Assessment of Children's Non-dietary Exposure to Chlorpyrifos in Indoor Environments

Chi-Hsuan Chang[1], Jeffry H. Shirai[2], John C. Kissel[2]

[1]Department of Public Health, National Taiwan University; [2]Department of Environmental and Occupational Health Sciences, University of Washington

Abstract

Chlorpyrifos is an organophosphate pesticide that was once widely used for residential pest control. Indoor residential use was banned by the US Environmental Protection Agency (USEPA) in 2000, due to concern over potential exposure to children. However, the physical-chemical properties of chlorpyrifos are such that residues persist indoors and measureable levels are frequently found in US homes. As a result, chronic low-level exposures to children are common. The Children's Total Exposure to Pesticides and Other Persistent Organic Pollutants (CTEPP) was a USEPA-funded study investigating children's exposure to over 50 pollutants at homes and daycare facilities in selected North Carolina and Ohio counties in 2000-2001. In the current project the fate and transport of chlorpyrifos in a model home and the resulting aggregate non-dietary dose of chlorpyrifos were simulated using a computer model that links a fugacity-based multi-compartmental indoor environment component to a physiologically-based pharmacokinetic module. Skin is described as a multi-compartment membrane and differentiated as exposed hand, exposed non-hand, and clothed. This model was developed as a general tool to assess the pathways that contribute to indoor exposure to semi-volatile organic compounds (SVOCs). Previous implementation of the model evaluated children's exposure to di-ethylhexyl phthalate (DEHP, a plasticizer commonly found in vinyl flooring) and nicotine. Future aims include application of the recently modified, more user-friendly version of the model to a suite of SVOCs. Preliminary results from the chlorpyrifos case study reveal slow flushing of the pesticide from indoor compartments and substantial contribution of the dermal route of exposure to aggregate non-dietary dose.

Introduction

The model used in this study was developed to be a general tool to assess the exposure pathways of SVOCs in indoor environments, focusing on selected non-dietary exposure routes. It has been implemented in predicting the indoor exposure of children to DEHP (Greenhall et al., 2011) and nicotine (Cooper et al., 2012). This fugacity-based multi-compartment model links the indoor environment components to physiologically-based pharmacokinetic components, and can be used to estimate exposures to a number of potential environmental contaminants of concern. Organic film layers on walls, hardwood and vinyl floors, carpet, windows and fabric are analyzed separately in the model. The model includes a multi-compartment membrane representation of three types of skin – exposed hand, exposed non-hand, and clothed (unexposed) skin – comprised of 15 layers of stratum corneum and 20 layers of viable epidermis for each skin type. A schematic of the model is shown in Figure 1.

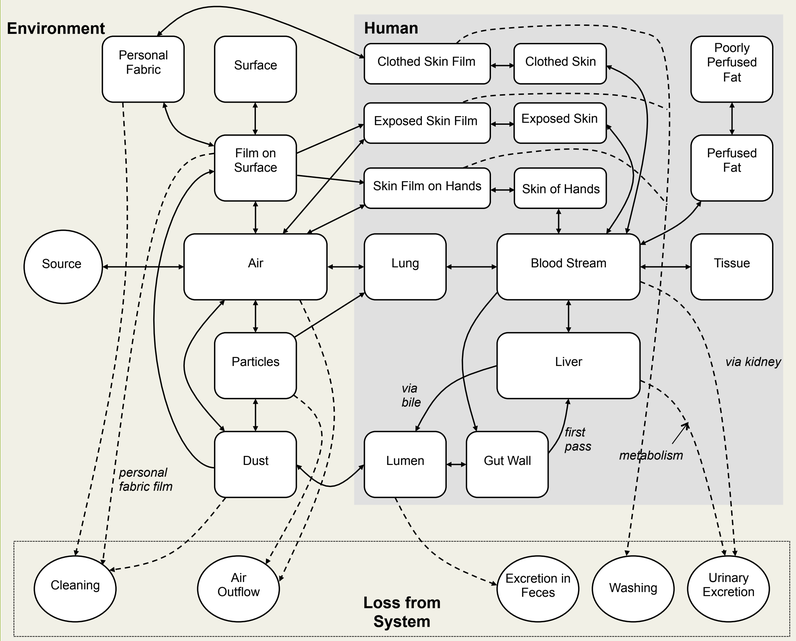

Figure 1. Schematic of fugacity-based indoor environment and PBPK human model

Figure 2 displays vapor pressures of a range of SVOCs that are of interest in indoor environments. The two compounds that have previously been studied using the model applied here – DEHP (Greenhall et al., 2011) and nicotine (Cooper et al., 2012) – have lower and higher vapor pressures than chlorpyrifos, respectively. Transport in indoor environments is strongly influenced by vapor pressure.

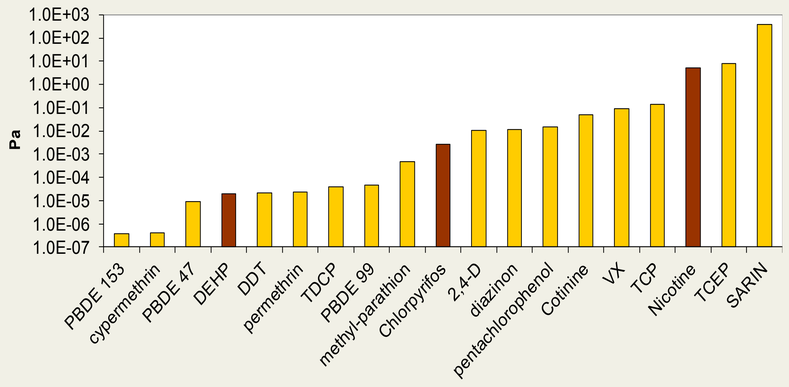

Figure 2. Vapor pressure (Pa) of several SVOCs in ascending order

Chlorpyrifos was selected to further test the flexibility and robustness of the model because of its chemical properties and because it is a well studied compound, having been included as an analyte in the Children's Total Exposure to Pesticides and Other Persistent Organic Pollutants (CTEPP) study among others. CTEPP was a USEPA-funded study that investigated children's exposure to over 50 pollutants at homes and daycares in selected North Carolina and Ohio counties in 2000-2001. The CTEPP NC study revealed an apparent shortfall between the estimated intake of chlorpyrifos and the expected urinary excretion of chlorpyrifos and its primary metabolite, 3,5,6-trichloro-2-pyridinol (TCPy) (Morgan et al., 2005).The work presented here aims to reevaluate this exposure scenario and predict the total aggregate dose of children to chlorpyrifos through multiple non-dietary exposure pathways. In doing so, the relative contribution of the selected non-dietary pathways was determined, including the extent to which the various types of skin exposure can explain the total aggregate dose.

Methods

The model consists of a system of differential equations implemented in MATLAB® using ode15s, a stiff solver that utilizes Runge-Kutta methods and variable time steps. Mass balance checks are built into the code. Modifications were made to the previous versions of the model and macros were created to link Microsoft ® Excel data sheets directly to MATLAB® for processing and model runs. As a result, the utilization of the model is more user friendly and less error prone. The model was run for different time lengths, ranging from 1 to 10 years. Initial conditions for the simulations shown here were adjusted to produce air levels of chlorpyrifos similar to the median observed in the CTEPP NC study. Corresponding levels in other compartments and doses to a child were also predicted.

Results

Table 1 summarizes relevant studies of chlorpyrifos indoor exposure which provide environmental levels of chlorpyrifos and/or children's TCPy concentrations in urine. The predictions of this model are also included in Table 1 with values for comparison.

Table 1. Measured and predicted values of indoor chlorpyrifos concentration and mass loads in air, surface wipe, and vacuum dust and TCPy levels in children's urine

Study	Air Conc (μg/m³)	Surface Wipe (μg/m²)	Dust Conc (μg/g)	Dust Load (μg/m²)	Urinary TCPy (ng/ml)
Measured					
CTEPP NC Home [a] (Morgan et al., 2005)	6.2E-3	0.1	0.14		5.2
AHHS [a] (Stout II et al., 2009)		0.1			
CCC [a] (Tulve et al., 2006)		0.2			
Julien et al., 2007 [a]		0.3	0.06		
Quandt et al., 2004 [b]		8.9±18.4			
CHAMACOS [a] (Bradman et al., 2006)		0.5			
Predicted					
This study	6.3E-3	0.29	0.48	0.24	1.2 [c]

[a] median; [b] arithmetic mean; [c] urinary TCPy due to non-dietary exposure.

Figure 3 displays the predicted fugacity gradient in each type of skin. The fugacity of the first layer of the skin is closely related to the fugacity of the skin film, and is 5 to 6 orders of magnitude lower than the vapor pressure of chlorpyrifos (2.7E-3 Pa). The fugacity at the outer boundary of the clothed skin is lower than that in the exposed skin due to mass transfer resistance in clothing. The fugacity at the external boundary of hand skin is reduced by relatively frequent hand washing. The inflection in the fugacity gradient in the skin occurs at the stratum corneum/viable epidermis boundary.

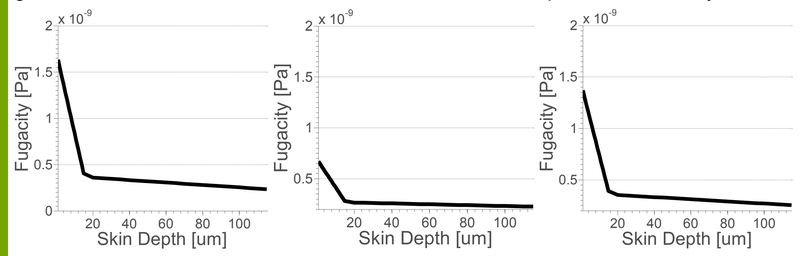

Figure 3. Predicted fugacity gradient in stratum corneum and viable epidermis of exposed non-hand skin, clothed and exposed hand skin

Contributions of individual exposure pathways to aggregate non-dietary exposure are shown in Table 2. Total dermal exposure is predicted to be dominant, providing 72% of the total non-dietary dose. Within dermal exposure, contributions are exposed non-hand skin > clothed skin > exposed hand skin. This ranking reflects the combined effects of variable surface area, mass transfer resistance and frequency of washing.

Table 2. Predicted aggregate non-dietary exposure to chlorpyrifos

	Oral (dust)	Inhalation (vapor)	Inhalation (particles)	Dermal	Total
Predicted dose (μg/kg/day)	2.4E-4	2.5E-3	1.7E-5	4.8E-2	5.1E-2
% of Total dose	0.5	4.9	3E-2	**94.6**	100

Discussion

1. Chlorpyrifos has a vapor pressure between that of nicotine and DEHP, the two SVOCs that have previously been investigated using the model structure shown here. As vapor pressure declines, the relative importance of direct inhalation as an exposure route also declines and the likely importance of dust ingestion increases. Estimates generated here suggest that for chlorpyrifos, indoor non-dietary exposures can be ranked as dermal > inhalation > dust ingestion.

2. The log Kow of chlorpyrifos (4.96) is intermediate between that of nicotine (1.7) and DEHP (7.6). The contribution to overall resistance to transport in the relatively hydrophilic viable epidermis would therefore be expected to be greater for chlorpyrifos than for nicotine and less for chlorpyrifos than for DEHP. Nevertheless, the stratum corneum remains the primary barrier for dermal uptake of chlorpyrifos (Figure 3).

3. Examination of multiple SVOCs for which both environmental and biomonitoring data are available provides opportunity to examine the ability of the model to predict outcomes over a range of physical-chemical properties. Model development is ongoing.

Acknowledgements

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