants' skin, whether they were wearing a single pant layer (controls) or coveralls and pants (intervention), suggests that very little malathion broke through the coveralls and accumulated on the intervention participants' clothing. Thus, the coveralls were likely effective in preventing accumulation of malathion on their regular work clothing. Additionally, given that very little malathion broke through worker clothing onto the skin, and the strong association we found between glove use and

MDA urinary metabolite levels, our findings indicate that, excluding strawberry consumption, most worker exposure was due to dermal absorption through the hands.

Conclusion

Glove use among strawberry harvesters significantly reduced malathion exposure as measured by malathion loading on hands, and MDA urinary metabolite levels. Clothing prevented virtually all accumulation of malathion on skin elsewhere on workers' bodies. The use of coveralls by intervention participants likely prevented malathion accumulation on the workers' regular clothing. The use of gloves and possibly handwashing to minimize pesticide levels on worker hands, and coveralls to prevent pesticide accumulation on worker clothing, is likely to reduce the potential for occupational take-home pesticide exposure to families and children among strawberry harvesters entering fields after expiration of the malathion post-harvest interval (72 h). The benefits of these intervention components may be more significant for farmworkers entering fields after expiration of the 12 h malathion re-entry interval, when malathion DFRs are likely to be higher than the levels we observed. In follow-up to this study, we are working with community partners, agricultural officials, and grower organizations to disseminate the study findings and identify workable strategies to prevent take-home pesticide exposure. Future research should focus on the specific benefits of handwashing and also evaluate whether these approaches can reduce farmworker and family exposure to other pesticides with different physical-chemical characteristics. Finally, behavioral interventions are needed to reduce consumption of strawberries in the field and the US EPA should evaluate the feasibility of encouraging harvesters to wear gloves when dislodgeable foliar pesticide residues are present in the fields.

Acknowledgements

This research was funded by NIEHS CBPR Grant RO1ES11352. Additional support was provided by US EPA Grant RD 83171001 and NIEHS Grant PO1 ES009605. Analysis for hand rinse, clothing patch, and DFR samples was supported by NIOSH. Additional support for environmental sample collection analysis and M Boeniger's time was provided by NIOSH. The contents of this paper are the responsibility of the authors and do not necessarily represent the official views of the funding agencies. The authors declare they have no competing financial interests. We thank the field staff and the farmworkers and farmers who participated in this study for their valuable time and commitment. We also thank Natividad Medical Center for hosting our field office in Salinas, CA.

Finally, we thank J Ferber and R Krieger for their technical assistance.

References

- Barr D.B., Allen R., Olsson A.O., Bravo R., Caltabiano L.M., and Montesano A., et al. Concentrations of selective metabolites of organophosphorus pesticides in the United States population. *Environ Res* 2005; 99(3): 314–326.
- Barr D.B., Bravo R., Weerasekera G., Caltabiano L.M., Whitehead Jr R.D., and Olsson A.O., et al. Concentrations of dialkyl phosphate metabolites of organophosphorus pesticides in the US population. *Environ Health Perspect* 2004; 112(2): 186–200.
- Boeniger M.F., and Lushniak B.D. Exposure and absorption of hazardous materials through the skin. *Int J Occup Environ Health* 2000; 6(2): 148–150.
- Bradman M.A., Harnly M.E., Draper W., Seidel S., Teran S., and Wakeham D., et al. Pesticide exposures to children from California's Central Valley: results of a pilot study. *J Expo Anal Environ Epidemiol* 1997; 7(2): 217–234.
- Bravo R., Caltabiano L.M., Weerasekera G., Whitehead R.D., Fernandez C., and Needham L.L., et al. Measurement of dialkyl phosphate metabolites of organophosphorus pesticides in human urine using lyophilization with gas chromatography-tandem mass spectrometry and isotope dilution quantification. *J Expo Anal Environ Epidemiol* 2004; 14(3): 249–259.
- Brouwer D.H., Kroese R., and van Hemmen J.J. Transfer of contaminants from surface to hands: experimental assessment of linearity of the exposure process, adherence to the skin, and area exposed during fixed pressure and repeated contact with surfaces contaminated with a powder. *Appl Occup Environ Hyg* 1999; 14: 231–239.
- CDC. *Second National Report on Human Exposure to Environmental Chemicals*. NCEH Pub. No. 02-0716. Centers for Disease Control and Prevention, National Center Environmental Health, Atlanta, GA, 2003.
- Coronado G.D., Vigoren E.M., Thompson B., Griffith W.C., and Faustman E.M. Organophosphate pesticide exposure and work in pome fruit: evidence for the take-home pesticide pathway. *Environ Health Perspect* 2006; 114(7): 999–1006.
- Csiszar E., Borsa J., Racz I., and Obendorf S.K. Reduction in human exposure to pesticide using traditional work clothing fabrics with chemical finishing: carboxymethylation and starch. *Arch Environ Contam Toxicol* 1998; 35(1): 129–134.
- Curl C.L., Fenske R.A., Kissel J.C., Shirai J.H., Moate T.F., Griffith W., and Coronado G., et al. Evaluation of take-home organophosphorus pesticide exposure among agricultural workers and their children. *Environ Health Perspect* 2002; 110(12): A787–A792.
- Curvin B.D., Hein M.J., Sanderson W.T., Nishioka M., and Buhler W. Acephate exposure and decontamination on tobacco harvesters' hands. *J Expo Anal Environ Epidemiol* 2003; 13(3): 203–210.
- DPR. *Pesticide Use Report, Annual 2003, Indexed by Chemical and by Commodity*. Department of Pesticide Regulation, California Environmental Protection Agency, Sacramento, CA, 2003.
- Fenske R.A. Comparative assessment of protective clothing performance by measurement of dermal exposure during pesticide applications. *Appl Ind Hyg* 1988; 3(7): 207–213.
- Fenske R.A., and Lu C. Determination of handwash removal efficiency: incomplete removal of the pesticide chlorpyrifos from skin by standard handwash techniques. *Am Ind Hyg Assoc* 1994; 55(5): 425–432.
- Gomes J., Lloyd O.L., and Revitt D.M. The influence of personal protection, environmental hygiene and exposure to pesticides on the health of immigrant farm workers in a desert country. *Int Arch Occup Environ Health* 1999; 72(1): 40–45.
- Hernandez B., Spencer J., Schneider F., Welsh A., and Fredrickson S. *A Survey of Dislodge Residues on Crop Foliage at Field Reentry, HS-1728*. Cal/EPA, Department of Pesticide Regulation, Worker Health & Safety Branch, Sacramento, CA, 1997 Available: <http://www.cdpr.ca.gov/docs/whs/pdf/hs1728.pdf> (Accessed September 8, 2006).
- Hernandez B., Spencer J., Schneider F., Welsh A., and Fredrickson S. *A Summary of Dislodgeable Foliar Pesticide Residues at Expiration of the Restricted Entry Interval, 1997–2001, HS-1784*. Cal/EPA, Department of Pesticide Regulation, Worker Health & Safety Branch, Sacramento, CA, 2002 Available: <http://www.cdpr.ca.gov/docs/whs/pdf/hs1784.pdf> (Accessed September 8, 2006).

- Hornung R.W., and Reed L.D. Estimation of average concentration in the presence of nondetectable values. *Appl Occup Environ Hyg* 1990; 5(1): 46–51.
- Israel B.A., Parker E.A., Rowe Z., Salvatore A., Minkler M., and López J., et al. Community-based participatory research: lessons learned from the Centers for Children's Environmental Health and Disease Prevention Research. *Environ Health Perspect* 2005; 113: 1463–1471.
- Keifer M.C. Effectiveness of interventions in reducing pesticide overexposure and poisonings. *Am J Prev Med* 2000; 18(4 Suppl): 80–89.
- Kissel J., and Fenske R. Improved estimation of dermal pesticide dose to agricultural workers upon reentry. *Appl Occup Environ Hyg* 2000; 15(3): 284–290.
- Korpalski S., Bruce E., Holden L., and Klonne D. Dislodgeable foliar residues are lognormally distributed for agricultural re-entry studies. *J Expo Anal Environ Epidemiol* 2005; 15(2): 160–163.
- Krieger R.I., and Dinoff T.M. Malathion deposition, metabolite clearance, and cholinesterase status of date dusters and harvesters in California. *Arch Environ Contam Toxicol* 2000; 38(4): 546–553.
- Lander F., and Hinkle K. Indoor application of anti-cholinesterase agents and the influence of personal protection on uptake. *Arch Environ Contam Toxicol* 1992; 22(2): 163–166.
- Lauwerys R.R., and Hoet P. *Industrial Chemical Exposure: Guidelines for Biological Monitoring*. Lewis Publishers, Boca Raton, FL, 1993.
- Lu C., Bravo R., Caltabiano L.M., Irish R.M., Weerasekera G., and Barr D.B. The presence of dialkylphosphates in fresh fruit juices: implication for organophosphorus pesticide exposure and risk assessments. *J Toxicol Environ Health* 2005; 68(3): 209–227.
- Lu C., Fenske R.A., Simcox N., and Kalman D. Pesticide exposure of children in an agricultural community: evidence of household proximity to farmland and take home exposure pathways. *Environ Res* 2000; 84(3): 290–302.
- Marquart H., Brouwer D.H., and van Hemmen J.J. Removing pesticides from the hands with a simple washing procedure using soap and water. *J Occup Environ Med* 2002; 44(11): 1075–1082.
- McCurdy S.A., Hansen M.E., Weisskopf C.P., Lopez R.L., Schneider F., and Spencer J., et al. Assessment of azinphosmethyl exposure in California peach harvest workers. *Arch Environ Health* 1994; 49(4): 289–296.
- Nigg H.N., Stamper J.H., and Queen R.M. Dicofoil exposure to Florida citrus applicators: effects of protective clothing. *Arch Environ Contam Toxicol* 1986; 15(1): 121–134.
- Obendorf S.K., Kasunick R.S., Ravichandran V., Borsa J., and Coffman C.W. Starch as a renewable finish to improve the pesticide-protective properties of conventional workclothes. *Arch Environ Contam Toxicol* 1991; 21(1): 10–16.
- Olsson A.O., Baker S.E., Nguyen J.V., Romanoff L.C., Udunka S.O., and Walker R.D., et al. A liquid chromatography—tandem mass spectrometry multiresidue method for quantification of specific metabolites of organophosphorus pesticides, synthetic pyrethroids, selected herbicides, and deet in human urine. *Anal Chem* 2004; 76(9): 2453–2461.
- Putnam A.R., Willis M.D., Binning L.K., and Boldt P.F. Exposure of pesticide applicators to nitrofen: influence of formulation, handling systems, and protective garments. *J Agric Food Chem* 1983; 31(3): 645–650.
- Racz I., Borsa J., and Obendorf S.K. Carboxymethylated cotton fabric for pesticide-protective work clothing. *Text Res J* 1998; 68(N1): 69–74.
- Saleh M.A., Kamel A., el-Demerdash A., and Jones J. Penetration of household insecticides through different types of textile fabrics. *Chemosphere* 1998; 36(7): 1543–1552.
- Spencer J.R., Sanborn J.R., Hernandez B.Z., Krieger R.I., Margetich S.S., and Schneider F.A. Long vs. short monitoring intervals for peach harvesters exposed to foliar azinphosmethyl residues. *Toxicol Lett* 1995; 78: 17–24.
- US Census Bureau. *Poverty Thresholds 2003, Current Population Survey*. US Census Bureau, Washington, DC, 2003 Available: <http://www.census.gov/hhes/www/poverty/threshld/thresh03.html> (Accessed July 23, 2007).
- US EPA. *Pesticide Worker Protection Standard Training*, 40CFR. Vol. Part 170.130 US Environmental Protection Agency, Washington, DC, 1992.
- US EPA. *Agricultural Transfer Coefficients*, Policy number 003.1 US Environmental Protection Agency, Science Advisory Council for Exposure, Washington, DC, 2000.
- US EPA. *The Worker Protection Standard for Agricultural Pesticides How To Comply Manual*. EPA 735-B-05-002. US Environmental Protection Agency, Washington, DC, 2005 Available: <http://www.epa.gov/agriculture/htc.html> (Accessed August 4, 2006).
- USDA. *The US Strawberry Industry 1970–2006*. 95003. US Department of Agriculture, Economic Research Service (ERS), Washington, DC, 2006 Available at: <http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1381> (Accessed January 10, 2008).
- Westgard J.O. *Westgard QC: Tools, Technology, and Training for Healthcare Laboratories*. Westgard QC, Inc., Madison, WI, 2003 Available: <http://www.westgard.com/> (Accessed January 10, 2003).
- Zhang X. *Human Pesticide Exposure Analysis: Urine Biomarkers of Organophosphorus Insecticides, Malathion, 2,4-D, and Triclopyr [PhD Thesis]*. University of California, Riverside, CA, 2005.