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REVIEW ARTICLE

Pesticide exposure pathways among children of agricultural workers

Patrizia Vida · Angelo Moretto

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Abstract
Aim The focus of this review is to highlight the evidence of the take-home pathway as an additional and substantial route of exposure for children of farm workers. Possible exposure of older children during farm work is not discussed.
Subject A critical examination of papers published during the last 15 years concerning this subject was performed.
Methods An extensive literature search of the most recent papers was carried out to identify papers describing and reporting circumstances of pesticide exposure among “agricultural workers’ children”. Exclusion criteria included papers older than 1990, those reporting pesticide exposures that occurred among residential settings, pesticide intake with diet (or dietary pesticide exposure) and any pesticide exposure related to individuals other than children (i.e. workers, consumers, bystanders). The data from a total of 11 studies which carried out environmental or biological, or both, sampling have been organised into tables.
Results Findings showed evidence of higher pesticide exposure for children of agricultural workers compared with those of non-agricultural workers. This could not be entirely explained by the proximity factor; outcomes suggested that a “take-home” pathway exists and contribute to increasing the indoor contamination of pesticide residues, thus the potential for exposure of children. Further, estimated scenarios indicated that non-dietary ingestion of pesticide residues could lead to intake that exceeds US Environmental Protection Agency (USEPA) oral chronic reference doses (RfD) (and even European Union acceptable daily intake).
Conclusions Although hardly anything can be done with the proximity factor, improving farm workers’ hygiene and correcting some improper behaviour could turn into a considerable benefit for children’s health.

Keywords Pesticide exposure · Children’s exposure · Farm workers’ children · Take-home pathway

Introduction

Concern about adverse effects of pesticides on human health has been voiced in numerous reports, and activities for prevention are carried out in most countries and at the international level. As pesticides are inherently toxic to living organisms, they are likely to affect human health (WHO 1990).

Acute events of poisoning have been of public health concern in past decades both in developed and developing countries. In 1990 the World Health Organization (WHO) estimated one million cases of unintentional poisoning per year. Nowadays, due to the ban of the most toxic compounds and the improved knowledge of safer practise by agricultural workers, cases of acute pesticide poisonings have steadily decreased in developed, high-income countries (Ekstrom et al. 1996; Sumner and Langley 2000). Unfortunately, the burden of acute pesticide poisoning (both accidental and self-inflicted) in the developing world continues to exist (Ecobichon 2001), though some countries recently started to highlight the problem in the public health agenda (Konradsen et al. 2003; Roberts et al. 2003).

Concern is still expressed for chronic low-level exposures in all countries evenly. Chronic pesticide exposures have been

P. Vida (✉) · A. Moretto
International Centre for Pesticides and Health Risk Prevention,
Azienda Ospedaliera Luigi Sacco-Polo Universitario,
Via G.B. Grassi 74, 20157 Milan, Italy
e-mail: patrizia.vida@icps.it

implicated in various diseases ranging from neurobehavioural disorders, developmental toxicity, endocrine disruption and impaired immune system to allergic reactions, especially of the skin. Papers investigating the increased risk of diverse types of cancer among agricultural workers have inconsistent findings and the association is still controversial (Eskenazi et al. 1999; Garry 2004; Jurewicz and Hanke 2006).

Concern for children

Children are at risk of pesticide exposures from sources and levels that are different from those of adults, even in the same exposure scenario. Children's respiratory rate, heart rate and metabolism are significantly diverse from adults (Bearer 1995) and, as stated by the fundamental maxim of paediatric medicine, "children are not little adults". Hand to mouth behaviour further adds to children's exposure via the oral route. In fact, children being closer to the ground (especially toddlers) have frequent opportunities to come into contact with pesticide residues, both inside and outside home (Garry 2004).

Agricultural workers' children

Children living in agricultural settings are subjected to a large variety of events that can lead to the possibility of cumulative and multi-pathway exposures. Playing in treated fields and spray drift are common patterns of exposure in rural areas. Nevertheless, there are even more subtle ways for children to come into contact with pesticides and this is particularly true for the children of agricultural workers, be they farmers, pesticide applicators or other farm workers such as labourers. The expression "take-home" pathway generally refers to the occurrence of agricultural pesticide residues brought into the house by farm worker's bodies, clothes and shoes when coming back home after performing field tasks. A work vehicle could also be a means of transporting pesticide residues, especially if it is used to bear children.

Aim

The focus of this review is to highlight the evidence of the take-home pathway as an additional and substantial source of exposure for children of farm workers, performing a critical examination of papers published during the last 15 years. Possible exposure of older children performing any agricultural work is not discussed in this review.

Methods

An extensive literature search was carried out in order to identify papers describing and reporting circumstances of pesticide exposure among agricultural children. The web-based research tools were the following:

- PubMed: keywords: "pesticide children", "pesticides exposure", "agricultural children", "children exposure". Another search criterion was to look among the section "related articles".
- Ovid: on-line software which allows queries to various data sets.
- Google: terms of search same as PubMed. This tool was of some help especially in searching reports and the grey literature.

Exclusion criteria rejected papers older than 1990 and whose outcomes concerned:

- Pesticide exposures occurring in residential settings
- Pesticide intake with diet (or dietary pesticide exposure)
- Any pesticide exposure related to individuals other than children (i.e. workers, consumers, bystanders)

In order to identify and measure sources of exposure the most common tools are epidemiological surveys, combination of surveys and visual observation, environmental sampling of indoor and outdoor residuals and biological monitoring (urine or blood serum analyses).

This review reports on those studies that included either environmental sampling or biological monitoring (often studies performed both) to evaluate agricultural children's exposure to pesticides. Papers concerning the evaluation of children's pesticide exposure due to residential use only are not reported. A total of 11 studies met the inclusion criteria and are examined in this review.

Most of the studies reported here had been carried out in the USA. The main outcomes are reported in the tables. Table 1 relates to studies which reported environmental sampling and Table 2 those which reported biological monitoring. Table 3 includes two studies that made a statistical analysis to find out whether there was a correlation between the environmental data and biological monitoring that had been measured. Several other studies, although reporting both measurements, did not attempt a statistical correlation between the respective findings.

Targets of environmental sampling studies were: house dust (especially from carpets), floor wipes, vehicle dust and wipes, children's hands and toy wipes, indoor/outdoor air and playground soil.

The target of the biological monitoring studies was in most of these studies urine dialkyl phosphate metabolites (DAPs) that are commonly investigated to yield information on organophosphorus (OPs) exposure; 3,5,6-trichloro-2-pyridinol (TCP) is reported in one study as it is the main metabolite of chlorpyrifos.

One study performed a risk assessment on pesticide intake through dust ingestion. The authors compared intake levels with oral chronic and sub-chronic reference doses (RfDs) provided by the US Environmental Protection Agency (USEPA). In this review those intake values have been utilised to make a comparison with Acceptable Daily Intake (ADI) established by the European Commission (2006).

Under the term “agricultural workers” we generally grouped all those engaged in agricultural occupations and tasks, be they farmers, farm workers, pesticide applicators or other labourers. In the same way we used the terms “agricultural family” or “agricultural households or residences” to indicate those families or homes where at least one person is involved in one of the tasks described above.

Results

Several studies concerning pesticide exposure assessment carried out both environmental and biological sampling, while others limited their research to biological monitoring. Below, the environmental sampling and the biological monitoring outcomes are treated separately with respect to all studies examined. Some of them that reported both environmental and biological monitoring findings are discussed in another section.

Environmental sampling

Indoor versus outdoor

Environmental sampling shows in general that pesticide residues among agricultural settings tend to accumulate in indoor rather than outdoor environments (WHO 1997). Simcox et al. (1995) found OP concentrations in agricultural house dust to be 17 times higher than those found in the yard soil (up to 17.1 versus 0.93 ppm, $p<0.05$), and Curwin et al. (2005) found almost the totality of outdoor air samples under the LOD (limit of detection) (except one of 98 samples).

Agricultural versus non-agricultural

Consistent differences were found between the parameters sampled among agricultural households compared with references. Simcox et al. (1995) found OP concentrations in agricultural house dust to be at least 17 times those in non-agricultural residences. Bradman et al. (1997) detected several times higher diazinon and chlorpyrifos concentrations and more frequent samples over the LOD in farm worker house dust even if they did not report recent storage and/or home use of pesticides.

Similar findings are reported in several studies (Lu et al. 2000, 2004; Fenske et al. 2002; Curwin et al. 2005) for OP insecticides (such as diazinon, chlorpyrifos, azinphosmethyl, phosmet) and herbicides (such as atrazine and metolachlor).

Proximity

Some studies showed a significant relationship between proximity of the households to the treated field and the levels of pesticide in house dust. Statistical correlation was found by Simcox et al. (1995) for those homes located within 50 feet (about 15 m) from the orchard (p=0.005). Lu et al. (2000) reported dust levels of OPs among agricultural homes within 200 feet twice as high as those in agricultural families living more distantly, while Fenske et al. (2002) found levels in closer homes nearly three times higher than in distant houses. Curl et al. (2002) on the contrary found no association between these two parameters.

Occupation/task performed

Substantially different pesticide levels in house dust were found within the agricultural households, depending on the occupation/task performed by the agricultural workers. Simcox et al. (1995) noted that the strongest correlation exists with “pesticide applicator status” versus non-applicators (p=0.0003 for parathion). The highest parathion levels among applicator residences (median 0.4 ppm, up to 2.6 ppm vs 0.3 ppm, up to 0.6 ppm in non-applicator) as well as the lowest frequency of samples below LOD was found by Fenske et al. (2002). Similar patterns were found for chlorpyrifos too (Fenske et al. 2002).

A positive correlation between levels of OPs in houses and in vehicles and the specific job task performed was found by Coronado et al. (2004). Thinning was associated with the highest levels of azinphosmethyl as compared to mixing, loading and applying pesticide formulation. Lu et al. (2000) found somewhat higher concentrations in applicator houses than in other agricultural residences, but the levels observed were not statistically different.

Take-home by vehicle and clothes

Pesticide residues were found in wipe samples of parent’s work boots and of the steering wheel of their cars (Lu et al. 2000). Curl et al. (2002) found also a strong correlation between the pesticide levels in house dust and in the vehicle dust.

Particularly, Curwin et al. (2005) detected the highest atrazine and metolachlor levels in the father’s changing area (up to 740 and 1400 ppb) and the laundry room (up to 530 and 1200 ppb) as compared to other rooms.

Children’s hands

A number of studies determined the pesticide contamination of hands of agricultural workers’ children with respect to children of reference families (Bradman et al. 1997; Lu et al. 2000, 2004). Bradman et al. (1997) revealed that two

Table 1 Environmental sampling

Author and year	Location	Study design	Children's age	Groups (number of subjects)	Target compounds	Main findings
Simcox et al. (1995)	Douglas and Chelan Co., WA, USA	Cross-sectional environmental sampling and questionnaire assessment	1–6 years	Agricultural (Ag) families (n=48) Farmers (n=26) Farm workers (n=22) Applicators (n=28) Non-applicators (n=20) Non-agricultural (non-Ag)/ reference families located >1/4 mile from orchard (n=11)	OPs: azinphosmethyl, phosmet, chlorpyrifos, ethyl parathion	OP concentrations in Ag homes: non-detectable (ND)-0.93 ppm in soil; ND-17.1 ppm in dust (17 times higher, $p<0.05$) OP concentrations in non-Ag homes: all levels below 1 ppm Statistical correlation for parathion found in house dust with proximity from orchard less than 50 ft (p=0.005), occupation farmer (p=0.0007) and applicator status (p=0.0003)
Bradman et al. (1997)	Central Valley, CA, USA	Cross-sectional environmental sampling and questionnaire assessment	1–3 years	Farm worker families (n=5) Reference/non-Ag (n=6)	33 pesticides	Diazinon in house dust: farm worker (4 homes): 0.7–169 ppm; non-farm worker (3 homes): 0.2–2.5 ppm Chlorpyrifos in house dust: farm worker (3 homes) 0.2–33 ppm; non-farm worker (2 homes) <1 ppm Other pesticides: <2 ppm in less than 4 homes Diazinon and chlorpyrifos: found on 3 children's hands of farm worker homes (20–220 ng/hand), 2 of these with the highest house dust concentrations Storage and home use of these compounds not reported at farm worker homes
Lu et al. (2000)	Douglas and Chelan Co. WA, USA	Cross-sectional environmental and biological sampling	9 months–6 years	Ag families (n=62), 91 children: Applicators (n=49), 72 children Farm workers (n=13), 19 children <200 ft from orchards (n=47) >200 ft from orchards (n=15) Non-Ag/reference families (n=14) located >1/4 mile from orchards with 18 children	OPs: azinphosmethyl, dimethyl OP, phosmet	Dimethyl OP median house dust levels in Ag families: 7 times reference (1.92 vs 0.27 ppm, $p<0.001$) Median pesticide levels in house dust of Ag families <200 ft about 2 times Ag families >200 ft (0.01–15 ppm vs ND-8.4 ppm (p=0.01) 10 to 61 Ag children with levels of OPs (up to 1.2 ppm) on their hands, while no levels in reference
Curl et al. (2002)	Yakima Valley, WA, USA	Environmental and biological sampling and questionnaire assessment	2–6 years	Ag families (n=218) with 218 children Proximity: <1 block 1–2 blocks 2–4 blocks 4–8 blocks 8 blocks–1 mile >1 mile	Azinphosmethyl, malathion, m-parathion, phosmet, chlorpyrifos, diazinon	Azinphosmethyl in dust: higher than other pesticides ($p<0.0001$), mean 0.53 ppm in house, 0.75 ppm in vehicle House and vehicle levels strongly associated (r^2=0.41, $p<0.0001$) Azinphosmethyl in house dust not associated with proximity to fields
Curwin et al. (2005)	Keokuk and Mahaska Co., IA, USA	Cross-sectional environmental sampling with repeated	Up to 8 years	Ag households (n=25) Non-Ag/reference (n=25)	Atrazine, metolachlor, acetochlor, alachlor,	88% air, 74% wipe samples were under the LOD (almost totality of the air blank samples) Chlorpyrifos in indoor samples: 0.04–0.23 μg/m^3 among Ag (6 homes) and 0.01–0.05 μg/m^3 among non-Ag (2 homes)

Table 1 (continued)

Author and year	Location	Study design	Children's age	Groups (number of subjects)	Target compounds	Main findings
		measures and questionnaire assessment			chlorpyrifos, glyphosate, 2,4-D	Average concentrations in dust: higher in Ag homes vs non-Ag for each pesticide, significantly higher for atrazine, up to 17 ng/cm^2 in Ag, and metolachlor, up to 9.8 ng/cm^2 in Ag (OR=9.4, 95% CI=3.25–25 and OR=2.1, 95% CI=1.1–3.9) Chlorpyrifos, glyphosate and 2,4-D: ubiquitous in dust among Ag and non-Ag homes in all rooms Atrazine and metolachlor dust levels: higher in father's change area (up 740 and 1400 ppb) and laundry room (up to 530 and 1200 ppb) than other rooms.
Lu et al. (2004)	Central Washington State and Seattle urban area, WA, USA	Cross-sectional environmental, and dietary sampling with repeated measures and questionnaire assessment	2–5 years; mean age: 3.8 for Ag children and 4.1 for non-Ag children	Ag families (n=6) Non-Ag/urban families (n=7)	OPs: diazinon, chlorpyrifos, azinphosmethyl, phosmet	All 6 agricultural house dust samples had detectable azinphosmethyl levels (range: 0.56–5.39 ppm during summer campaign) None of the hand or toy wipe samples collected from non-Ag children showed detectable levels of OPs Detectable levels of chlorpyrifos and azinphosmethyl was found on samples coming from Ag children's hands and toys (up to 0.27 µg/sample for azinphosmethyl in hand wipe and 0.45 µg/sample in toy wipe) 12 items consumed by non-Ag children contained quantifiable OPs, while only 6 were found in Ag children's diets
Fenske et al. (2002)	Douglas and Chelan Co. WA, USA	Cross-sectional environmental and biological sampling with repeated measures	9 months–6 years	Ag families (n=61) with 91 children: Applicators (n=49) involving 72 children Farm workers (n=12) involving 19 children Proximity: <200 ft >200 ft Non-Ag/reference families located >1/4 mile from orchards (n=14) involving 18 children	Chlorpyrifos and parathion	Median chlorpyrifos in house dust: applicators 0.4 ppm (up to 2.6), farm workers 0.3 ppm, non-Ag 0.1 ppm, statistically different ($p<0.001$); similar pattern for parathion ($p<0.01$) Median house dust levels of chlorpyrifos were 4 times higher in Ag families than in references Median dust chlorpyrifos Ag homes <200 ft from orchards: 0.4 ppm vs 0.15 ppm (p=0.01)
Coronado et al. (2004)	Yakima Valley, WA, USA	Cross-sectional environmental and biological (part of a larger study) and questionnaire assessment	2–6 years	213 farm worker homes including 218 children (of which analysis conducted for 156 house dust samples and 190 vehicle dust samples)	Azinphosmethyl, other OPs	Thinning was with higher levels of azinphosmethyl in house and vehicle dust Mixing, loading or applying pesticide formulations not associated with higher levels of pesticide in house and vehicle dust

of the three positive children had the highest pesticide levels in their house dust. Through wipe sampling, all those studies found detectable OP levels on the hands of children living in farm worker or pesticide applicator homes whereas no positive wipe samples had been collected from reference children's hands. Azinphosmethyl concentrations (Lu et al. 2004) on children's toys were higher than those of hand wipes (up to 0.45 µg/sample versus 0.27 µg/sample).

Biological monitoring

Higher concentrations of DAP metabolites in children's urine had been detected during spraying months (peak in June) compared with winter months (geometric means of dimethyl phosphate 0.15 versus 0.05 µmol/l, p=0.009) by Koch et al. (2002). Fenske et al. (2002) found TCP in urine to be at least three times higher in children whose garden was sprayed with OPs (independently from parental occupation). Similar findings are described by Rodriguez et al. (2006) who found 8 h after the application three times higher levels of TCP in children's urine than those detected before the application.

Agricultural versus non-agricultural

Findings of some studies showed statistically significant higher levels of pesticide metabolites in the urine samples of agricultural children versus reference children. Loewenherz et al. (1997) detected fourfold higher dimethyl phosphate (DMTP) concentrations in the urine of pesticide applicator children than those in references (0.021 versus 0.005 µg/ml, p=0.015). A very similar pattern of differences had been found by Lu et al. (2000) (0.05 versus 0.01 µg/ml, p=0.09). Coronado et al. (2004) found that levels of dimethyl metabolites were associated with parental thinning performed in the previous 3 months (about 92% of the samples had detectable levels) but not with parental mixing, loading or applying pesticide formulations. Instead, a non-significant correlation with the agricultural status or parental occupation was found by Koch et al. (2002) and Fenske et al. (2002).

Proximity

Two studies found a positive correlation between urine metabolites and the proximity to the treated field. Loewenherz et al. (1997) found an higher frequency of detectable levels of DMTP in applicator children (p=0.036), and a stronger correlation was observed by Lu et al. (2000) among agricultural children; they found significantly higher concentrations of OP metabolites in those living within 200 feet from treated orchards (p=0.01). No association with proximity was found in other papers (Curl et al. 2002; Koch et al. 2002; Fenske et al. 2002).

Curl et al. (2002) found a clear association between parental and children's levels of methyl DAP metabolites, r^2=0.18 and p<0.0001. In this study it is also evident that children's concentrations were higher than those of adults (creatinine-adjusted geometric mean 0.14 versus 0.09 µmol/l). Rodriguez et al. 2006 also found a significant correlation between children's and adults' levels of TCP in the evening sample taken the day of chlorpyrifos application (r^2=0.73, p=0.03).

Loewenherz et al. (1997) detected marginally significant higher levels of pesticide metabolites among the younger of each paired set of children (paired analysis of the 21 sibling pairs, p=0.040).

Environmental versus biological findings

Few studies made a statistical analysis to assess whether a correlation could be identified between concentrations in indoor environments and biological indicators such as urinary pesticide metabolites. The strongest correlation between OP house dust levels and DAP metabolites in children's urine was found by Curl et al. (2002) with a r^2= 0.15 and p<0.0001 for creatinine-adjusted appraisal (very similar results for non-adjusted). For the same variables Lu et al. (2000) found a marginally significant correlation only.

Non-dietary intake

Dust ingestion exposure scenarios investigated by Bradman et al. (1997) showed that children of two homes with the highest diazinon levels in house dust had an estimated intake that exceeded the USEPA OPP's (Office of Pesticide Programs) chronic oral RfD of 9×10^{-5} mg/kg body weight per day (USEPA 1995). In fact chronic estimated daily intake was 2.5×10^{-4} mg/kg body weight per day for the house with a diazinon dust level of 20 ppm, while it was 1.1×10^{-3} mg/kg body weight per day for the house with a dust level of 169 ppm. For the latter, the USEPA sub-chronic RfD of 9×10^{-4} mg/kg body weight per day was also exceeded. In the home with a diazinon dust concentration of 20 ppm children were found with residues on their hands of 220 ng/sample, so ingestion scenarios of 2.1×10^{-4} exceeded the chronic oral RfD.

The ADI for diazinon established at European level, 2×10^{-4} mg/kg body weight per day (for this active substance the evaluation is still pending) would be exceeded in the case of house dust levels of 169 ppm (European Commission 2006).

Concerning another 32 pesticide residues investigated in home dust or on children's hands, ingestion scenarios did not exceed either the chronic or sub-chronic RfD and were not considered to represent a health risk either singly or grouped together (Bradman et al. 1997).

Table 2 Biological monitoring (metabolites in urine)

Author and year	Location	Study design	Children's age	Groups (number of subjects)	Target compounds	Main findings
Loewenherz et al. (1997)	Douglas and Chelan Co. WA, USA	Cross-sectional biological monitoring with repeated measures	Up to 6 years Mean age of applicator children 3.45 years and 3.48 years for references	Pesticide applicator households: children (n=70) Children's age bands: 0–2 years ($n1$=19, $n2$=20) 3–4 years ($n1$=25, $n2$=25) 5–6 years ($n1$=19, $n2$=20) Reference households: children (n=18), living >200 ft from orchards Children's age bands: 0–2 years ($n1$=8, $n2$=8) 3–4 years ($n1$=4, $n2$=3) 5–6 years ($n1$=5, $n2$=5)	DMTP, DMDTP metabolites	DMTP median levels: applicator children 0.021, reference children 0.005 µg/ml (p=0.015) Younger children in each pair had higher metabolite levels than those of the elder (paired analysis of the 21 sibling pairs, p=0.40) Proximity to the field associated with higher frequency of detectable DMTP in applicator children (p=0.036)
Lu et al. (2000)	Douglas and Chelan Co. WA, USA	Cross-sectional environmental and biological sampling	9 months–6 years	Ag families (n= 62), with 91 children: Applicators (n=49) with 72 children Farm workers (n=13) with 19 children Proximity: <200 ft (n=47) >200 ft (n=15) Non-Ag/reference families (n=14) located $>1/4$ mile from orchards with 18 children	DMTP, DMDTP, dimethyl OP metabolite	Median OP metabolite: 0.05 µg/ml in Ag children vs 0.01 in reference (p=0.09) DMTP and OP metabolite: ND-0.6 µg/ml in Ag children living <200 ft vs ND–0.3 µg/ml in Ag children living >200 ft (p=0.01)
Curl et al. (2002)	Yakima Valley, WA, USA	Environmental and biological sampling and questionnaire assessment	2–6 years	Ag families (n=218) with 218 children Proximity: <1 block 1–2 blocks 2–4 blocks 4–8 blocks	DAP metabolites: DMP, DMTP, DMDTP, DEP, DETP	Creatinine-adjusted geometric mean dimethyl DAP: 0.09 µmol/l in adult and 0.14 µmol/l in child Methyl DAP in child and adult from the same house significantly associated (r^2=0.18, $p<0.0001$) No association of child urine levels of dimethyl DAP with proximity to the field

Table 2 (continued)

Author and year	Location	Study design	Children's age	Groups (number of subjects)	Target compounds	Main findings
				8 blocks-1 mile >1 mile		
Koch et al. (2002)	Central Washington State, USA	Longitudinal biological monitoring study with repeated measures (18 months)	2–5 years	Farm worker children (n=27)	Dimethyl and diethyl DAP metabolites	Geometric means for DAP metabolites higher in the spraying months: dimethyl in June 1998 0.15 vs about 0.05 μmol/l in following winter months (p=0.009 for dimethyl and p=0.018 for diethyl)
				Non-Ag children (n=17)		Male levels higher than female (p=0.005 for dimethyl, p=0.046 for diethyl)
				Proximity: <200 ft (n=5) >200 ft (n=39)		No association with age, parental occupation or residential proximity to the field
Fenske et al. (2002)	Douglas and Chelan Co. WA, USA	Cross-sectional environmental and biological sampling with repeated measures	9 months–6 years	Applicator families (n=49) involving 72 children	TCPy (major urine metabolite of chlorpyrifos)	Children in 20 homes with reported OP use in the garden had higher TCPy concentrations than did others (8.3 vs 2.4 μg/l, p=0.02)
				Farm worker families (n=12) involving 19 children		No association with parental occupation or proximity to the orchards
				Non-Ag/reference families located >1/4 mile from orchards (n=14) involving 18 children		
Coronado et al. (2004)	Yakima Valley, WA, USA	Environmental and biological sampling (part of a larger study) and questionnaire assessment	2–6 years	213 farm worker homes including 218 children (of which analysis conducted for 156 house dust samples and 190 vehicle dust samples)	Dimethyl metabolites: DMP, DMTP, DMDTP	Parental thinning (previous 3 months) associated with higher dimethyl metabolite levels in children (91.9% detectable vs 81.3% of those who had not thinned in the last 3 months, p=0.02)
						Mixing, loading or applying pesticide formulations reported by 20% of the farmers not associated with dimethyl concentrations in children
Rodriguez et al. (2006)	Leon and Chinandega, Nicaragua	Cross-sectional biological monitoring	2–12 years	7 applicator families (7 children)	TCPy and IMPy (major urine metabolite of diazinon)	Child TCPy peaked 8.5 h after application with a geometric mean of 2.99 μg/l, 3 times increase from the pre-application level but not statistically significant (p>0.05)
				10 plantation families (10 children)		Significant correlation between adult and child TCPy levels (r^2=0.73, p=0.03)
						No significant evidence of exposure to diazinon in children

Table 3 Environmental versus biological findings

Author and year	Location	Study design	Children's age	Groups (number of subjects)	Target compounds	Main findings
Lu et al. (2000)	Douglas and Chelan co. WA, USA	Cross-sectional environmental and biological sampling	9 months–6 years	Ag families (n=62), with 91 children:	OPs: azinphosmethyl, dimethyl OP, phosmet	Marginally significant association between house dust concentrations (azinphosmethyl, phosmet or combined dimethyl OP pesticides) and urinary metabolites for either Ag families or references (r^2= 0.12, p=0.09)
				Applicators (n=49) with 72 children	DMTP, DMDTP, dimethyl OP metabolite	
				Farm workers (n=13) with 19 children		
				Proximity: <200 ft (n=47) >200 ft (n=15)		
				Non-Ag/ reference families (n=14) located >1/4 mile from orchards with 18 children		
Curl et al. (2002)	Yakima Valley, WA, USA	Environmental and biological sampling and questionnaire assessment	2–6 years	Ag families (n=218) with 218 children	Environmental sampling: azinphosmethyl, malathion, m-parathion, phosmet, chlorpyrifos, diazinon	Concentrations of azinphosmethyl in house dust significantly associated with dimethyl DAP levels in child urine (non-adjusted: r^2= 0.14, p<0.0001; creatinine adjusted r^2=0.15, p<0.0001)
				Proximity: <1 block 1–2 blocks 2–4 blocks 4–8 blocks 8 blocks–1 mile >1 mile	DAP metabolites: DMP, DMTP, DMDTP, DEP, DETP	

Discussion

Opportunities for childhood exposure to pesticides have been considered of concern because of the potential adverse effect on the health of the younger individuals. Particularly, chronic and low-level exposure may occur throughout their lifetime for those living in agricultural settings, not only directly when engaged in field tasks, but inside their home also.

Environmental sampling shows in general that pesticide residue levels are higher in the indoor environment rather than outdoor, where chemical and biological degradation processes are more rapid.

In the same rural community concentrations are several times higher among agricultural households compared with non-agricultural. To a certain extent this can be explained by the proximity factor, which allows spray drift to come inside home, especially in orchards, where pesticides are sprayed at some height above the soil. Farms are located very close to the treated fields and often other agricultural workers (non-farmer) are likely to live in the neighbourhood. The inclusion in the study of a reference population living in the proximity of a treated field may help to solve this issue, though such a population is not likely to be found.

Higher pesticide concentrations among agricultural homes seem linked to the occupation performed by the householders, the strongest association being possible with “applicator status” (Simcox et al. 1995; Fenske et al. 2002; Lu et al. 2000).

This contrasts with the findings by Coronado et al. (2004), who found the strongest association between house and vehicle dust and workers that performed thinning operations, instead of those that had been mixing, loading or applying formulations. It has been supposed that thinning operations may have been performed after inadequate re-entry intervals.

There are a number of improper behaviours that may put contaminated bodies, clothing and boots into contact with indoor environments. Considering the findings of the questionnaire administered by Gladen et al. (1998) (see Table 4), about 80% of the farm workers surveyed wash themselves after work in the bathroom and wash working clothes with the same machinery used for all laundry. This is supported by the findings of Curwin et al. (2005): higher pesticide levels were detected in the father's changing area and in the laundry room compared with other rooms. The distributions of the pesticides throughout the various rooms sampled suggest that strictly agricultural pesticides (such as the herbicides atrazine and metolachlor) are potentially being brought into the home on the farmer's body, shoes and clothing, confirming the existence of potential para-occupational pathways of exposure. The take-home pathway is further demonstrated by analysis showing a significant correlation between pesticide concentrations in house dust and respective vehicle dust (Curl et al. 2002).

An association between pesticide exposure and presence of urine DAP metabolites is well known (Aprea et al. 2000; Azaroff 1999).

As expected, biological monitoring studies generally confirm the fact that agricultural children are more exposed to pesticides than non-agricultural. In particular, the metabolites in children's urine were higher and more frequently above the LOD among the children whose parent performed thinning in the last 3 months compared with other occupations such as handling and applying pesticide formulations. However, no clear and consistent association between urine metabolites and proximity was found with the exception of Lu et al. (2000) (see Table 2).

Children's and adults' levels of pesticide metabolites are linked as ascertained by Curl et al. (2002). It is interesting to note that children's concentrations were even higher than those of adults living in the same household. This indicates a higher exposure/absorption of children as compared to their parents. This may be due to certain behaviour of the children (as further explained below).

Another remarkable fact was found by Loewenherz et al. (1997), who detected the highest concentrations among the younger of each paired set of children (from the same family). Hand to mouth contacts, typical behaviour of toddlers and younger children, may have led to a higher intake of pesticides.

Few studies reported here analysed the correlation between pesticide concentrations in indoor environments and levels of a biological indicator of exposure such as urine DAP metabolites (Curl et al. 2002). The most likely explanation may be that the vehicle used for commuting to work is a vector of pollution and that the residues measured inside the vehicle are indicators of contaminated worker's clothing or skin. As this study revealed no association between house dust levels of pesticides with proximity to the field it is unlikely that spray drift could justify that correlation. It was also considered improbable that the residues of the pesticide come from residential use.

Scenarios studied by Bradman et al. (1997) highlighted the matter of non-dietary intake exposure, especially concerning toddlers. In two farm worker homes the intake estimates exceeded the oral chronic RfD (in one case even the sub-chronic) for the risk of cholinesterase inhibition. Considering the concentrations measured by Lu et al. (2000) on children's hands, up to 1.2 ppm, the intake scenario via hand to mouth contact may be even worse. Some uncertainties arose from the fact that, though dust ingestion and hand to mouth contact had been investigated in this study, nothing was said about potential inhalation of contaminated house dust or dermal uptake, or if children had "pica behaviour". This is surely an issue of concern, even if, due to the conservative approach of the risk assessment, the excess of the US and EU reference doses does not mean that poisoning or any other adverse health effect will occur. Nevertheless, multi-pathway pesticide exposure in children should consider non-dietary ingestion, at least for those cases where high pesticide levels are found inside the home (dust, floor wipes, etc.) or on children's hands.

The outcomes of this review suggest that hazardous behaviours and habits should be avoided. Residues on skin, working clothes and shoes may be brought inside home, increasing indoor pesticide contamination as the potential exposure to children (Curwin et al. 2002, 2005).

Table 4 Behaviour and habits among agricultural workers (Gladen et al. 1998)[a]

Activity
27% of applicators has stored pesticides at home
79% washed in bathroom after work
81% wash working clothes separately in the same machine used for all laundry
62% take off working boots before entering the house
24% of IA male children aged up to 5 perform activities associated with farming (17% in NC), and percentages increase with age

[a] Questionnaire assessment of 26,793 farmer pesticide applicators carried out among pesticide applicators from Iowa and North Carolina in order to better understand their behaviour and habits that can affect the exposure of their children to pesticides

Conclusions

The findings showed evidence of higher pesticide exposure for children of agricultural workers compared with those of non-agricultural families. Scenarios indicated, for at least two studies, that non-dietary ingestion could lead to an estimated intake that exceeds USEPA oral chronic RfD (and even EU ADI). These outstanding exposures are due both to the proximity factor and the take-home pathway. Hardly anything can be done for the former, while improving farm workers' hygiene and correcting some improper behaviour could result in a considerable reduction of the risk for children.

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