LINEAR REGRESSION MODELING TO PREDICT HOUSEHOLD DUST TEQ AND TCDD CONCENTRATION

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Abstract
Household dust samples were obtained from the residences of eligible participants in the University of Michigan Dioxin Exposure Study (UMDES). Linear regression models were used to determine which factors explained the variations in household dust toxic equivalency (TEQ, calculated based on the 2005 World Health Organization TEFs) and 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) concentrations measured from the participants in the UMDES and to quantify how much of the variation each factor explained. Potential dust predictor variables were derived from the UMDES questionnaire, dust sampling field data notes and results from the household dust and soil sampling laboratory analyses. Household dust samples were obtained from 764 study participants over the course of three sample seasons. For the TEQ regression model, a higher soil dioxin TEQ from around the house provided the greatest explanation of the variation in the model and was associated with a higher household dust TEQ (Est., 0.336; ΔR^2, 10.754). For the TCDD concentration regression model, a higher soil dioxin TCDD concentration from around the house provided the greatest explanation of the variation in the model and was associated with a higher TCDD concentration in household dust (Est., 0.261; ΔR^2, 10.078).

Introduction
The University of Michigan Dioxin Exposure Study (UMDES) was conducted to explain the variation in serum levels of polychlorinated dibenzodioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) and polychlorinated biphenyls (PCBs) and to quantify how much of the variation each factor explained. The study was undertaken in response to concerns of environmental contamination in the Tittabawassee River floodplain in Midland and Saginaw Counties in Michigan and in areas within the City of Midland, Michigan. Household dust was determined to have some explanatory value for the variation in serum levels of PCDDs, PCDFs and PCBs and household dust samples were obtained from eligible UMDES study participants. The purpose of the present study is to describe which factors explained the variations in household dust toxic equivalency (TEQ) and 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) concentrations measured from participants in the UMDES and to quantify how much of the variation each factor explained. [Note: TEQ values presented were based on the World Health Organization 2005 TEFs].[1]

Materials and Methods
UMDES study participants were recruited from five populations, described elsewhere[2], from areas in Midland, Saginaw, Bay, Jackson and Calhoun Counties in Michigan using a two-stage area probability household sample design. In order to be eligible for household dust sampling, a participant had to be eligible to provide a serum sample, had to be the owner of their residence and had to have lived in their residence for at least five years. Detailed methods for sample selection, recruitment, eligibility and consent are described elsewhere.[3]

The household dust sampling protocol was based on the American Society for Testing and Materials (ASTM) method "Standard Practice for Collection of Floor Dust for Chemical Analysis".[4] A High Volume Small Surface Sampler (HVS3), capable of capturing 99.95% of particles above 0.3μm aerodynamic mean diameter, was used to collect each household dust sample. Sample locations were selected by the samplers after entering a residence and were generally taken from one or two locations with a high potential for human exposure. Bulk dust and filter samples were combined and a single household dust sample from each residence was analyzed by Vista Analytical Laboratory, Inc. (El Dorado Hills, California, USA) for the WHO designated 29 PCDD, PCDF, and PCB congeners[1] using US EPA methods 1668[5] and 8290[6]. The full UMDES protocol, including the household dust sampling protocol[7], is available online at www.umdioxin.org.

Congener concentration is the outcome of interest presented in this report. Congener concentration is the amount of a PCDD, PCDF or PCB congener per gram of dust, measured in pg/g or parts per trillion (ppt). Household dust levels can also be measured in terms of congener loading. Congener loading is the amount of a PCDD, PCDF or PCB congener per square meter of floor surface, measure in pg/m^2. Congener loading was also calculated and analyzed and the results of those analyses will be presented in future reports.

Potential household dust predictor variables were derived from the UMDES questionnaire (i.e., work history, property use and remediation variables), household dust sampling field data notes (i.e., sampling season and floor surface variables) and results from the household dust and soil sampling laboratory analyses. Continuous variables were reported in years or days to account for a participant's total cumulative exposure to a potential source of contamination while living in their current residence. Based on the data available, several potential predictor variables were also created to group participants into different exposure categories. Categorical variables were created to explain sample season, floor surface sampled and floor replacement after a flood. Sample season was determined based on the month the household dust was sampled. Each floor surface sampled was classified as a high pile carpet (i.e., velvet carpet), low pile carpet (i.e., berber carpets) or a hard floor surface. A variable was also created for residences that had been affected by river flooding to differentiate between floor surfaces that had been replaced after the flooding and floor surfaces that had not been replaced after the flooding.

SAS version 9.1 statistical software was utilized to complete all analyses.[8] TEQs were calculated based on the World Health Organization 2005 TEFs.[1] The TEQ and TCDD concentration outcome variables were transformed to a log base10 scale. Histograms confirmed that the distributions of the outcome variables were extremely skewed in the original scale and were normalized after transformation. Descriptive statistics were calculated using both unweighted data and survey sample weighted data. Graphs were also created to explain important relationships between household dust and soil TEQ and TCDD concentrations. Tables and boxplots, available on the UMDES website, www.umdioxin.org, provide descriptive statistics and distributions by region for the TEQ and 29 dioxin congeners.

Linear regression modeling used data from five imputed data sets and survey sample weights generated based on the 764 subjects who had household dust measurements taken. Final variable selection was based on forward and backward selection techniques after testing for interactions and collinearity. For example, sampling time was not included in the regression models because sampling time was directly related to dust loading or how much dust there was on a floor surface per square meter of floor surface. The final variable list only included a soil concentration variable and other statistically significant variables.

Overall adjusted r-square values were calculated for both the TEQ and TCDD concentration regression models to describe how well each model explained the total variation. Additionally, the change in the adjusted r-square (ΔR^2) was calculated after removing each significant variable one at a time to determine which predictor variables provided the greatest explanation of the variance in each model.

Results and Discussion

Household dust samples were obtained from 764 study participants over the course of three sample seasons. 205 of those samples were from the Floodplain region, 161 from the Near Floodplain region, 168 from other parts of Midland/Saginaw not in the floodplain, 32 from the Midland Plume and 198 from the Jackson and Calhoun region. 224 household dust samples were taken in Fall 2004, 432 samples were taken in Summer 2005 and 108 samples were taken in Spring 2005. The mean age of the floor surfaces sampled was 12.2 years. Prior to sampling, five residences had been remediated as a result of dioxin contamination.

Scatterplots showed a positive correlation between the soil TEQ and TCDD dioxin concentration around the house and the household dust TCDD concentration. As the soil TEQ and TCDD dioxin concentration around the house increased, the household dust TEQ and TCDD concentration also increased. These relationships were confirmed by the positive parameter estimates in the linear regression models shown in Table 1 (TEQ Est., 0.336; TCDD Est., 0.261). Scatterplots are not included in this report.

Regression models, using both forward and backward selection methods, produced similar results and therefore, only the backward selection method is presented. Table 1 shows the parameter estimates, the overall adjusted r-square and the change in r-square (ΔR^2) for the TEQ and TCDD concentration regression models.

Table 1: Significant Parameter Estimates, Overall Adjusted R-square Values and Change in Adjusted R-square Values for TEQ and TCDD Concentrations in Household Dust
(Shaded estimates: var. associated with higher levels, Non-shaded estimates: var. associated with lower levels)

	TEQ		**2378 TCDD**	
	Estimate**	**ΔR^2**	**Estimate****	**ΔR^2**
Soil				
Soil dioxin concentration around house (log ppt)	0.336	10.754	0.261	10.078
Region				
Living in M/S floodplain vs. J/C	-0.288	2.258		3.256
Living in M/S near floodplain vs. J/C	-0.326			
Living in M/S out of floodplain vs. J/C	-0.167			
Living in Midland plume vs. J/C	-0.191		0.481	
Property Use				
Indoor/Outdoor Pets (yrs*)			-0.005	1.248
Weed killers used on the property (yrs*)	-0.005	0.922		
Trash burned at the house (yrs*)	0.004	0.97	0.003	0.426
Work History				
Worked at a chemical company other than Dow (yrs*)			0.010	0.216
Lived with a Dow worker (yrs*)			0.012	0.640
Recreational Activities				
Water activities in contaminated areas (days*)			0.000	0.502
Floor Surface				
Age of floor surface (yrs*)	0.009	5.536		
Floor replaced after flooding vs. not flooded		-0.172		
Floor not replaced after flooding vs. not flooded	0.411			
Dust Load (log g/m^2)	-0.148	2.346	-0.162	3.650
Sampling Season				
Spring 2005 (Mar-May) vs. fall 2004 (Sept-Dec)		4.708		3.556
Summer 2005 (June-Aug) vs. fall 2004 (Sept-Dec)	-0.264		-0.139	
Remediation				
House remediated for dioxins	0.149	-0.08	0.305	0.012
Overall Adjusted R-square (%)	**23.650**		**40.168**	

* Years/days in which subjects lived at the sampled residence
** All parameter estimates are significant at alpha=0.05 level
† TEQ values were based on the World Health Organization 2005 TEFs[1]

For the TEQ model, trash burning at the house, older floor surfaces, flooring that was not replaced after a flood and remediation for dioxins were associated with a higher household dust TEQ. Soil dioxin concentration around the house was also associated with a higher TEQ in household dust after controlling for all other important covariates in the model. Living in any region other than the Jackson and Calhoun region, using weed killers on the property, a higher dust loading level and household dust sampling in the summer were associated with a lower household dust TEQ.

For the TCDD concentration model, living in the Midland Plume region, trash burning at the house, working at a chemical company other than the Dow Chemical Co., living with a Dow Chemical Co. worker, participating in water activities in the contaminated area and remediation for dioxins were associated with higher TCDD concentrations in household dust. Soil dioxin concentration around the house was also associated with higher TCDD concentrations in household dust after controlling for all other important covariates in the model. Having indoor/outdoor pets, a higher dust loading level and household dust sampling in the summer were associated with lower TCDD concentrations in household dust.

The overall adjusted r-square values show that the backward selection models explained about 23% of the variation in TEQs in household dust and about 40% of the variation in TCDD concentrations in household dust. Based on the change in adjusted r-square values for both the TEQ and TCDD concentration models, the soil dioxin concentration around the house provided the greatest explanation of the variance in the models. Sampling season, age of the floor surface (TEQ only), dust loading, and region also provided a relatively large explanation of the variance in the models.

Congener concentration and congener loading are both important outcomes for household dust studies and in future reports, congener loading will also be reported.[9]

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