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Child-Like Mannequin for Observation and Measurement of Spray Drift Particle Deposition for Pesticide Exposure Assessment

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Potential human exposure occurs when airborne spray droplets or vapors resulting from mixing, loading and applying pesticides are present in nearby rural and urban residential areas. Even though miniscule portions of the applied pesticide move with air currents or diffuse from target areas to any particular point, spray drift represents inefficiency of the application process and sometimes produces exposures of regulatory, environmental, or health concern. Drift has many definitions. The Spray Drift Task Force (1997) defined spray drift as the off-site movement of spray droplets before deposition. A broader definition (USEPA, 1999) is physical movement of pesticide through air at the time of application, or soon thereafter, to sites other than that intended for application.

There are few means to determine the potential magnitude of human exposure to drift. Most commonly pesticide air levels (amount/m^3) and of default exposure factors are used to estimate inhalation exposure. Ventilation rate (m^3/hour), exposure time, lung retention of chemicals (70% or less), lung absorption (100%), and body weight (kg) can be used to calculate a limiting value. In most cases pesticide exposures to vapor or very small particles (<5 microns) resulting from drift yield dosages far below levels associated with systemic toxicity.

Persons in close proximity may be more directly exposed to larger amounts of pesticide. Visible spray particles can be a major concern of accidentally exposed persons. At the same time, due to concentration and time considerations, the possibility of developing a significant absorbed dose is remote. Flat spray deposition papers have been used to a limited extent to collect spray drift particles, but the results of this type of monitoring are difficult to relate to the potential exposure of particle deposition. A child-like mannequin has been used to distinguish the distribution of pesticide fallout on flat deposition papers (ug/cm^2) from the potential distribution of spray particles on skin and clothing of a child (ug/person). The work provides a means to factor surface deposition for estimation of dermal dose when direct monitoring is not feasible.

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Table 1. Surface area of mannequin and 2-3 year-old child.

Body Region	Total Surface Area	
	Mannequin[a] % (cm^2)	Child[b] % (cm^2)
Head	24% (470)	14% (840)
Arms and Hands	23% (340)	17% (1025)
Torso	18% (440)	39% (2350)
Legs and Feet	35% (680)	30% (1810)
Total	100% (1930)	100% (6030)

[a]Mannequin surface areas were determined gravimetrically using aluminum foil to cover body regions.
[b]USEPA Exposure Factors Handbook (1997).

MATERIALS AND METHODS

Spray particles were simultaneously collected on a flat, alpha-cellulose paper (ACC) and on a child-like mannequin on the ACC. Black paint was sprayed to qualitatively demonstrate the deposition pattern of particles (Figure 1). Quantitative measurements were made using a commercial malathion formulation.

Child-like toy mannequins were purchased from local retail outlets (Series 69928; "Doug" model; Mattel Company, Westbury, NY). Clothing was removed and aluminum foil was used to cover the surface for gravimetric determination of area (Table 1). Mannequins were held upright on an inverted glass funnel during spray applications in the center of an ACC (Whatman® #3030-917; 46 cm x 57 cm).

Createx™ Opaque Black Airbrush paint was diluted 1:6 with water for qualitative studies of particle deposition. Quantitative studies utilized malathion sprays prepared by diluting 1 mL (A) or 2 mL (B) of Ortho Malathion 50 Plus® Insect Spray (50% a.i.) to 600 mL with deionized water. A Campbell Hausfeld Spray Gun (DH4200) attached to a utility ladder was used to apply. Spray (110 bursts of A, 110 bursts of B, or 55 bursts of B, respectively) were produced by squeezing and instantaneously releasing the spray gun trigger. The nozzle tip was fixed at 85° below the horizontal plane, 10 ft. 3 in. above and 3 ft. 6 in. in front of the mannequin. Following the malathion spray, the ACC and the mannequin head, torso, arms and hands, and legs and feet were separated. Each was held in sealed storage bags at -20°C until analysis. Malathion was extracted with ethyl acetate

Figure 1. Deposition and distribution of spray droplets on a flat ACC and a 24" mannequin sprayed with 55 bursts of black airbrush paint at 85° below the horizontal plane using a Campbell Hausfeld spray gun positioned above and in front of the mannequin.

Table 2. Deposition pattern of spray particle deposition (μg malathion/cm^2) on body regions of mannequin and flat papers (ACC).

Model	Head	Torso	Arms & Hands	Legs & Feet	Mannequin Average[a]	Flat Papers
		Spray Mix A 110 Spray Bursts				
1	0.11	0.04	0.07	0.06	0.07	0.40
2	0.18	0.08	0.10	0.10	0.11	0.57
3	0.22	0.08	0.13	0.14	0.15	0.78
		Spray Mix B 110 Spray Bursts				
4	0.74	0.55	0.54	0.54	0.59	1.95
5	0.60	0.38	0.46	0.39	0.46	1.60
6	0.77	0.41	0.37	0.43	0.50	2.70
		Spray Mix A 55 Spray Bursts				
7	0.22	0.08	0.11	0.12	0.13	0.60
8	0.24	0.07	0.15	0.11	0.14	0.54
9	0.50	0.15	0.28	0.16	0.27	1.00

[a]mannequin average = surface area of region (cm^2) x deposition ($\mu g/cm^2$) total mannequin surface area (cm^2).

(Fisher Scientific, Optima Grade), using an Eberbach shaker [1.5 in. throw at 270 cycles/min. (shaker travels 3 in. per cycle)] for 2 consecutive, 10-minute intervals. Aliquots (25 mL) were retained for analysis. Samples were analyzed on a Hewlett Packard 5890 Gas Liquid Chromatograph with an HP-5 column and a flame photometric detector. Malathion deposition was calculated using a standard curve, internal standard (diazinon), and corrected for specific (body region) extraction efficiencies.

RESULTS AND DISCUSSION

Although it is clear that the duration and extent of skin contact will determine the amount of exposure resulting from spray particle deposition, quantitative data are lacking in the literature. Since the USEPA will apparently use "discretion to pursue violations (USEPA, 1999)" concerning drift, clarification of origins of community concern about drift and the nature of potential health outcomes becomes especially important for responsible exposure assessment. Visualization of particle deposition can be used to relate environmental monitoring data to the human exposure potential of airborne particles. Conventional biological exposure monitoring of drift deposition and absorption of extremely low amounts of drift is usually not feasible due to (concentration x time) relationships.

Table 3. Percent of flat paper (ACC) deposition in each mannequin body region.

Mannequin	Head[a]	Torso[a]	Arms & Hands[a]	Legs & Feet[a]	Mannequin Average[b]
		Spray Mix A	110 Bursts		
1	25.8	9.1	16.4	14.5	17.5
2	31.0	13.2	17.7	17.5	19.3
3	28.7	9.6	16.9	17.7	19.2
		Spray Mix B	110 Bursts		
4	37.9	28.4	27.9	27.6	30.3
5	37.6	23.8	28.6	24.3	28.8
6	28.6	15.1	13.8	16.0	18.5
		Spray Mix A	55 Bursts		
7	36.6	12.6	17.8	19.2	21.7
8	43.8	13.6	28.0	20.5	25.9
9	50.1	15.1	27.8	15.8	27.0
Average ± SD	35.6 ± 5.2	15.6 ± 4.2	21.7 ± 4.1	19.2 ± 2.8	23.1 ± 4.9

[a]Mannequin region percent of ACC = [deposition per mannequin region ($\mu g/cm^2$) ÷ ACC deposition ($\mu g/cm^2$)] x 100).
[b]Mannequin Average = [$\sum$ mannequin region percent of ACC (%) x mannequin region surface area (cm^2)] ÷ total mannequin surface area (cm^2).

The black paint spray deposition pattern on the large, flat ACC was relatively uniform and much more intense than the pattern on the mannequins. More spray was retained on the head than any other body regions. Spray particles did not reach most areas such as inside of the legs, sides of the torso, inside the arms and under the chin. The pattern could be simply modeled using round objects such as a play ball, head of iceberg lettuce, and table tomatoes sprayed under the same conditions, only the upper halves of the spherical objects were darkened. This spray deposition pattern on round objects would approximate the area of the corresponding hemisphere, $2\pi r^2$, rather than that of a sphere, $4\pi r^2$. Similar conditions and limited deposition would occur on the human body. Since the spray particles were concurrently deposited on the flat ACC and the child-like mannequin, the paint studies gave showed of substantially greater retention of spray on the flat ACC than on the mannequin (Figure 1).

The measured deposition of pesticide spray particles is reported in Table 2. Here again significantly less malathion was deposited on the mannequins than on the ACCs (Students paired *t*-test; $p < 0.01$). The percent of ACC deposition on the mannequin {percent of ACC = [body region deposition ($\mu g/cm^2$) ÷ ACC

Table 4. Percent of total mannequin deposition by body region.

Mannequin	Head[a]	Torso[a]	Arms & Hands[a]	Legs & Feet[a]
		Spray Mix A 110 Spray Bursts		
1	37.6	9.5	22.4	30.5
2	37.6	11.6	20.1	30.7
3	37.2	9.0	20.5	33.2
		Spray Mix B 110 Spray Bursts		
4	30.4	16.5	21.0	32.1
5	32.2	14.7	22.9	30.1
6	37.9	14.5	17.1	30.6
		Spray Mix A 55 Spray Bursts		
7	40.6	10.1	18.5	30.8
8	40.0	9.0	23.9	27.1
9	45.6	10.0	23.7	20.8
Average	37.7 ± 2.9	11.7 ± 1.9	21.1 ± 1.5	29.6 ± 2.4

[a]Percent of Total Deposition = [deposition per mannequin region ($\mu g/cm^2$) ÷ total deposition on mannequin ($\mu g/m^2$)] x 100

deposition ($\mu g/cm^2$)] x 100} is reported in Table 3. The average deposition on the mannequin was only 23.2 ± 3.2% of the deposition on the ACC. The percent of deposition on each body region {percent of deposition = [body region deposition ($\mu g/cm^2$) ÷ total deposition on mannequin ($\mu g/cm^2$)] x 100} is reported in Table 4. Deposition on flat surfaces must be modified to represent potential spray drift deposition on 3-dimensional surfaces.

Several examples of the use of flat surface sampling strategies which result in excessive human exposure estimates are available. Particle fallout exposure measurements have been prepared for worst-case scenarios of ethyl and methyl parathion (Draper and Street, 1981) and carbofuran (Draper et al., 1981) application and drift. Human dermal exposure was estimated by direct extrapolation of the surface pesticide residues to unclothed skin areas (2,930 cm^2). The potential human dermal exposure was 70 ug/kg (absorbed dosage about 10 ug/kg) at the immediate boundary of the sprayed alfalfa field (Draper and Street, 1981). Flat spray deposition cards were also used to monitor the effectiveness of aerial applications of malathion bait during pest management operations in California (CDHS, 1991).

An unexpected application of environmental monitoring using mannequins results in improved risk management and risk communication. Nuisance levels of particle or vapor drift may trigger sensory responses, uneasiness, anxiety and even illness (not usually associated with traditional measures of toxicity of pesticide sprays) create an opportunity for risk managers to communicate the nature and extent of potential exposures with concerned persons. Unfamiliar "chemical" odors, the sight of spray in the air and the sounds of a spray rig, and/or even deposition of fine particles on skin or an automobile windshield or windowpane may prompt apprehension and illness. Risk assessments utilizing surface deposition measurements and mannequins may help risk communicators clarify individual concerns. This practice might be especially valuable if margins-of-exposure (MOE) founded upon determination of absorbed dosage and potential systemic toxicity can be distinguished from MOEs for adverse experiences due to nuisance or sensory stimuli.

Determination of the pesticide exposure potential of children has major regulatory importance resulting from the FQPA of 1996 which calls for aggregating exposures from all sources. Mannequin exposures can augment the process and improve the reliability of extreme, limiting value estimates of human exposure, particularly aggregate exposure estimates developed for regulatory risk assessments. Based upon exposure factors like food and water consumption and breathing rates, the exposure potential on a kg body weight basis of children is greater than the exposure potential of adults. Since adults and children share similar surface area to body weight relationships there is less reason to apply an additional FQPA children's uncertainty factor in the evaluation of pesticide exposure resulting from particle deposition on clothing and skin. Pesticide deposition on the contoured surface of child-like mannequin has been used to demonstrate that flat surface deposition is not suitable for estimation of potential human exposure from spray drift particles.

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