Quantifying Exposure to Pesticides on Commercial Aircraft

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16. Abstract

Many countries require aircraft disinsection, treating aircraft landing in their countries using insecticides, to minimize the spread of non-native potential disease vectors and harmful pests. Disinsection is done while passengers are on-board aircraft, immediately prior to boarding, or as a residual treatment on all cabin surfaces. The most common pesticides used contain a 2 % synthetic pyrethroid insecticide, typically permethrin or *d*-phenothrin. A wipe sampler that employed filter paper and water for the collection of pyrethroids from soft and hard surfaces in the aircraft cabin was developed. It was evaluated in a laboratory setting and recoveries were 80-100% from table trays, seat handles and rugs; and 40-50% from seat cushions. The wipe sampler is easy to use, requires minimum training, and is compatible with current air security regulations. Surface wipe samples were collected from various surfaces on 15 US domestic and 45 international flights. While pesticides were essentially not detected in samples collected from US domestic flights, permethrin was routinely detected on all surface types on flights that entered or left countries requiring residual treatment or performed maintenance of aircraft servicing those countries. The surface loadings were all below 1μg/cm^2, more than an order of magnitude below the application guidelines which could be due to transference to passengers's clothing or skin when they sat or touched surfaces containing the pesticide or the pesticides degraded over time. Air concentrations and deposition levels measured for a simulated disinsection of a mock Boeing 767 was consistent with the literature indicating that it was an appropriate facility to evaluate potential pesticide exposure from disinsection. A CFD model of air concentrations and surface loadings following pesticide application during flight was formulated and model concentrations similar to those measured in the mock facility. These results indicate that potential inhalation, dermal and ingestion exposures of flight crewmembers and passengers to pyrethroid pesticides are likely to occur. Urine samples were collected from 28 flight attendants, 18 – 65 years of age, with 17 working on the flights that were not disinsected with pyrethroid insecticides, and 11 working on disinsected flights. Flight attendants working on disinsected planes had significantly higher urinary levels of permethrin metabolites in the post- and 24hr-post flight samples than the pre flight urine. Flight attendants working on international flights connected to Australia where residual treatment is mandated had higher urinary permethrin metabolite levels than those on either domestic or other international flights or the general US population matched on age. This study documents that flight attendants on commercial aircrafts disinsected with pyrethroid insecticides are exposed to pesticides at levels that result in elevated body burden and internal accumulation comparable to pesticide applicators, exceeding levels in the general US population. It is expected that flying public would be similarly exposed to pesticides on those flights.

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Abbreviations:
GC/MS – gas chromatograph/mass spectrometer
EI – electron impact
SIM – Selective monitoring mode
WHO – World Health Organization
µg – microgram
µg/cm^2 – microgram per square centimeter
cfm – cubic feet per minute
ACH – Air Exchange Rate\
DDT – dichloro-diphenyl-trichloroethane
LOD – limit of detection
GM – Geometric means
SD – Standard deviation
NC – Not calculated
3-PBA – 3-phenoxybenzoic acid
cis-Cl2CA – *cis*-3-(2,2-Dichlorovinyl)-2,2-dimethylcyclopropane carboxylic acid
trans-Cl2CA – *trans*-3-(2,2-Dichlorovinyl)-2,2-dimethylcyclopropane carboxylic acid
c*is*-Br2CA – *cis*-3-(2,2-dibromovinyl)-2,2-dimethylcyclopropane-1-carboxylic acid
4F-3-PBA – 4-fluoro-3-phenoxybenzoic acid
Key words: disinsection, flight attendant, pyrethroid, insecticide, pesticide, exposure

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1.1 Introduction

Disinsection of aircraft, e.g. the spraying of pesticides within commercial aircraft, began in the mid 1940's to halt the reintroduction of mosquitoes that carry malaria from areas from which it was eradiated (Sullivan et al 1962). Initially a mixture of pyrethrins and DDT was used and was determined to be effective to kill mosquitoes the entered the aircraft cabin or cargo hold. Since the 1970s disinsection of commercial aircraft has been mandated by a limited number of countries to prevent the transport of insects which pose health threats to humans, animals and plants (Gantz et al. 2000). The most commonly used pesticides are a 1-2% solution of permethrin or d-phenothrin. Residual application needs to be effective for at least 8 weeks with typical application rates of 50µg/cm^2 on carpets and up to 20µg/cm^2 on other surfaces including seats, tray tables etc (Rayman 2006, New Zealand MAF 2007). The use of pesticides within an enclosed area, such as an airplane cabin, either while passengers and crew are on board or as residual treatment potentially exposes individuals to pesticides via inhalation, dermal absorption or ingestion if food contacts sprayed areas. Application methods used are in concert with the recommendations for aircraft disinsection by the World Health Organization (Rayman, 2006) though concerns have been raised about potential adverse health effects from the exposures to pesticides from these application methods (van Netten 2002, Kilburn 2004, Murawski 2005, Gratz et al., 2000 Hocking and Hocking 2005, Rayman 2006). Currently, twenty-four countries (17 for all flights and 7 for flights originating from specific regions) (US DOT 2011, http://ostpxweb.ost.dot.gov/policy/safetyenergyenv/disinsection.htm accessed 1-26-2012) require airlines to perform disinsection on international flights landing within their borders, and most countries reserving the right to require disinfection when there is a perceived threat of vector-borne disease (Sutton et al., 2007).

Permethrin and *d*-phenothrin have been confirmed as the active agents in commercially available pesticide produced specifically for use on aircraft to be sprayed while or before passengers and crew are on board (van Netten 2002). The air concentration of *d*-phenothrin were determined to rapidly decline once the airplane's air conditional system was operational and the insecticide has been found to effectively kill flying insects during the spray as was the residue on the surfaces (Berger-Preiss et al 2006). Measurable air concentrations of permethrin has been reported on two domestic US flights, though spraying of aircraft within the US has been banned (Spicer et al., 2004). Pesticide levels on surface followed an exponential decline over a couple of months (Mohan and Weisel 2010).

The health effects of pyrethroids have been studied prior to their introduction as the most commonly used insecticides in commercial and residential settings. The World Health Organization (WHO) conducted series of field trials on various materials and methods for the aircraft disinsection (Sullivan et al. 1964; Sullivan et al. 1972), and published the latest recommendations on this basis in 1995 (WHO/HQ 1995), but additional data have identified new risks that were not considered by WHO in its original risk estimate. For examples, pyrethroids are recognized to be lipophilic components and potential neurotoxicants that modify the kinetics of voltage-sensitive sodium and calcium channels (Clark and Symingtong 2007; Ray and Fry 2006; Shafer and Meyer 2004; Shafer et al. 2005; Soderlund et al. 2002).

Pyrethroids are considered to have low mammalian toxicity (Narahashi 2001; Soderlund et al. 2002), and the WHO described aircraft disinsection as a procedure that would not cause a risk to human health "if carried out with the recommended precautions" (Rayman, 2006; WHO/HQ, 1995). However, many anecdotal cases of adverse health effects suggested to be due to pyrethroids exposure on aircrafts have been reported by flight attendants to government agencies, labor unions, airlines, and environmental groups. These include irritations of the skin and mucosa, sore throat, vomiting, abdominal pain, headache, dizziness and nausea, etc. (Murawski 2005; Sutton et al., 2007).

Only limited sampling of aircraft surfaces for pesticides has been reported. Collection was done by placing pads on different surfaces while pesticide was being sprayed (Berger-Preiss et al. 2004, 2006) or within the framework of an occupational evaluation (Sutton et al. 2007). Collection of wipe samples from some airline surfaces, such as seats which have soft fabric material and a foam backing, can be difficult since soft materials can absorb the liquid used as a wetting agent to facilitate sample collection. Wipe sampling is a common approach used in occupational settings to screen for potential dermal exposure to complement use of patches, measurement on clothing, direct measures of skin contamination using rinses and swabs, and biological monitoring. Wipe sampling in occupational settings has included using a variety of different media, such as cotton gauze, cotton swabs, disposable paper towels, and filter paper with acetone, hexane, methanol, water, ethyl ether and petroleum ether used as wetting agents depending upon the contaminant being collected. Wipe samplers using filters have been reported for hard surfaces in occupational settings but not for soft surfaces that might absorb the wetting agent.

Collecting wipe samples from surfaces on aircraft to evaluate potential exposure and residual pesticide levels on materials present in in-use aircraft need to be done without disruption of the airline's operation. An additional practical consideration in sampling from in-use aircraft is sampling materials need to pass through security and not adversely affect the surfaces of the aircraft. Biomarker measurements, such urinary metabolite concentrations are used to establish exposures to environmental contaminants. No measurements of urinary metabolite levels of pyrethroid insecticides have been reported for flight attendants though urinary levels at other populations including pregnant women, infants, children and general population exist (Barr et al. 2010).

2.1 Development of Wipe Sampler

2.1.1 Materials and Methods:

Testing of the wipe samplers was done in a room containing an economy row of three airline seats, a section of a carpet from an aircraft and additional parts from an aircraft. The aircraft materials were sprayed with permethrin to achieve the loadings typically used for disinsection of aircraft (Raymond 2006) in order to test the collection efficiency of the different wipe samplers.

Materials

A used, economy aircraft three-seat row with tray tables was employed for this analysis. Commercial grade permethrin was sprayed on selected surfaces after dilution to a 0.5% solution by adding 37ml of the pesticide concentrate to one liter of water and mixing well in the sprayer tank. Clear plastic sprayers (3 oz) were used to wet the filter papers used to wipe surfaces.

Application of pesticide spray

To evaluate the wipe samplers a known amount of the pesticide permethrin was sprayed onto a used coach airline seat, food tray, rug section and arm rest. A uniform spray was obtained by adjusting the applicator nozzle and spraying the pesticide over the surface in two back and forth passes. The reproducibility of the residue loading was checked by placing filter paper (9cm) in a Petri dish at multiple locations over a $2m^2$ area, equivalent to the size of a seat cushion and back. The loading across the surface had a residual standard deviation (RSD) of ±7.7%. The application rate was determined with each experiment by placing a filter paper on the surface and measuring the amount of pesticide deposited. Sprayed surfaces were allowed to air dry prior to sampling.

Wipe Samplers

The collection efficiencies of the sampler for the pesticide permethrin were evaluated for two hard surfaces: airplane tray tables and airplane arm rests, and two soft surfaces: airplane seat cushions and airplane carpet. The surfaces evaluated were used or surplus materials from commercial aircraft.

The wipe method used a Whatman Circle Filter Paper (9cm) as the sampling medium. These filters were selected for evaluation because they are readily availability, inexpensive and the target pesticides, as well as many other contaminants that are often measured in wipe samples, are not detectable in extracts or digests of the filter. For hard surfaces the filter was placed on the surface to be sampled, sprayed with approximated 0.7ml of water using a mister, rotated by approximately 90° to moisten the surface (being careful to minimize any tearing of the filter), and transferred to a storage container. The process was repeated with a second wet filter and then the residual liquid was wiped from the surface with a dry Whatman Circle Filter. A similar procedure was followed for the soft surfaces, such as seat cushion and rugs with pressure was applied to the second and third dry filters to "blot" or collect the water that was on the surface or seeped below the surface of seat material or rug pile.

Sample Analysis

The sampling media was placed in a 40ml vial with a measured volume of between10-30ml hexane added to completely cover the filter material and the vial sonicated for 20 minutes to extract the permethrin. The hexane volume was reduced (initially to 1.0ml and subsequently to 0.2 ml) under a stream of air at room temperature and 1.0µl was injected onto an Agilent 6890/5973 GC-MS. The method detection limit was $2\mu g/cm^2$ when the final volume was 200µl. The calibration curve was linear over the entire range of the concentrations analyzed, with samples whose concentration exceeded the linear range diluted as needed. Permethrin was not detected in the blank samples and spike recoveries done directly to the extracts and on the filter indicated no losses or interferences were present in the analysis. External standards were analyzed with each sample batch indicating that permethrin was stable over the sample analysis time period.

2.1.2 Results and Discussion:

The Whatman Filter was found to be compatible with water as a wetting agent and provided consistent recoveries from both hard (>90%) and soft surfaces (40% seat cushions, 70% rugs). Similar materials have been used to successfully collect wipe samples with different wetting agents from hard surfaces within occupational settings for a variety of contaminants (McArthur 1992) and from home surfaces (Boeninger et 2008) but no literature reports of its use for collection of contaminants from soft surfaces were found.

To evaluate how many different filters provided the optimum recovery of permethrin from the soft surfaces a sequence of filters that alternated one wet and two dry filters were used with each filter analyzed individually (Figure 1). These tests were done the day after the surface was sprayed to allow for water from the spray to evaporate from the surface prior to sampling. Minimal amounts of pesticide were recovered from the surface after three sequential surface wipes of three filters were used indicating that a three series of three wipes (one wet and two dry) was optimal for recovery. Collection of samples from the surface was found to decrease with time, presumable due to losses from the surface as similar declines were observed from

both hard and soft surfaces (Figure 2a and 2b). These results suggest that the most important factor in recovering permethrin from soft surfaces appeared to be solubilizing the permethrin into the wetting agent rather than the collection of dust particles that might contain the pesticide.

The amount of pesticide recovered from a seat cushion was less than half of the applied pesticide suggesting that some of the pesticide might be absorbed by the polyurethane foam within the seat cushion and not completely released to the water. Subsequent sampling from the area that had been previously sampled did not recover any additional pesticide while recoveries of 40% of the amount sprayed were retrieved from areas adjacent to the initially sampled area. This suggests that the pesticides not collected by the method are not retrievable by the wipe collection method being used, but rather absorbed into the seating material. Thus, pesticides not collected by the sample might not present a potential dermal exposure to the passengers or crew onboard aircraft.

Contact pressure and time can be important considerations in recovery of some substances from surface onto filter paper. The recovery from the seat was examined using two different individuals, one male and one female, who were expected to apply different amount of pressure because of differences in their size and strength. The recoveries of pesticides for the two individuals were 37.7±5.3 and 39.7±3.8%, indicating that there were no inter-individual differences for these two individuals.

2.1.3 Conclusion:

A simple wipe pesticide sampler was developed using Whatman Filters and water as a wetting agent to collect permethrin from both soft cushion and rug surfaces in addition to hard surfaces. Consistent recoveries were obtained from each surface type. While wipe samplers have been used successfully for collection of pesticides from hard surfaces, wipe samplers have not be used to collect pesticides from in-use aircraft seats and rugs, which this method was designed for. Thus, the wipe sampler can be used to estimate potential dermal exposure to individuals sitting for extended times on cushioned seats. People are potentially exposed to pesticides from airline seats if bare skin contacts the seat or from transfer of the pesticide residual to a person's clothing. The transfer of pesticides from the seat to a person would be facilitated if either a liquid spills onto the surface or the seat become moist from perspiration that results from sitting for an extended time period. The sampler uses materials that can readily be brought through security and onto planes and the sample collection presents no disruption to the flight crew procedures, though permission should be obtained before sampling is done to avoid any misunderstanding with the flight crew or fellow passengers.

Figure 1. Sequential Analysis (µg) of Each Filter Wipe from an Airline Seat to Establish the Optimal Number of Filters to Use for Maximum Recovery.

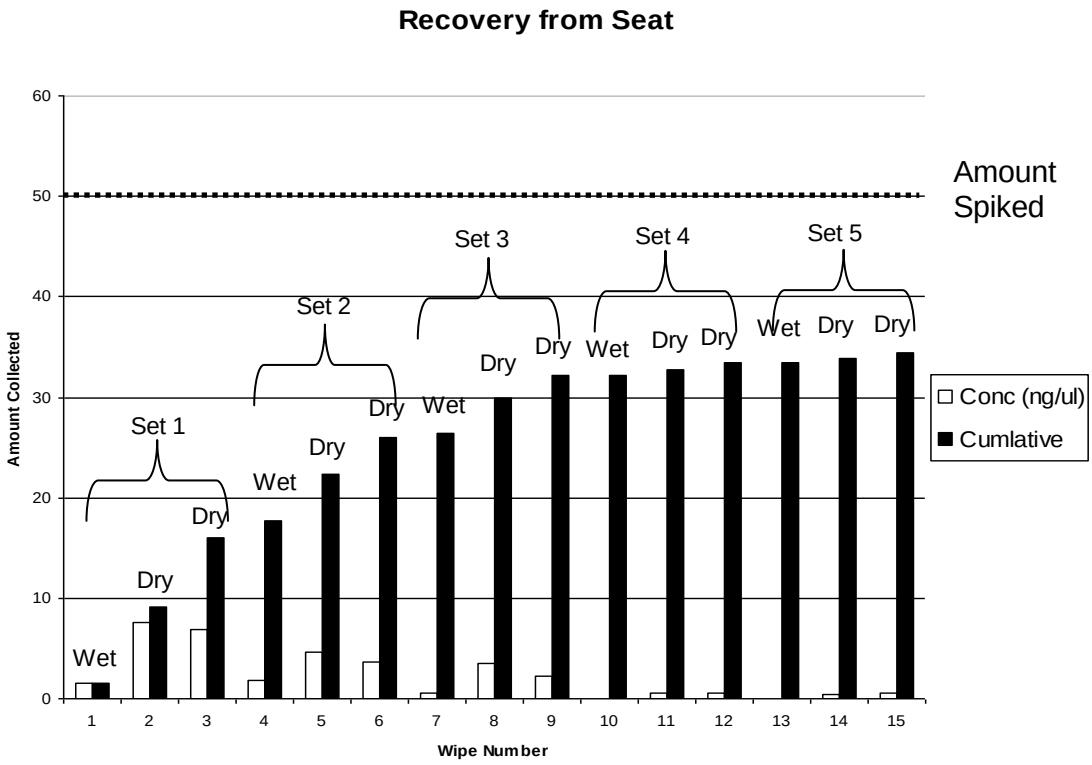
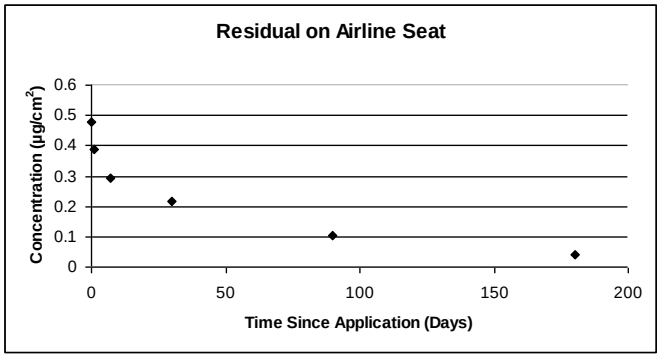
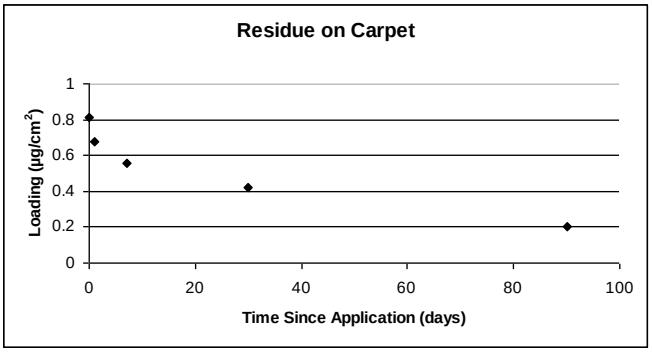


Figure 2a & b. Surface Loading Residue of Permethrin on Airline Seats (a) and Airline Carpet (b) with Time Since Application





3.1 Pesticide Surface Loading on In-Use Aircraft

3.1.1 Methods

Collection of Samples from Commercial Airlines

Wipe samples were collected from around the passenger seat and common areas using of filter pack of 9.0 cm round Whatman 41 cellulose fiber filters with water as a wetting agent (Mohan and Weisel 2010). Samples were collected from hard surfaces (front and back of the tray tables, arm rests, walls, galleys), rugs, and soft surfaces (seat cushions, backs of seats) within the aircraft cabin on 15 US domestic flights, 18 flights landing in Central or South America, 8 flights landing in Australia or New Zealand, 4 flights landing in Africa or Europe and 15 flights landing in Asia during 2008 and 2009 with some destinations flown to multiple times.

Simulated aircraft cabin

Controlled spraying experiments were conducted within a mock Boeing 767 aircraft cabin located at Kansas State University that had a volume of 95 m^3 (width × length × height: 5.0 m × 9.6 m × 2.3 m) and 11 rows of 7 seats across. The seats were occupied by heated mannequins to simulate the heat load from passengers so that the turbulence within the cabin realistically represents that for an occupied commercial aircraft. The simulated aircraft was disinsected with commercially available aircraft disinfection products, pre-spray and top of descent, containing 2% permethrin and 2% *d*-phenothrin by weight, respectively. Two people simultaneously sprayed the plane while walking along the two isles in a fashion analogous to the method used by flight attendants while passengers would be on-board. Air samples were collected onto adsorbent traps for subsequent analyses for permethrin and d-phenothrin. Deposition samples were collected using Whatman circle filter (9 cm) placed in an opened Petri dish.

Sample preparation and analysis

The filter set and tenax air samples were extracted, assisted by ultrasonication for 45 minutes and mechanical shaking, into 30 ml and 10 ml, respectively, of hexane with an internal standard (500 ng/µl). The hexane was reduced to approximately 200µl under a stream of clean air and analyzed by GC/MS vial for analysis. A 1 µl aliquot of the concentrated solution analyzed by GC/MS using a RTX5 column and the MS operated in the EI mode using selected ion monitoring (SIM).

3.1.2 Results and Discussions

Surface deposition levels of pyrethroids

Pyrethroid pesticides were detected in only a single sample collected in the aircraft cabin on US domestic flights consistent with pesticide sprays not currently approved for use in the US for airplanes (US EPA 2008, US EPA 2009). Permethrin surface loadings were commonly detected on aircraft flying international routes that likely entered countries mandating disinsection. The mean permethrin levels were from below detection (0.001ug/cm^2) to 0.46 µg/cm^2 while *d*-phenothrin was mostly below detection. The levels measured were all well below the application guidelines for surface loading for residual treatment which are 50 µg/cm^2 on rugs and 20 µg/cm^2 on other surfaces within the aircraft cabin. The lower levels than the treatment loading likely reflect that permethrin levels on airline seats degrade exponentially with time when undisturbed surfaces are left exposed, with a decline of a factor of two was observed within 30 days (Mohan and Weisel 2010) and would also be expected to be removed when surfaces are contacted by passengers or cleaned by maintenance crew leading to potential dermal exposure.

For a single flight, typically it was found that either all or none of the wipes samples had detectable levels of permethrin consistent with the entire aircraft being treated and redistribution occurring. Similar permethrin loadings of 0.17-0.69 µg/cm^2

were reported for wipe samples taken by a flight attendant reported as a personal communication in a National Research Council report (NRC 2002). In a Californian study surface loadings were measured between 15 minutes and 28 hours after residual treatment was applied (Sutton et al 2007). The surface loadings in that study varied over six orders of magnitude from 0.0015 to 3500 μg/cm^2, with mean and median values of 58 and 0.16 μg/cm^2 across the various surface types sampled from 9 aircraft. The highest loadings were on material (blankets, tissues, headset) which were not sampled in the current study. Wipe samples from hard surfaces had median, mean and maximum values of 0.075, 17 and 416 μg/cm^2, respectively, while fabric pieces which were cut from seat covers (soft surfaces) and directly extracted had median, mean and maximum values of 1.0, 3.9 and 11 μg/cm^2. The median loadings reported for those samples collected shortly after spraying were similar to the maximum value measured in the current study.

Tukey box plots portraying the median, 25%, 75% and the range of the loadings for samples that had measurable values for each surface type sampled are given in Figure 4. All types of surfaces have similar loadings, though some individual values for the rug and seat top were higher. The presence of permethrin on tray table indicates potential indirect ingestion exposure to permethrin could occur in addition to dermal exposure when hands or bare arms or legs touch the various surfaces within a treated airplane.

Simulated Aircraft/Disinsection Study

The permethrin and *d*-phenothrin air concentrations measured in the mock Boeing 767 cabin over 40 minutes during and following disinsection when the air ventilation system was operated at a high flow rate ranged from 39 to 112 μg/m^3, while when the air ventilation system was set at a low flow rate ranged from 105 to 260 μg/m^3. These values are similar to those reported by Berger-Preiss et al. (2004), who measured a median *d* -phenothrin air concentration of 21 μg/m^3 (3 - 80 μg/m^3) in a 40 minute sample during and following an in-flight spraying application. In that study between 107 - 204 grams of aerosols containing 0.32 % pyrethrin were released into an A310 aircraft cabin with the air ventilation system operating.

The median deposition measured for both permethrin and *d*-phenothrin during the simulated disinsection for the high ventilation condition varied across the plane from 0.08 to 0.13 μg/cm^2 with a maximum value was 0.19, while under low ventilation condition the range was 0.64 to 0.69 μg/cm^2 with a maximum value of 1.2 μg/cm^2. Berger-Preiβ (2004) measured *d*-phenothrin surface loadings of 0.10 to 1.16 μg/cm^2 following a pre-embarkment stray method. The deposition levels measured during top of decent spraying on two flights collected in a similar manner by placing a filter out while the flight attendant walked down the aisle were 0.014 and 0.25 μg/cm^2 for permethrin and 0.005 and 0.025 μg/cm^2 for *d*-phenothrin. The in-flight deposition values are more reflective of with the high ventilation condition of the simulation study.

3.1.3 Conclusions

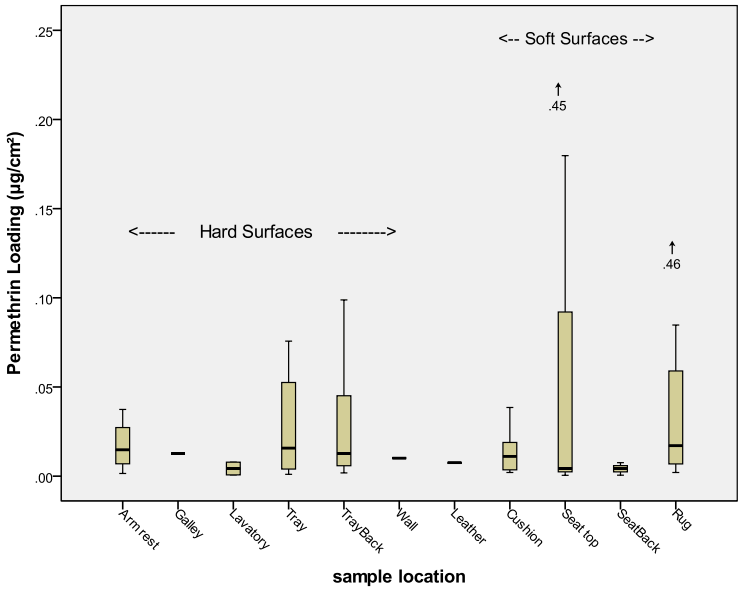
Permethrin was routinely detected on flights to and from countries that require residual disinsection treatment and counties having maintenance facilities for airlines but at levels that were at least one order of magnitude lower than the application guidelines. These lower levels likely reflect degradation with time and removal from surfaces due to contact of the surfaces by passengers and actions by the cleaning crew. *d*-Phenothrin was only detected on a few flights but was present in the two deposition samples collected while active spraying was done with passengers aboard. Air and surface deposition levels of pesticides measured in a mock Boeing 767 aircraft cabin were consistent with other controlled studies and in-flight measurements with the levels being a function of the ventilation conditions. While the number of samples collected is insufficient to determine the distribution of surface loadings on aircraft, these results indicate that potential inhalation, dermal and ingestion exposures of the flight crewmember and passenger to pyrethroid pesticides are likely to occur.

Table 3 Descriptive Statistics of Pesticide Loading Measured on International Flights Grouped by Surface Type and Destination

Destination Continent	Mean * Permethrin Loading ($\mu g/cm^2$)	Mean * Phenothrin Loading ($\mu g/cm^2$)	Max Permethrin ($\mu g/cm$)	Max Phenothrin ($\mu g/cm$)	Total Flights Sampled	Number Permethrin Above Detection	Number Phenthrin Above Detection
Hard Surface							
Asia	0.025±.032	.0023±.0003	0.099	0.0021	19	9	2
Australia	0.018±.015	ND	0.037		6	6	0
Caribbean	ND	ND			9	0	0
Europe	0.004±.02	0.018±.002	0.0037	0.018	1	1	1
N. America	0.024±.032	0.002±.0002	0.076	0.002	23	6	3
S. America	ND	ND			3	0	0
Soft Surface							
Asia	0.033±.021	0.0045	0.062	0.0045	18	4	1
Australia	0.039±.031	ND	0.0096		6	6	0
Caribbean	ND	ND			6	0	0
Europe	0.006±.093	ND	.006		1	1	0
N. America	.093±.199	ND	0.449		14	5	0
S. America	ND	ND	ND		2	0	0
Leather							
Asia	0.0075	0.0021	0.0075	0.0021	1	1	1
Rug							
Asia	0.012±.008	ND	0.022		14	6	0
Australia	0.27	ND	0.462		2	2	0
Caribbean	ND	ND			3	0	0
N. America	0.018±.022	ND	0.033		8	2	0
S. America	ND	ND			1	0	0
Deposition							
Asia	0.034±.002	0.031±.026	0.035	0.061	3	2	3

* Mean of samples with detectable levels of indicated pesticide

Figure 4. Tukey Box and Whisker Plot of Permethrin Concentration for Samples with Measureable Levels by Surface Sampled – (Displayed are: Midline of box is median, Box is lower and upper quartile, and minimum and maximum at end of line. Outliers are given as individual numbers)



4.1 THE CFD MODEL

4.1.1 Methods:

The CFD model of the 11 row twin-aisle airliner cabin mockup based on the one developed by Mazumdar and Chen (2008) and modified to the cabin dimensions of the experimental mockup to include a 10^{-3} m^3 cubical volumes at the breathing zone is shown. Simulations were done for two different air exchange rates: 29 ACH (1400 cfm) and at 1 ACH (48 cfm). The amount sprayed, 776.5 mg, walking speed of the people spraying along with the height release were all assumed to be the same in all experiments. Thus, experimental variability was not accounted for in the model.

To simulate a moving spray, the pesticide release was modeled using a series of sequential linear sources (8 nos.) along the length of the cabin. Each source remained active for a second, as the sources became sequentially active from Row 1 towards Row 11. The cabin surface area to volume ratio from the CFD model was 3.78 m^2/m^3. The pesticide was modeled as species which gave the flexibility to appropriately scale the exposures for any specified amount of pesticide spraying. The deposition of pesticide on the cabin surfaces was modeled using the species reaction module. Degradation or backward reaction of the pesticide was not considered. To simulate the temporal variation of pesticide deposition and air concentration, time steps from 0.05 s, during the initial period of pesticide spraying, to 0.1 s, when the pesticide deposition rate and the air concentration were less, was used.

4.1.2 RESULTS AND DISCUSSION

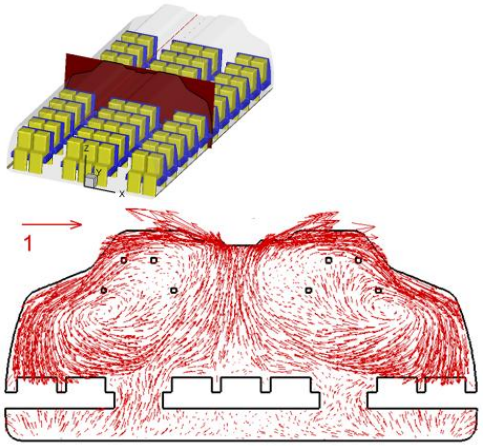
The airflow across the cabin cross-section at 1400 CFM (29 CH) shows high momentum of air from the overhead slot which is distributed to the side walls and rises at the center of the cabin (Figure 5a). A nearly symmetric vortex structure is observed across the cabin cross-section. At 48 CFM (1 ACH) the thermal plume from the passengers dictate the flow pattern in the cabin. The flow pattern shown for the 1 ACH case is the reverse of what is observed for the 29 ACH case but at a significantly lower average airflow velocity (Figure 5b). The pesticide air concentration and deposition loading for sideways spraying is shown in Figure 4XX for the 29 ACH condition at several time points: 8 seconds (during the spraying), 1 minute and 4 minutes. The air concentration buildup while spraying is apparent at 8 seconds, a nearly uniform air concentration is observed at 1 minute, which then decays further as ventilation of the cabin dominants with no new sources (4 minutes). The deposition shows an increase in the cumulative loading with time over the three points displayed. Further, an asymmetry of pesticide concentration across the cabin cross-section is observed. The net deposition is greater near the aisle. The loadings on some of the seats and passengers were higher than 0.25 $\mu g/cm^2$. The net depositions increased over the initial 240 seconds (4 minutes), with very little change subsequently. An asymmetry in pesticide deposition is observed across the cabin. At the lower 48 CFM (1 ACH) itt took longer for the pesticide concentration to go below 10 $\mu g/m^3$ compared to 480 seconds (8 minutes) for the 29 ACH case.

The CFD estimates of pesticide deposition are shown as box plots showing the average value and the 25 and 75 percentile values on the surfaces along with the experimental data in Figure 7. The maximum and minimum depositions observed on those surfaces are also presented. The median, maximum, minimum and the 25 and 75 percentile values on the surfaces were obtained from the CFD deposition results in the computational cells on each surface. The CFD model predicts the depositions of pesticide on the lap and seat-top at high air exchange rate reasonably well. Multiple experimental data is shown at several locations as the measurements were repeated several times to test the repeatability of the results. Both CFD and experimental measurements show no major variation in deposition characteristics for sideways and overhead spraying at the high air exchange rate. The spatial variation of net deposition across the cabin is not significant as uniform mixing is expected at a high air exchange rate.

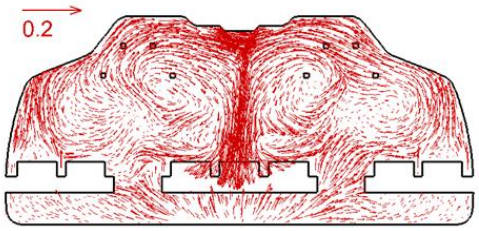
However, CFD results in Figure 8 shows that the spatial variation can be significant at low air exchange rates. The window seats (6A & 6G) have much less deposition compared to the middle seats (3D, 6D & 9D). No major variation in deposition characteristics is observed for sideways and overhead spraying. Surface deposition levels varied from 0.33 to 1.22 $\mu g/cm^2$ for the low-ventilation experiments compared to 0.05 to 0.20 $\mu g/cm^2$ for the high ventilation case. A more uniform deposition behavior across the seats is seen in the experiments compared to CFD. The CFD model simulates the depositions at the middle seats (3D, 6D & 9D) reasonably well. However it predicts a much lower deposition for the window seats (6A & 6G). The CFD simulations were done assuming that the momentum of released pesticide spray was negligible. The pesticide hence followed the bulk airflow.

4.1.3 CONCLUSION

A CFD model was effectively able to model the spatial and temporal variation of pesticide deposition and concentration in a mock Boeing 767. Two contrasting flow features were observed for the high (29 ACH) and the low (1 ACH) air-exchange rate indicated air-exchange rate has a significant impact on the deposition characteristics of pesticide inside the cabin.The pesticide air concentrations fell below 10 $\mu g/m^3$ within 8 minutes and 20 minutes for 29 ACH & 1 ACH respectively. Surface deposition levels varied from 0.33-1.22 $\mu g/cm^2$ for the low-ventilation experiments compared to 0.05-0.20 $\mu g/cm^2$ for the high ventilation case. The CFD model simulated the measured depositions of pesticide across the cabin reasonably well for the high air-exchange rate. However at the low air-exchange rate, discrepancies were observed between CFD simulations and experimental measurements near the window seats.

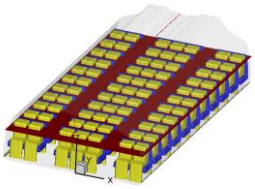


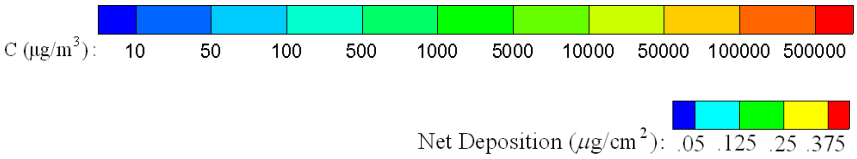
(a)



(b)

Figure 3. Comparison of airflow across the cabin cross-section for (a) 1400 CFM (29 ACH) and (b) 48 CFM (1 ACH)





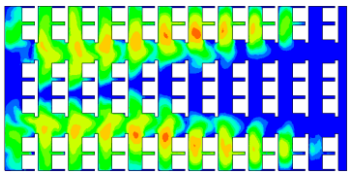
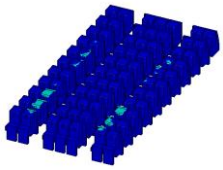
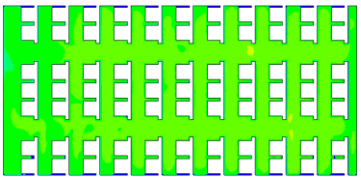
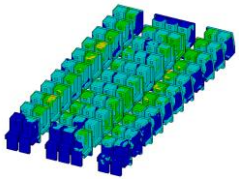
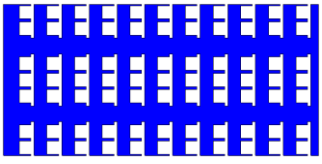
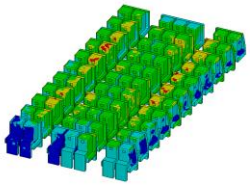
Concentration (µg/m^3)	Net deposition (µg/cm^2)
 t=8s	 t=8s
 t=60s	 t=60s
 t=480s	 t=480s

Figure 4. The concentration of pesticide at breathing level and net deposition on passengers and seats for sideways spraying at1400 CFM (29 ACH)

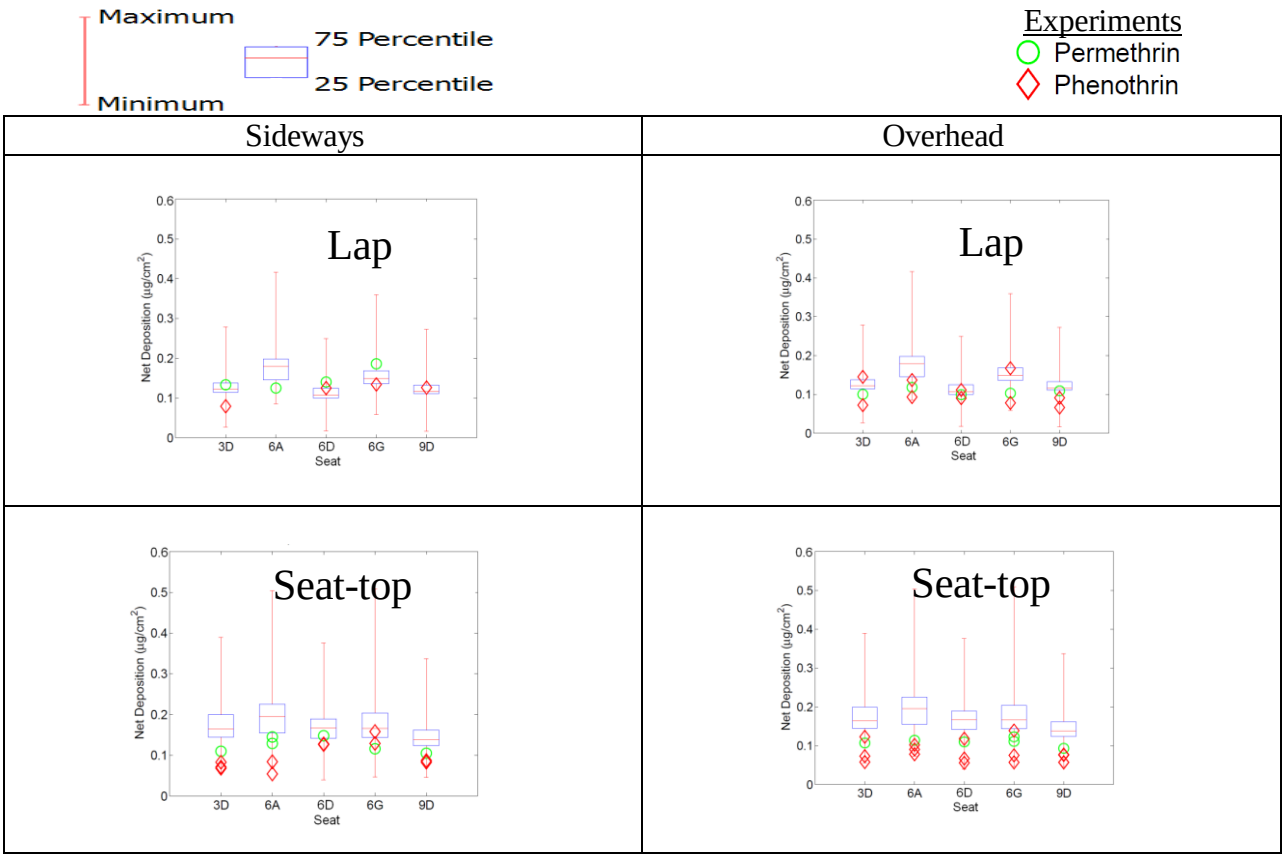


Figure 7. Comparison of CFD predictions (box plot) with experimental measurements of pesticide deposition on the lap and seat-top of passengers 3D, 6A, 6D, 6G & 9D the high ventilation rate

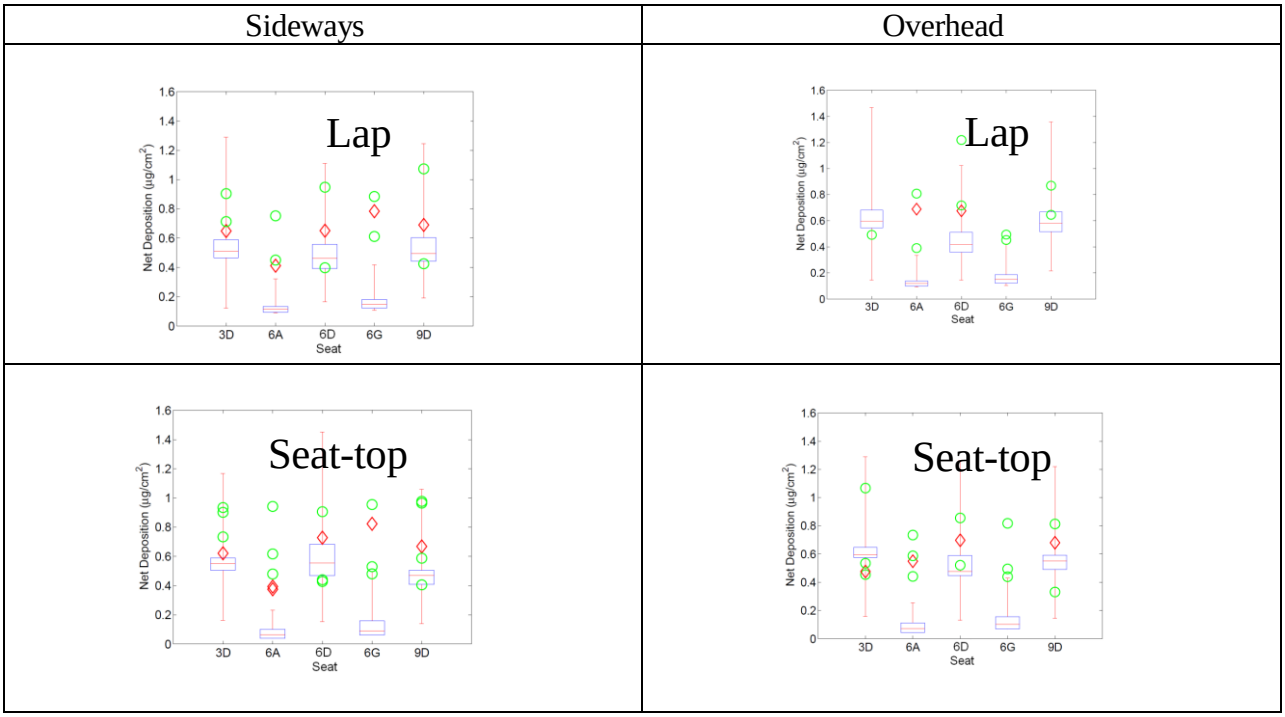


Figure 8. Comparison of CFD predictions (box plot) with experimental measurements of pesticide deposition on the lap and seat-top of passengers 3D, 6A, 6D, 6G & 9D at the low ventilation rate

5.1 Urinary Level of Pesticide Metabolites in Flight Crew

5.1.1 Methods

Sample and data collection

Twenty eight flight attendants working on commercial aircrafts were recruited with 7 flight attendants flying on domestic US routes and 21 on international routes. Eleven subjects were categorized into a "disinsection group" based on the following criteria: (1) either working on aircrafts that entered countries requiring disinsection, and indications were made that pyrethroids were used to meet the requirement; or (2) information provided by the subjects indicating that the aircrafts had been treated previously using residual treatment method even though they only entered the countries which do not require disinsection. Three urine samples were provided by each flight attendant, one before the selected flight, one upon landing and a third 24 hours later. The urine samples were analyzed for pyrethroid metabolites by GC/MS and creatinine by UV spectroscopy. Appropriate quality control steps were taking including recovery studies, use of internal standards, blank analyses and duplicate analyses. Both parametric and non-parametric statistical analyses were performed dependent upon the distribution of the raw or log transformed data.

5.1.2 Results and Discussion

Tables 5 the distributions of the volume based of 3-PBA, *cis*- and *trans*-Cl2CA, the primary metabolites from permethrin and d phenothrin. Similar results were obtained for the creatinine corrected values, with the total GM for *trans*-Cl2CA in the disinsection group being 3.92 µg/g adjusted for creatinine while that for non-disinsection group was 0.58 µg/g adjusted for creatinine. The total GM of *cis*-Cl2CA in the disinsection group was 0.98 µg/g adjusted for creatinine, and that for non-disinsection group was 0.23 µg/g adjusted for creatinine. The metabolites *cis*-Br2CA and 4F-3-PBA were also measured but the data are not presented here since they are metabolites of pyrethroids not used on the aircraft flown and therefore were detectable in less than a quarter of the samples.

For flight attendants who did not fly on planes that were disinsected, the urinary levels of pyrethroid metabolites in pre-flight samples were not significantly different from those in post-flight samples nor were they significantly different from those in 24hr-post flight samples. For flight attendants who flew on planes that were disinsected, the 3-PBA, *cis*- and *trans*-Cl2CA levels in the post-flight samples had significantly higher levels than those in the pre-flight samples (3-PBA: $p < 0.0001$; *cis*-Cl2CA: $p = 0.0005$; *trans*-Cl2CA: $p < 0.0001$) with the average increasing percentages of 569 %, 797 % and 857 %, respectively. The post flight samples were also significantly higher than those in the 24hr-post-flight samples (3-PBA: $p = 0.0004$; *cis*-Cl2CA: $p = 0.01$; *trans*-Cl2CA: $p = 0.008$). Urinary levels of 3-PBA, *cis*- and *trans*-Cl2CA in the 24hr-post-flight samples were also significantly higher than those in pre-flight samples (3-PBA: $p = 0.0006$; *cis*-Cl2CA: $p = 0.001$; *trans*-Cl2CA: $p < 0.0001$).

The levels of 3-PBA, *cis*- and *trans*-Cl2CA in pre-flight samples from the disinsection group were higher (approximately twice) than those from non-disinsection group (3-PBA: $p = 0.01$; *cis*-Cl2CA: $p = 0.01$; *trans*-Cl2CA: $p = 0.001$). The disinsection group also had higher levels of 3-PBA, *cis*- and *trans*-Cl2CA in post-flight samples than those in non-disinsection group (3-PBA: $p < 0.0001$; *cis*-Cl2CA: $p = 0.002$; *trans*-Cl2CA: $p = 0.0005$), and in 24hr-post-flight samples (3-PBA: $p = 0.0009$; *cis*-Cl2CA: $p = 0.005$; *trans*-Cl2CA: $p = 0.002$). Figure 5 presents the distribution of the combined urinary pyrethroid metabolite levels by exposure conditions and sampling types. Wide variations in concentrations were measured, ranging from 0.34 µg/g to 11.2 µg/g creatinine in the non-disinsection group, and from 0.60 µg/g to 93.8 µg/g creatinine in the disinsection group.

Significant associations were identified between urinary levels of 3-PBA, *cis*- and *trans*-Cl2CA and the post-disinsection duration, the period of the time between when the plane was disinsected and when the post flight urine samples was collected ($R^2 = 0.71$, 0.65 and 0.59, respectively). This association followed an exponential decay (Figure 6).

The GMs and the medians of the total levels of 3-PBA in the non-disinsection group were approximately 2 – 3 times of NHANES levels. However, no significant percentile differences were found between them ($p = 0.69$). Urinary levels of 3-PBA in the post-flight samples from flight attendants who flew on planes that were disinsected were more than 10 times higher than the GMs in the NHANES data, as well as for each of the percentiles examined ($p = 0.016$). The GM and median of 3-PBA in the pre-flight samples were 5 times higher than the NHANES levels. For 3*cis*- and *trans*-Cl2CA in the post- and 24hr-post urine samples from disinsection group were also higher than the NHANES levels at each percentile (75^{th}, 90^{th} and 95^{th}).

The significantly higher levels of 3-PBA, *cis*- and *trans*- Cl2CA in the post-flight urine samples for the flight attendants who flew on disinsected aircraft and the increase in post to pre-flight samples for that group indicate that residual disinsection of aircraft results in an increase in body burden of pesticides in flight attendants. Permethrin was reported by the flight attendants to be the pesticide used to treat the aircrafts flown. This is consistent with the pattern of metabolites, 3-PBA, *cis* and *trans*-C12CA, measured to be included in the post-flight samples.

Previous studies revealed rapid metabolization and excretion of pyrethroids with levels returning to base line with one to several days (Eadsforth et al. 1988, Sams and Jones 2011, Leng et al. 1997). Similar results were observed in this study with

the levels of 3-PBA, *cis*- and *trans*-Cl2CA in 24hr-post flight urine samples greatly reduced compared to the post-flight samples. In spite of the rapid metabolization and excretion of pyrethroids, the creatinine adjusted levels of urinary permethrin metabolites in pre-flight samples from participants who flew on routes to countries requiring disinsection were above the corresponding background levels observed in the U.S. general population and flight attendants who flew domestic routes. This suggests a possible chronic higher body burden of pesticides for those flight attendants who routine fly on disinsected aircraft.

Few data are available in the open literature with which the results in this study can be compared with although pyrethroid metabolites in urine have been studied for almost 30 years in different occupational settings. In a study by Kolmodln-Hedman et al. (1982), the highest urinary level of permethrin metabolites detected were 260 µg/L in the morning void in one forestry worker following a 6-hour permethrin exposure to 11 – 85 µg/m^3, but no detectable amount of metabolites were observed in the afternoon samples. Concentrations of 3-PBA in urine samples from ten workers working in greenhouses for more than 12 h after application of deltamethrin ranged from < LOD – 52 µg/L (Tuomainen et al. 1996). Pest control workers had reported concentrations of 3-PBA from < 0.5 – 277 µg/L (Leng et al. 1997). These results suggested that urinary metabolite levels of pyrethroids varied greatly among different occupations. In this study, the creatinine adjusted concentrations of 3-PBA ranged from 2.18 – 71.0 µg/g for flight attendants flying on disinsected aircrafts through residual treatment, suggesting their exposure to permethrin is similar to pesticides applicators. None of the flight attendants in this study reported spraying pesticides themselves; rather the aircrafts they flew on had been treated previously on the ground using the residual disinsection method to meet the requirement. Exposure to residual treatment would likely be associated with dermal uptake of pyrethroids as flight attendants spend up to 15 hours working, sitting and sleeping on surfaces in the international flights that were treated. In addition, potential nonintentional ingestion of pyrethroids contaminated food could also occur by contacting dirty hands or surfaces, e.g. tray tables. Potential inhalation exposure can not be ruled out since permethrin is a semi-volatile organic compound that could slowly partition into the gaseous phase from the internal surfaces of the aircraft, and be consequently inhaled into human bodies. In addition, the resuspended particles containing permethrin could also be inhaled particularly when laying down in the crew rest areas.

5.1.3 Conclusions

Flight attendants working on the pyrethroids disinsected aircraft had significant higher concentrations of 3-PBA, *cis*- and *trans*- Cl2CA in the post- and 24hr-post flight urine samples than those working on non-disinsected aircrafts and the general U.S. population, indicating they had elevated body burden due to practice of disinsection of aircrafts with pyrethroids, predominantly permethrin. The creatinine adjusted levels of 3-PBA, *cis*- and *trans*- Cl2CA in the post-flight urine samples reflected the short-term exposure to pyrethroids, while those in the pre-flight urine samples suggested the accumulation of body burden under steady state in a long-term period for those flight attendants routinely working on pyrethroid treated aircrafts. Post-disinsection duration was positively associated with the levels of 3-PBA, *cis*- and *trans*- Cl2CA. This study suggests that an evaluation of the potential health risks from this occupational exposure to pyrethroids should be done.

Table 5. Distribution of volume-based urinary concentrations of 3-PBA pyrethroid metabolites among the flight attendants and NHANES General US Population (µg/L)

Metabolite	GM (SD)	Range
3-PBA		
Non-disinsection[a]		
Pre-flight	0.86 (0.86)	0.11–3.40
Post-flight	1.01 (0.60)	0.22–2.33
24-hr-post	1.06 (1.13)	0.13–3.86
Disinsection[b]		
Pre-flight	1.36 (1.20)	0.30–3.62
Post-flight	14.40 (22.97)	0.78–81.53
24-hr-post	4.53 (5.86)	1.34–20.78
NHANES 2001-2002 Total	0.318	
Age 20-59	0.314	

Abbreviations: GM, geometric mean; SD, standard deviation.
[a]Including flight attendants working on disinsected aircrafts.
[a]Including flight attendants working on non-disinsected aircrafts.
[c]Data for general US population from Barr et al. (2010).

Figure 4 The distribution of the combined urinary pyrethroid metabolite levels by exposure conditions and sampling types

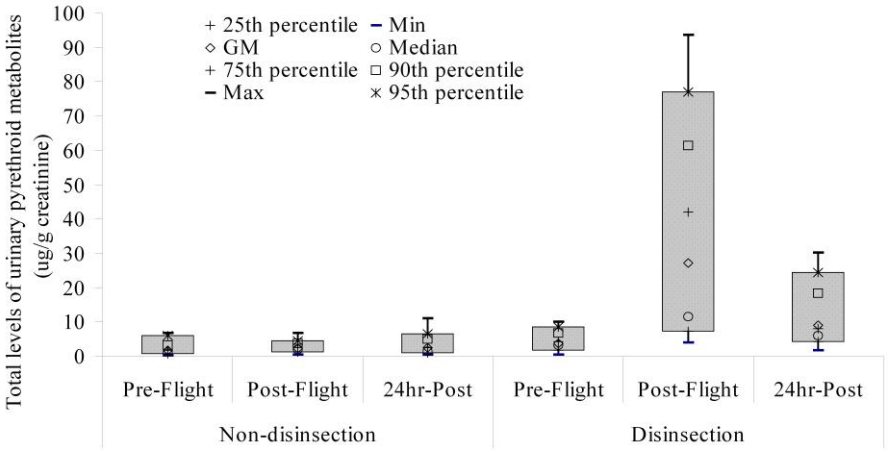
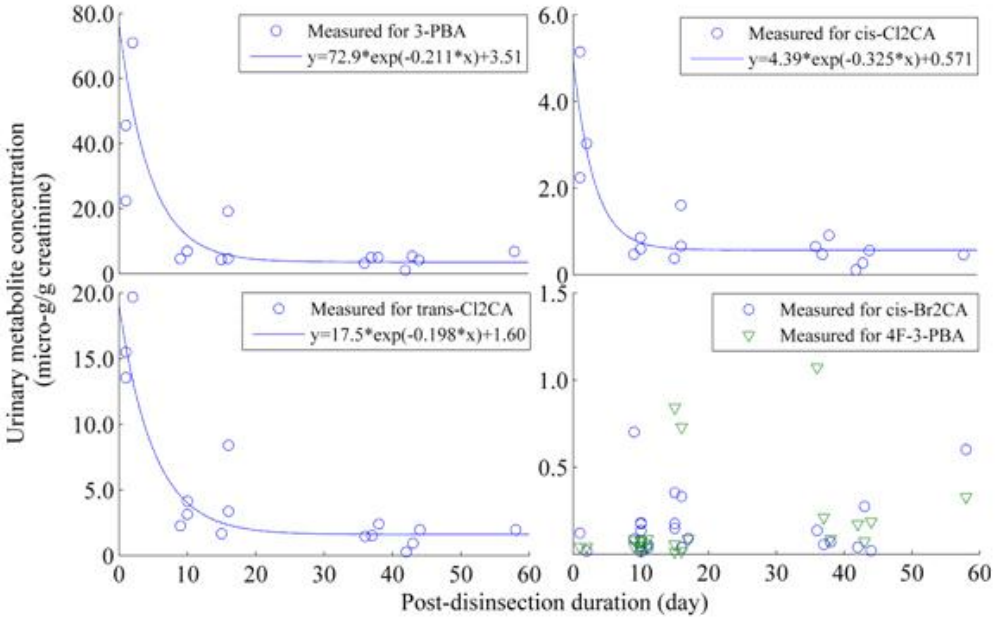


Figure 5 Post-disinsection durations and the urinary concentrations of pyrethroid metabolites in the disinsection group



6.1 Overall Conclusions:

These results indicate that measureable levels, within the WHO guidelines, of pyrethroid pesticides are present on surfaces throughout aircraft that are disinsection if they fly into countries which require this practice, countries where maintenance of aircraft that service these countries is done or into countries whose routes may include areas requiring disinsection of aircraft. Thus, potential inhalation, dermal and ingestion exposures of flight crewmembers and passengers to pyrethroid pesticides are likely to occur on an array of flights. Elevated permethrin body burdens for flight attendants working on aircraft that were disinsected with pyrethroid insecticides were documented based on urinary metabolite levels being significantly higher immediately after a flying on a disinsected aircraft and compared to other flight attendants working on other routes or the general US population matched on age. The risks to crew members and the flying public associated with exposure to pyrethroids at the levels need to be reviewed.

7.1 Implications and Recommendations:

This study documented that flight attendants on commercial aircrafts disinsected with pyrethroid insecticides are exposed to pesticides at levels that result in elevated body burden and internal accumulation of the pyrethroids exceeding the general US population and comparable to pesticide applicators. It is expected that flying public would be similarly exposed to pesticides on those flights. The risk calculation done by WHO when recommendations on the practice of disinsection were made prior to the results on the body burden to crewmembers on disinsected aircraft and to recent toxicological studies on adverse effects of these disinsection. A review of the risk due to pesticide exposure crew and passengers on aircraft flying into countries required disinsection should be done and alternate approaches to prevent the transport of insects on commercial aircraft should be evaluated.

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