



Review Article

Dermal Exposure Associated with Occupational End Use of Pesticides and the Role of Protective Measures



Ewan MacFarlane^{1,*}, Renee Carey², Tessa Keegel^{1,3}, Sonia El-Zaemay⁴, Lin Fritschi²

¹ Monash Centre for Occupational and Environmental Health, School of Public Health and Preventive Medicine, Monash University, Melbourne, Australia

² Western Australian Institute for Medical Research, University of Western Australia, Perth, Australia

³ McCaughey Centre, University of Melbourne, Melbourne, Australia

⁴ School of Population Health, University of Western Australia, Perth, Australia

ARTICLE INFO

Article history:

Received 20 March 2013

Received in revised form

29 July 2013

Accepted 31 July 2013

Keywords:

agricultural workers' diseases

occupational exposure

pesticides

protective clothing

skin absorption

ABSTRACT

Background: Occupational end users of pesticides may experience bodily absorption of the pesticide products they use, risking possible health effects. The purpose of this paper is to provide a guide for researchers, practitioners, and policy makers working in the field of agricultural health or other areas where occupational end use of pesticides and exposure issues are of interest.

Methods: This paper characterizes the health effects of pesticide exposure, jobs associated with pesticide use, pesticide-related tasks, absorption of pesticides through the skin, and the use of personal protective equipment (PPE) for reducing exposure.

Conclusions: Although international and national efforts to reduce pesticide exposure through regulatory means should continue, it is difficult in the agricultural sector to implement engineering or system controls. It is clear that use of PPE does reduce dermal pesticide exposure but compliance among the majority of occupationally exposed pesticide end users appears to be poor. More research is needed on higher-order controls to reduce pesticide exposure and to understand the reasons for poor compliance with PPE and identify effective training methods.

© 2013, Occupational Safety and Health Research Institute. Published by Elsevier. All rights reserved.

1. Introduction

According to the United States Environmental Protection Agency (EPA), pesticides are defined as substances used to prevent, destroy, repel, or mitigate any pest ranging from insects, animals, and weeds to microorganisms [1]. Occupational end users of pesticides may experience bodily absorption of the pesticide products they use and this puts them at risk of possible health effects associated with pesticide exposure.

The purpose of this paper is to provide a guide for researchers and practitioners working in the field of agricultural health or other areas where occupational end use of pesticides and exposure issues are of interest. Dermal exposure is an important issue for pesticide applicators [2,3], and the aim of this paper is to describe and characterize dermal exposure to pesticides among pesticide end users, and protective measures that mitigate exposure.

2. Health effects of pesticide exposure

Chemical pesticides consist of an active ingredient, the actual poison, and a variety of additives, which improve the efficacy of its application and action. Pesticides can be classified or grouped according to the target organisms (e.g., insecticides, fungicides, and herbicides), chemical structure of the compound (e.g., organochlorine, organophosphorus, phenoxy acid herbicides, urea, and pyrethroids) [4,5], or type of health hazard involved [6].

Health effects resulting from pesticide exposure vary according to the individual pesticide involved and may be the result of exposure via the dermal, oral, or inhalational routes, however, dermal exposure is the most relevant route of exposure for pesticide applicators [2,3]. Health effects may be classified as acute or chronic, based on the period it takes for symptoms of toxicity to develop.

* Corresponding author. MonCOEH, School of Public Health and Preventive Medicine, Monash University, The Alfred Hospital, Commercial Road, Melbourne 3004, Australia.

E-mail address: Ewan.MacFarlane@monash.edu (E. MacFarlane).

This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (<http://creativecommons.org/licenses/by-nc/3.0>) which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

Acute toxicity is normally the result of a single exposure and the symptoms are seen within a comparatively short time of exposure, usually within hours or days. Liquid formulations are generally more hazardous than solid state products because it is more difficult for a solid to pass through the skin or mucous membrane [7]. Acute health effects may include irritation of skin or eyes or respiratory irritation.

Chronic effects may include neurological and mental health effects, mutagenic or reproductive effects, endocrine effects, and cancer. For chronic effects, the level of evidence on which a determination of toxicity is made is often poor. Although acute effects are relatively easy to demonstrate in animal experiments, or are seen after poisonings, the chronic effects of pesticides are more difficult to study. Toxicological studies can provide information regarding mechanisms and effects in animals, but epidemiological studies of exposure in humans are needed in order to establish causation. However, many epidemiological studies combine exposure to all pesticide groups together, resulting in a dilution of effect, because it is not plausible that such a diverse collection of chemicals would have the same effect. By contrast, studies examining individual pesticide groups may not provide sufficient study power for definitive statements. Most studies categorize pesticide exposure as a dichotomous variable (exposure or no exposure) with no evidence on level or frequency [8]. As well as the misclassification of exposure, there can be misclassification of outcome, such as when all cancers are grouped together rather than examining the risk of cancer at specific sites [9].

3. Occupational pesticide users – jobs associated with pesticide use

Occupational end users of pesticides include workers who are involved in the application of pesticides or who re-enter treated areas shortly after pesticide application. Such workers are mostly classifiable as (1) agricultural workers, (2) structural/urban pest controllers, or (3) municipal, public utilities, parks and gardens workers, and foresters. Each of these groups has distinctive pesticide exposure profiles due to differences in the context and purpose of pesticide use.

Agricultural workers are one of the major groups of pesticide-exposed workers. The types of pesticide, frequency of use, and application method vary according to the farm type and the commodities being grown. Although agricultural activity accounts for the majority of occupational pesticide use [10,11], farm pesticide use is generally an intermittent, seasonal task and only one of the wide range of tasks undertaken by farm workers [10,12]. Consequently, the exposure frequency and total exposure time among most farm workers are typically lower than for pesticide applicators in other industries [13]. Dedicated agricultural pesticide applicators have more frequent exposure than farm operators but may have fewer years of pesticide use [14]. Many of the published cohort studies of pesticide exposure and health effects have focused specifically on agricultural workers who are licensed pesticide users (e.g., [15–19]). However, there is evidence suggesting that pesticide exposure may not be universal among farm workers, and a large proportion of workers in the farming sector may not be exposed to pesticides directly [20,21].

Dedicated nonagricultural pest control operators (structural or urban pest controllers) comprise a comparatively small fraction of the pesticide-exposed workforce, however, their exposure pattern is systematically different from that of agricultural pesticide applicators [22]. These nonagricultural pest controllers are exposed on a more regular basis because the application of pesticides is a central task of their job [23,24]. Another important difference is that nonagricultural pest controllers' work is predominantly

associated with built environments and applying pesticides indoors, including restricted spaces [25].

Other occupational pesticide users include turf workers, such as greenkeepers and other sports facilities caretakers, ornamental gardeners, and park workers who may use weedicides, fungicides, and insecticides to maintain turf and gardens [26]. Herbicide use is characteristic of workers involved in maintenance of public infrastructure and in particular clearance of vegetation from linear infrastructure corridors such as roads, railway lines, and overhead electrical distribution lines (line clearance) [26]. Line clearance and other vegetation control tasks using herbicides may also be common among forestry workers [27].

4. Pesticide-related work tasks

The principal route of exposure with end use of pesticides is through skin contact [3]. Respiratory entry appears to be more limited, likely due to low vapor pressures of many pesticides [28,29].

Assessing exposure to pesticides in real-life situations is difficult. It is seldom possible to assess pesticide exposure by direct biological measurement in large epidemiological studies, so pesticide exposure has often been assessed using surrogates of exposure, such as self-reported questionnaire data, leading to imprecise exposure assessment [13,29]. Exposure estimates based on individual-use records have been shown to result in substantial dose misclassification [30–32].

In general, pesticide end use involves the following basic sequential stages: (1) mixing and loading, (2) application, and (3) clean-up. Although exposure levels may vary widely between individual operators, mixing and loading are the tasks associated with the greatest intensity of exposure. It is during the mixing/loading phase that workers are exposed to concentrated product and when high exposure events (e.g., spills) are most likely [3,28]. However, because pesticide application is typically a longer duration task than mixing and loading, total contamination incurred while applying pesticide may exceed mixing and loading [29]. There is also evidence that equipment cleaning at the end of the task may also be an important source of exposure, at least in some workers [29].

The amount of pesticide deposited on the operator's skin depends on the type of application equipment used [3,10,29]. Hand spraying with wide-area spray nozzles is associated with greater operator exposure than narrowly focused spray nozzles [31]. When pesticides are applied using tractors, spraying equipment mounted directly on the tractor is associated with a higher degree operator exposure than when the spray equipment is attached to a trailer [3].

Due to differences in individual work habits, the distribution of pesticide deposition on different parts of the operator's body is also subject to variation [3]. Several studies of body surface contamination in agricultural applicators show that the hands and forearms are the part of the worker's body subject to the greatest pesticide contamination during preparation and application of pesticides [3,13,29]. However, the thighs, forearms, chest, and back may also be subject to significant contamination [3,13].

Cleaning of pesticide application equipment may also be a source of operator exposure. Equipment cleaning is an important farm pesticide task, and time devoted to cleaning may be a substantial proportion of the mix/load/apply/clean-up sequence [3,29]. In a study of workers' whole-body dermal contamination, Baldi et al [29] demonstrated that equipment cleaning may contribute appreciably to workers' cumulative daily dermal exposure and, as with other pesticide tasks, considerable variation was observed between workers.

Applying pesticides to livestock, particularly sheep dipping, is a source of occupational pesticide exposure on livestock farms but

there are relatively few published data about worker exposures during this task. Published data from the UK suggest that like other applicators, skin absorption is the main route of exposure during sheep dipping and particularly associated with handling of concentrates, and to a lesser extent splashing with dilute dip as animals pass through the bath. Inhalation does not appear to be an important route of exposure [33]. Given that dip baths need to be regularly topped up with concentrate, handling is frequent and the potential for skin contamination among those workers who handle the concentrate is high [33].

Unexpected events are also an important source of surface contamination for applicators and the exposure levels associated with these events can result in acute and long-term health effects [34]. Such events include spills and splashes that may lead to high personal exposure and can overwhelm usual protective measures. In the Agricultural Health Study (USA) 14% of farmers licensed to apply restricted pesticides reported ever having had such an exposure event [34]. The unexpected problems that lead to high exposure events are most common during mixing/loading and application phases but may also occur during clean-up [29].

Although workers who prepare and apply pesticides have been the main focus of research to date, workers re-entering sprayed fields after pesticide treatment may also be exposed, sometimes to a significant degree [20,35,36]. There is evidence that re-entry workers may have pesticide absorption greater even than applicators, possibly because safety training and use of personal protective equipment (PPE) are less and their duration of exposure may be greater than that of applicators [20,36,37]. Re-entry exposure is a particular problem if workers re-enter treated fields very soon after pesticide application [28]. Field workers may also be inadvertently exposed to spray drift from neighboring fields, and overexposure events of this kind, each involving groups of workers, have been documented [11,38]. An Australian field study conducted in the early 1990s found 6% inhibition of erythrocyte cholinesterase in workers re-entering cotton fields for weed removal after aerial spraying [35]. Although the degree of cholinesterase inhibition was not associated with symptoms in this study, the findings were statistically significant and demonstrate the principle that re-entry workers are at risk of pesticide absorption.

There is a lack of published data about pesticide exposure among nonagricultural pest controllers. A survey of Australian termite control operators showed that use and maintenance of protective equipment was poor and the frequency of splashes and spills was high. Hands and the lower part of the body received most surface contamination and, although the wearing of appropriate gloves may protect the hands, the legs, and abdomen are less protected by the standard clothing used [25]. In the same study, cholinesterase inhibition monitoring indicated that these workers did appear to have significant pesticide absorption [39].

There is a limited published literature on exposure in turf pesticide applicators. As with other pesticide exposed workers, skin deposition appears to be the most important route of exposure. Although deposition on the hands remains important, there is a consistency of evidence that in these workers the majority of body surface deposition may occur on the lower body [40,41]. Therefore protective clothing in addition to gloves, particularly covering the feet, legs, and abdomen, may be especially important in this group [31,40,41]. Type of spray nozzle may also be an important factor modifying applicator exposure, with wide-angle nozzles causing greater exposure to the operator [31,32]. Unlike other occupational pesticide use situations, for lawn applicators spraying appears to be the task associated with highest exposure and mixing and loading may be less important sources of exposure. This difference may have important implications for exposure

and risk assessment in this group [32]. Exposure in forestry workers is complicated by additional factors unique to the forestry work environment such as height of vegetation and terrain conditions [27].

5. Absorption through the skin

Pesticides may be absorbed through the layers of the epidermis into the body [42,43]. The rate of penetration of active and inert pesticide agents varies according to a range of biological and environmental factors. Rates of absorption for pesticides are generally estimated through *in vitro* and *in vivo* human and animal testing [44]. There have also been attempts to describe percutaneous absorption through the development of mathematical models incorporating a range of variables obtained from *in vitro* and *in vivo* tests, such as age, anatomical site, ambient temperature, humidity, and pesticide concentration [44–46].

Pesticide formulations vary in ability to be absorbed through the skin [47]. For example emulsifiable concentrates are more readily absorbed than other formulations [48]. Presence of other material on the skin, such as the active ingredient of sunscreen, may promote the penetration of agents through the skin [49,50] and absorption is affected by temperature and humidity [51].

Rates of absorption through the skin are different for different parts of the body. Compared to the forearms, pesticides are absorbed 12 times faster at the site of the genitals, four times faster at the site of the head, and three times faster at the site of the trunk [44–46]. Rates of absorption can also be affected by higher skin temperature. Higher temperatures will also increase cutaneous blood flow, leading to an amplified circulation of pesticides within the body [44–46]. Further influencing factors include the number of follicles, the thickness of the stratum corneum, the sebum composition, and the distance of blood vessels to the surface of the skin [52].

Another possible effect of pesticide contact with the skin is that the agent may remain in the skin itself and can act as a reservoir for release in the future [44]. Consideration of dermal absorption as well as the potential reservoir function of the skin should be taken into account when conducting risk assessments for individual pesticides [44]. The circumstances of exposure may provide an indication of the amount of pesticide absorbed [43].

6. Reducing exposure to pesticides

Following the hierarchy of control, the most obvious way to reduce pesticide exposure is to ban pesticide use. There is a clear role for governments in the approval of pesticides for use following strict risk criteria, and in setting strict requirements for control of their use, and for establishing programs to encourage the substitution of less hazardous alternatives to replace more hazardous pesticides. Although efforts have been made internationally to ban the most hazardous pesticides, it is known that in many lower income countries, banned products are widely used [53].

There is a paucity of research investigating the feasibility and effectiveness of higher-order control measures for pesticide end users and the inherent nature of the agricultural sector limits the applicability of higher-order controls. Administrative controls other than training, such as rotation of workers and other forms of exposure time limitation, may be feasible in some contexts outside agriculture. However, the noninstitutional nature of the agricultural industry and large proportion of small businesses in this sector are likely to limit the practicability of higher-level control measures, such as engineering and barrier controls in many agricultural workplaces. This is because higher-order control measures generally rely on environmental modification, which is not as

feasible in the farm environment as it is in a factory or office. The urban/structural pest control industry is also dominated by small businesses [22] and workers in this sector characteristically work in environments over which they do not have structural control. Institutional level administrative controls may be feasible for pest controllers employed by local government agencies and for pesticide users in the public infrastructure sector, although these comprise a minority of pesticide users [21].

Taking into consideration these issues, much of the responsibility falls to the individual worker to use PPE and use it correctly. In the next sections we review the evidence regarding effectiveness and compliance with PPE.

7. PPE for dermal pesticide exposure

Various types of PPE may be used to limit dermal exposure, including gloves, long-sleeved clothing, chemical-resistant coveralls, boots, and hats. The PPE ultimately used is influenced by the toxicity of the pesticide being used, the circumstances of exposure, and the worker's personal preferences, among other factors [54]. At a minimum, most pesticide products require the use of gloves and boots [55], and as a general rule, more toxic pesticides require the use of more PPE.

Different PPE types provide differing levels of protection against dermal exposure. Gloves were found to provide the most effective protection against pesticide exposure in Danish greenhouse workers [56], whereas a study of US citrus farmers found dermal exposure to be reduced by 27% by the use of gloves, 38% by the use of coveralls, and 65% by the use of both gloves and coveralls [57]. The effectiveness of PPE also varies according to the protective features of the PPE itself, the way in which the pesticide is applied, and the way in which PPE is utilized by workers, such as correct fitting and maintenance.

The ability of protective clothing to protect against exposure is primarily influenced by fabric type, including thickness and weight [58]. One study observed very little to no penetration through fabrics thicker than 0.8 mm, regardless of other factors [54], with workpants providing much greater protection than thinner work shirts [59]. In addition, although garments made of both barrier and non-barrier fabrics have been shown to decrease dermal exposure [60], greater protection is afforded by waterproof polypropylene fabrics than by cotton garments [61]. For example, an Italian study found penetration through cotton clothing to range from 11.2% to 26.8%, whereas penetration through synthetic material was <2.4% [62], although a study of US citrus farmers found little difference between synthetic materials and woven garments [63].

PPE effectiveness, in particular penetration of pesticides through clothing, may be influenced by application method [64–66], however, the literature is somewhat inconsistent concerning this question. Stewart and colleagues [67], for example, found low-pressure and backpack spraying to be associated with greater penetration through clothing than high-pressure spraying, whereas Machera and colleagues [68] found low-pressure backpack application led to lower penetration than high-pressure hand lance spraying.

The ways in which PPE is actually used is also an important determinant of PPE effectiveness. Penetration resistance may be affected by worker movements that increase the transfer of dusts and/or liquids through fabric, as well as by sweating [63]. For example, greater penetration has been observed through parts of a polyethylene coverall where the movement of the worker is likely to create friction [68]. In addition, the protective features of PPE are dependent on proper use. For example, workers who roll their sleeves up or remove their gloves are at increased risk of dermal exposure [62].

8. PPE compliance

Evidence suggests that PPE use may be poor among pesticide end users. An Australian study found that use of clothing that provided basic skin covering when applying pesticides was far from universal [69]. The majority of contamination is consistently found on the hands, therefore, gloves are a key PPE item. In one French observational study of vineyard workers, <5% of workers wore gloves during pesticide tasks [3]. A US survey showed that self-reported PPE usage varied widely between different pesticide classes. Although gloves were the most commonly reported PPE item for most pesticide classes and tasks, substantial proportions of users never used gloves for pesticide tasks (15–55%), and only 25–30% reported always using gloves for mixing and application [70]. In a study of French vineyard workers [71], 62% wore gloves during mixing, only 10% wore gloves during application, and 41% wore gloves during equipment cleaning. It was noted that skin contamination of the hands was high even when gloves were worn, suggesting that improper use, breakthrough permeation, or other factors may reduce the potential effectiveness of PPE even when it is used [71]. Use of inappropriate types of gloves has also been noted as a frequent problem among applicators [70]. It is also important to note that these published data have come from self-reported surveys or observation of workers who have volunteered. In both cases the reported or observed usage rates are likely to overestimate actual use in general; either because of over-reporting, greater diligence under observation, or differential recruitment of more safety conscious workers.

Few data about protective equipment use in animal pesticide applicators has been published. In a UK study of sheep dippers, waterproof boots and trousers were commonly worn but gloves were used by only 30–50% of workers [33,72]. Australian data suggest that compliance with personal protective clothing among Australian sheep dippers may be similarly poor and is likely to be inadequate to protect users from low-level exposure [73].

Particular pesticide products have specific PPE requirements and compliance with such requirements has been shown to vary. A study of the use of restricted pesticides by US dairy farmers, for example, found that <50% of users fully complied with PPE requirements for 12 of the 15 pesticides studied [74]. Higher toxicity pesticides with more burdensome PPE requirements were generally associated with the lowest compliance, with highest compliance demonstrated for those pesticides requiring the use of gloves only. In addition, for nine of the pesticides, the majority of applicators reported wearing no PPE during application. Another study involving 554 US farm workers found that less than half of the respondents reported wearing protective clothing [75], whereas an observational study of US orchard farmers found coveralls to be worn by a minority of workers involved in mixing and applying pesticides [76].

Studies have found correlations between the extent of worker training and compliance with PPE requirements. For example, Australian farmers who received formal farm chemical training were more likely to report the use of skin protective equipment (including gloves, clothing, and boots) when mixing and applying pesticides [69]. Similar relationships have been found in the US [75] and UK [77]. A final point to note is that the use of protective clothing may also confer a false sense of security on workers and may lead to behavior that can result in increased exposure [78].

9. Methods to increase PPE usage

By their nature, pesticide tasks are generally undertaken in the field or in other environments and contexts that are not amenable to the sorts of institutional or organizational-level controls that may be possible, for example, in a factory workforce. Therefore PPE,

specifically protective clothing, remains a key control measure for managing dermal exposure. Use of PPE in the farm workplace is governed mainly by voluntary behavior [79], and recent research suggests that factors influencing the use of personal protective measures include availability of PPE in the workplace, perceived control, previous adverse health consequences of pesticide exposure, and having had specific safety training [55,75,77,79,80].

Evidence for the effectiveness of safety training in the promotion of personal protection is contradictory [70], and it is likely that local factors including the quality and content of safety training and the receptivity of the audience may vary in different local contexts. A US dairy farmer study found that an educational session regarding the hazards associated with pesticides increased the use of PPE, although it did not lead to complete compliance with PPE requirements [80]. Thus, even with training in the use of and risks surrounding pesticides, some pesticide workers may still neglect to abide fully by recommendations for PPE [77]. Compounding this is the fact that not all workers receive training, with the literature indicating that approximately half of all pesticide users may not have had training in pesticide safety [69,77,81]. Reynolds et al [70] also found that use of PPE, including gloves, was more likely when odorous agrochemicals were used, irrespective of the toxicity of the product, and suggested the addition of odorant to the more toxic pesticides may be an effective intervention strategy.

One likely reason for the lack of PPE worn by workers is thermal comfort. As the protection afforded by protective clothing increases, the breathability of the fabric is generally decreased, meaning it is less comfortable for use in warm conditions [54]. Therefore, although pesticide workers may appreciate the protective benefits of PPE, they may avoid using it because of physical discomfort [58]. Pesticide workers may also view the use of PPE as cumbersome and unnecessary [81], with farmers who consider themselves too busy to use PPE during pesticide application less likely to actually use it [74]. Inclination to use PPE has been shown to be related to the training that pesticide users receive [69], suggesting that if workers are not aware of the risks, they may be less likely to view PPE as important.

Use of PPE is also dependent on its availability in the workplace [75] and although employers are legally required to provide PPE to their workers [82], compliance is not guaranteed. A US study found that only 41.8% of farm workers were provided with PPE [75], whereas another reported estimates ranging from 35.3% to 84.6% for the provision of different types of PPE, with long-sleeved shirts, gloves, and boots most frequently being provided [83]. Lack of availability may be a particular issue for migrant and minority workers [81], with 36.8% of Hispanic workers being provided with PPE, compared to 83.3% of white workers [75].

10. Discussion

Use of pesticides is widespread in several different industries and exposure presents a significant health risk to workers involved in the end use of pesticides. The majority of pesticide absorbed into the body comes from dermal exposure, and PPE in the form of appropriate gloves and clothes has been shown to reduce absorption. However, compliance among the majority of occupationally exposed pesticide end users appears to be poor. The reasons for poor compliance are not clear and, although training appears promising, there is poor understanding of the delivery modes, content, and teaching methods that are most effective.

Conflicts of interest

The authors' have no conflicts of interest to report.

References

- Environmental Protection Agency (USA). Pesticide industry sales and usage: 1998 and 1999 market estimates. Washington DC: USEPA; 2002.
- van Hemmen JJ, Brouwer DH. Assessment of dermal exposure to chemicals. *Sci Total Environ* 1995;168:131–41.
- Lebailly P, Bouchart V, Baldi I, Lecluse Y, Heutte N, Gislard A, Malas J-P. Exposure to pesticides in open-field farming in France. *Ann Occup Hyg* 2009;53:69–81.
- Benavides FG, Benach J, Muntaner C, Delclos GL, Catot N, Amable M. Associations between temporary employment and occupational injury: what are the mechanisms? *Occup Environ Med* 2006;63:416–21.
- Alavanja MC, Hoppin JA, Kamel F. Health effects of chronic pesticide exposure: cancer and neurotoxicity. *Annu Rev Public Health* 2004;25:155–97.
- World Health Organization. The WHO recommended classification of pesticides by hazard and guidelines to classification 2009. Geneva (Switzerland): World Health Organisation; 2010.
- Reifenrath WG. Enhanced skin absorption and fly toxicity of permethrin in emulsion formulation. *Bull Environ Contam Toxicol* 2007;78:299–303.
- Wirdefeldt K, Adami HO, Cole P, Trichopoulos D, Mandel J. Epidemiology and etiology of Parkinson's disease: a review of the evidence. *Eur J Epidemiol* 2011;26(Suppl 1):S1–58.
- Boffetta P, Mundt KA, Adami HO, Cole P, Mandel JS. TCDD and cancer: a critical review of epidemiologic studies. *Crit Rev Toxicol* 2011;41:622–36.
- Curwin B, Hein M, Sanderson W, Barr DB, Heederik D, Reynolds SJ, Ward EM, Alavanja MC. Urinary and hand wipe pesticide levels among farmers and nonfarmers in Iowa. *J Expo Sci Environ Epidemiol* 2005;15:500–8.
- Calvert GM, Karnik J, Mehler L, Beckman J, Morrissey B, Sievert J, Barrett R, Lackovic M, Mabee L, Schwartz A, Mitchell Y, Moraga-McHaley S. Acute pesticide poisoning among agricultural workers in the United States, 1998–2005. *Am J Ind Med* 2008;51:883–98.
- van Drooge HL, Groeneveld CN, Schipper HJ. Data on application frequency of pesticide for risk assessment purposes. *Ann Occup Hyg* 2001;45(Suppl 1):S95–101.
- Arbuckle TE, Burnett R, Cole D, Teschke K, Dosemeci M, Bancej C, Zhang J. Predictors of herbicide exposure in farm applicators. *Int Arch Occup Environ Health* 2002;75:406–14.
- Alavanja MC, Sandler DP, McDonnell CJ, Lynch CF, Pennybacker M, Zahm SH, Mage DT, Steen WC, Wintersteen W, Blair A. Characteristics of pesticide use in a pesticide applicator cohort: the Agricultural Health Study. *Environ Res* 1999;80:172–9.
- Blair A, Sandler DP, Tarone R, Lubin J, Thomas K, Hoppin JA, Samanic C, Coble J, Kamel F, Knott C, Dosemeci M, Zahm SH, Lynch CF, Rothman N, Alavanja MC. Mortality among participants in the agricultural health study. *Ann Epidemiol* 2005;15:279–85.
- Fleming LE, Bean JA, Rudolph M, Hamilton K. Mortality in a cohort of licensed pesticide applicators in Florida. *Occup Environ Med* 1999;56:14–21.
- Sperati A, Rapiti E, Settini L, Quercia A, Terenzoni B, Forastiere F. Mortality among male licensed pesticide users and their wives. *Am J Ind Med* 1999;36:142–6.
- Blair A, Sandler D, Thomas K, Hoppin JA, Kamel K, Coble J, Lee WJ, Rusiecki J, Knott C, Dosemeci D, Lynch CF, Lubin J, Alavanja M. Disease and injury among participants in the Agricultural Health Study. *J Agric Saf Health* 2005;11:141–50.
- Bonner MR, Lee WJ, Sandler DP, Hoppin JA, Dosemeci M, Alavanja MC. Occupational exposure to carbofuran and the incidence of cancer in the Agricultural Health Study. *Environ Health Perspect* 2005;113:285–9.
- Coronado GD, Thompson B, Strong L, Griffith WC, Islas I. Agricultural task and exposure to organophosphate pesticides among farmworkers. *Environ Health Perspect* 2004;112:142–7.
- MacFarlane E, Glass D, Fritsch L. Is farm-related job title an adequate surrogate for pesticide exposure in occupational cancer epidemiology? *Occup Environ Med* 2009;66:497–501.
- MacFarlane E, Benke G, Goddard D, Sim M. Urban pest control operators in Australia. *Occup Environ Med* 2007;64:422–7.
- Wang HH, MacMahon B. Mortality of pesticide applicators. *J Occup Med* 1979;21:741–4.
- MacFarlane E, Benke G, Del Monaco A, Sim MR. Cancer incidence and mortality in a historical cohort of Australian pest control workers. *Occup Environ Med* 2009;66:818–23.
- Cattani M, Cena K, Edwards J, Pisaniello D. Potential dermal and inhalation exposure to chlorpyrifos in Australian pesticide workers. *Ann Occup Hyg* 2001;45:299–308.
- MacFarlane E, Benke G, Del Monaco A, Sim MR. Causes of death and incidence of cancer in a cohort of Australian pesticide-exposed workers. *Ann Epidemiol* 2010;20:273–80.
- Green LM. A cohort mortality study of forestry workers exposed to phenoxy acid herbicides. *Br J Ind Med* 1991;48:234–8.
- Burns C, Mahlborg W, Dutra JP. Pesticide exposure among farm workers. *Environ Res* 2007;105:285–8.
- Baldi I, Lebailly P, Jean S, Rougetet L, Dulaurant S, Marquet P. Pesticide contamination of workers in vineyards in France. *J Expo Sci Environ Epidemiol* 2006;16:115–24.
- Harris SA, Corey PN, Sass-Kortsak AM, Purdham JT. The development of a new method to estimate total daily dose of pesticides in professional turf

- applicators following multiple and varied exposures in occupational settings. *Int Arch Occup Environ Health* 2001;74:345–58.
- [31] Harris SA, Sass-Kortsak AM, Corey PN, Purdham JT. Development of models to predict dose of pesticides in professional turf applicators. *J Expos Anal Environ Epidemiol* 2002;12:130–44.
- [32] Harris SA, Sass-Kortsak AM, Corey PN, Purdham JT. Pesticide exposures in professional turf applicators, job titles, and tasks performed: implications of exposure measurement error for epidemiologic study design and interpretation of results. *Am J Ind Med* 2005;48:205–16.
- [33] Buchanan D, Pilkington A, Sewell C, Tannahill S, Kidd M, Cherrie B, Hurley J. Estimation of cumulative exposure to organophosphate sheep dips in a study of chronic neurological health effects among United Kingdom sheep dippers. *Occup Environ Med* 2001;58:694–701.
- [34] Alavanja MC, Sprince NL, Oliver E, Whitten P, Lynch CF, Gillette PP, Logsdens-Sackett N, Zwierling C. Nested case-control analysis of high pesticide exposure events from the Agricultural Health Study. *Am J Ind Med* 2001;39:557–63.
- [35] Clarke L, Churches T. Pesticide exposure in cotton chippers in the Gwydir Valley 1991–92. Moree (Australia): Australian Centre for Agricultural Health and Safety; 1992.
- [36] Strong LL, Thompson B, Coronado GD, Griffith WC, Vigoren EM, Islas I. Health symptoms and exposure to organophosphate pesticides in farmworkers. *Am J Ind Med* 2004;46:599–606.
- [37] Ward MH, Prince JR, Stewart PA, Zahm SH. Determining the probability of pesticide exposures among migrant farmworkers: results from a feasibility study. *Am J Ind Med* 2001;40:538–53.
- [38] O'Malley M, Barry T, Ibarra M, Verder-Carlos M, Mehler L. Illnesses related to shank application of metam-sodium, Arvin, California, July 2002. *J Agromed* 2005;10:27–42.
- [39] Dyer SSM, Cattani MM, Pisaniello DDL, Williams FFM, Edwards JJW. Peripheral cholinesterase inhibition by occupational chlorpyrifos exposure in Australian termiticide applicators. *Toxicology* 2001;169:177–85.
- [40] Slocum AC, Shern LC. Spray deposition patterns during simulated work activities by lawn care specialists. *J Environ Sci Health B* 1991;26:259–78.
- [41] Cowell JE, Lottman CM, Manning MJ. Assessment of lawn care worker exposure to dithiopyr. *Arch Environ Contam Toxicol* 1991;21:195–201.
- [42] Pesticides Liden C. In: Johansen JD, Frosch PJ, Lepoittevin J-P, editors. *Contact dermatitis*. Berlin (Germany): Springer; 2010. p. 927–36.
- [43] Routt Reigart J, Roberts JR. Recognition and management of pesticide poisonings. Washington DC: US Environmental Protection Agency; 1999.
- [44] Kielhorn J, Melching-Kollmuss S, Mangelsdorf I. *Dermal Absorption*. Geneva (Switzerland): United Nations Environment Programme, the International Labour Organization & the World Health Organization; 2006.
- [45] Wester RC, Maibach HI, Bucks DA, Aufreere MB. *In vivo* percutaneous absorption of paraquat from hand, leg, and forearm of humans. *J Toxicol Environ Health* 1984;14:759–62.
- [46] Poet TS. Assessing dermal absorption. *Toxicol Sci* 2000;58:1–2.
- [47] Carrico RM, Coty MB, Goss LK, Lajoie AS. Changing health care worker behavior in relation to respiratory disease transmission with a novel training approach that uses biosimulation. *Am J Infect Control* 2007;35:14–9.
- [48] Lamm F. Small businesses and OHS advisors. *Saf Sci* 1997;25:153–61.
- [49] Graveling R, Sanchez-Jimenez A, Lewis C, Groat S. Protecting respiratory health: what should be the constituents of an effective RPE programme? *Ann Occup Hyg* 2011;55:230–8.
- [50] Heron RJL. Worker education in the primary prevention of occupational dermatoses. *Occup Med* 1997;47:407–10.
- [51] Cherrie JW, Semple S, Christopher Y, Saleem A, Hughson GW, Philips A. How important is inadvertent ingestion of hazardous substances at work? *Ann Occup Hyg* 2006;50:693–704.
- [52] Gardner D, Carlopio J, Fonteyn PN, Cross JA. Mechanical equipment injuries in small manufacturing businesses. Knowledge, behavioural, and management issues. *Int J Occup Saf Ergon* 1999;5:59–71.
- [53] Al-Haj MA, Awadh NA, Ali AA. Survey of Pesticides used in Qat cultivation in Dhale' and Yafe' and their Adverse Effects. *J Nat Appl Sci* 2005;9:103–10.
- [54] Lee S, Obendorf SK. Statistical model of pesticide penetration through woven work clothing fabrics. *Arch Environ Contam Toxicol* 2005;49:266–73.
- [55] Perry MJ, Marbella A, Layde PM. Association of pesticide safety knowledge with beliefs and intentions among farm pesticide applicators. *J Occup Environ Med* 2000;42:187–93.
- [56] Lander GH, Hinkle K. Indoor application of anti-cholinesterase agents and the influence of personal protection on uptake. *Arch Environ Contam Toxicol* 1992;22:163–6.
- [57] Nigg HN, Stamper JH, Queen RM. Dicofol exposure to Florida citrus applicators: effects of protective clothing. *Arch Environ Contam Toxicol* 1986;15:121–34.
- [58] Obendorf SK, Csiszar E, Maneefuangfoo D, Borsa J. Kinetic transport of pesticide from contaminated fabric through a model skin. *Arch Environ Contam Toxicol* 2003;45:283–8.
- [59] Fenske RA, Hamburger SJ, Guyton CL. Occupational exposure to fosetyl-Al fungicide during spraying of ornamentals in greenhouses. *Arch Environ Contam Toxicol* 1987;16:615–21.
- [60] Coffman CW, Stone J, Slocum AC, Landers AJ, Schwab CV, Olsen LG, Lee S. Use of engineering controls and personal protective equipment by certified pesticide applicators. *J Agric Saf Health* 2009;15:311–26.
- [61] Aprea C, Terenzi B, De Angelis V, Sciarra G, Lunghini L, Borzacchi G, Vasconi D, Fani D, Quercia A, Salvan A, Settini L. Evaluation of skin and respiratory doses and urinary excretion of alkylphosphates in workers exposed to dimethoate during treatment of olive trees. *Arch Environ Contam Toxicol* 2004;48:127–34.
- [62] Vitali M, Protano C, Del Monte A, Ensabella F, Guidotti M. Operative modalities and exposure to pesticides during open field treatments among a group of agricultural subcontractors. *Arch Environ Contam Toxicol* 2009;57:193–202.
- [63] Fenske RA, Birnbaum SG, Methner MM, Lu C, Nigg HN. Fluorescent tracer evaluation of chemical protective clothing during pesticide applications in central Florida citrus groves. *J Agric Saf Health* 2002;8:319–31.
- [64] Keifer MC. Effectiveness of interventions in reducing pesticide overexposure and poisonings. *Am J Prev Med* 2000;18:80–9.
- [65] Driver J, Ross J, Mihan G, Lunchick C, Landenberger B. Derivation of single layer clothing penetration factors from the pesticide handlers exposure database. *Regul Toxicol Pharmacol* 2007;49:125–37.
- [66] Nigg HN, Stamper JH, Easter E, DeJonge JO. Protection afforded greenhouse pesticide applicators by coveralls: a field test. *Arch Environ Contam Toxicol* 1993;25:529–33.
- [67] Stewart PA, Fears T, Kross B, Ogilvie L, Blair A. Exposure of farmers to phosmet, a swine insecticide. *Scand J Work Environ Health* 1999;25:33–8.
- [68] Macheria K, Goumenou M, Kapetanakis E, Kalamarakis A, Glass CR. Determination of potential dermal and inhalation operator exposure to malathion in greenhouses with the whole body dosimetry method. *Ann Occup Hyg* 2003;47:61–70.
- [69] MacFarlane E, Chapman A, Benke G, Meaklim J, Sim M, McNeil J. Training and other predictors of personal protective equipment use in Australian grain farmers using pesticides. *Occup Environ Med* 2008;65:141–6.
- [70] Reynolds SJ, Tadevosyan A, Fuortes L, Merchant JA, Stromquist AM, Burmeister LF, Taylor C, Kelly KM. Keokuk County rural health study: self-reported use of agricultural chemicals and protective equipment. *J Agromedicine* 2007;12:45–55.
- [71] Baldi I, Brochard P, Mohammed-Brahim B, Rolland P, Salamon R. Retrospective estimation of methods of pesticide occupational exposure. *Rev Epidemiol Sante Publique* 1999;47:165–74.
- [72] Pilkington A, Buchanan D, Jamal GA, Gillham R, Hansen S, Kidd M, Hurley J, Soutar C. An epidemiological study of the relations between exposure to organophosphate pesticides and indices of chronic peripheral neuropathy and neuropsychological abnormalities in sheep farmers and dippers. *Occup Environ Med* 2001;58:702–10.
- [73] National Registration Authority for Agricultural and Veterinary Chemicals Expert Panel. The relevance to sheep husbandry practices in Australia of the UK Institute of Occupational Medicine (IOM) Report: 'Epidemiological study of the relationship between exposure to organophosphate pesticides and indices of chronic peripheral neuropathy, and neuropsychological abnormalities in sheep farmers and dippers'. Canberra (Australia): National Registration Authority for Agricultural and Veterinary Chemicals; 2000.
- [74] Perry MJ, Marbella A, Layde PM. Compliance with required pesticide-specific protective equipment use. *Am J Ind Med* 2002;41:70–3.
- [75] Strong LL, Thompson B, Koepsell TD, Meischke H. Factors associated with pesticide safety practices in farmworkers. *Am J Ind Med* 2008;51:69–81.
- [76] Hines CJ, Deddens JA, Coble J, Alavanja MC. Fungicide application practices and personal protective equipment use among orchard farmers in the agricultural health study. *J Agric Saf Health* 2007;13:205–23.
- [77] Avory G, Coggon D. Determinants of safe behaviour in farmers when working with pesticides. *Occup Med (Lond)* 1994;44:236–8.
- [78] Eakin JM. Leaving it up to the workers: sociological perspective on the management of health and safety in small workplaces. *Int J Health Serv* 1992;22:689–704.
- [79] Lichtenberg E, Zimmerman R. Adverse health experiences, environmental attitudes, and pesticide usage behavior of farm operators. *Risk Anal* 1999;19:283–94.
- [80] Perry MJ, Layde PM. Farm pesticides: outcomes of a randomized controlled intervention to reduce risks. *Am J Prev Med* 2003;24:310–5.
- [81] Gomes J, Lloyd OL, Revitt DM. 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;72:40–5.
- [82] Stone J, Padgett S, Wintersteen W, Shelley M, Chisholm S. Iowa greenhouse applicators perceptions and use of personal protective equipment. *J Environ Health* 1994;57:16–22.
- [83] Cameron L, Lalich N, Bauer S, Booker V, Bogue HO, Samuels S, Steege AL. Occupational health survey of farm workers by camp health aides. *J Agric Saf Health* 2006;12:139–53.