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Contribution of children's activities to lead contamination of food

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This study evaluates the relationship of children's hygiene habits and food-handling behaviors on lead levels on hands and handled foods for toddlers living in lead-contaminated homes. Forty-eight inner city toddlers previously identified as having elevated blood lead levels participated in three consecutive days of designated food-handling activities. During the visits, duplicate diets were obtained, the child handled a banana, a hot dog, and had his/her hands wiped with a moist towelette. In addition, wipe samples were collected from the kitchen floor, and food items were deposited on and subsequently collected from the kitchen floor. All samples were analyzed for lead. The child's caregiver completed a questionnaire, which addressed the child's hygiene and eating behaviors. It was demonstrated that children's contact with residential dust containing lead can transfer lead to food. Both lead in the home and on the children's hands contribute to the contamination of food, and hence potential dietary exposure. Mean lead in handled bananas was 26 μg/kg and on hot dogs 65 μg/kg, and mean lead values on cheese and apple slices that had been on the floor were 119 and 215 μg/kg. In addition, the child's hygiene habits as reported by the parent indicate that lack of basic hygiene patterns within a high lead environment can contribute to children's dietary exposure to lead. *Journal of Exposure Analysis and Environmental Epidemiology* (2001) **11,** 407–413.

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Introduction

Children living in households with lead contamination are susceptible to lead exposure through ingestion and inhalation of leaded dust. Toddlers are more susceptible to exposure than either infants or older children because of their increased mobility and independence compared to infants, and their more frequent hand-to-mouth activities compared to older children (Freeman et al., 2001). Mouthing activities of young children may produce incidental or non-dietary ingestion of environmental contaminants. Hand-to-mouth activities such as mouthing toys and sucking fingers or thumbs are associated with elevated blood lead in young children (Charney et al., 1980; Bellinger et al., 1986; Baghurst et al., 1992; Langphear et al., 1996; Freeman et al., 1997). At the same time, lead levels on children's hands are associated with blood lead levels and with lead levels in homes and playgrounds (Charney et al., 1980; Angle et al., 1984; Bornschein et al., 1985; Duggan and Inskip, 1985; Duggan et al., 1985; Que Hee et al., 1985; Thornton et al., 1990), and positive correlations exist between lead on children's hands, lead in the environment, and blood lead levels (Angle et al., 1984; Duggan et al., 1985; Baghurst et al., 1992; Melnyk et al., 2000).

These findings demonstrate that children living in an elevated lead environment have contaminants on their hands and that children's mouthing activities produce incidental or non-dietary ingestion of environmental contaminants. None of these studies determined the relationship between contaminated hands and eating habits: the question of whether the child contaminates his own food supply was not addressed. While these studies find associations between reported hand-to-mouth activities and blood lead levels, there is little understanding of the relationship between the hygiene habits of young children and dietary lead exposure. This article evaluates how food may become contaminated in lead-contaminated homes, the relationship of food handling by the child and hygiene behaviors to hand lead levels, and lead levels of food handled by toddlers.

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Methods

The study population was comprised of 48 families with a child between 1 and 4 years old who had a previous blood lead level greater than 15 μg/dl and was not currently undergoing chelation or participating in another lead study. The families were from Newark, New Jersey, and adjacent communities. Informed consent was obtained from the parents prior to the child's participation. Child assent was based on willingness of the child to participate in the activities after they had been demonstrated by the field team. At the time of recruitment, the last mean blood lead measure for 34 of 48 children was 23.5±6.2 μg/dl (range 15–42, n=34). No written record of blood lead was found for 14 children, although parent reportage and clinic reports cited elevated blood lead levels.

The study consisted of three visits to each child's home on three consecutive days. During the first visit, parents were trained to collect duplicate diets for the participating child. The child was weighed, the palms of the child's hands were wiped with a baby wipe, and the surface areas of the child's hands traced on graph paper. The mother completed a questionnaire about the child's hygiene and mouthing activities, and a dust sample was collected from the floor with a baby wipe, typically in the kitchen, in an area identified by the parent as one from which the child might pick up food.

On the second and third visits, the child was given opportunities to handle food items, and other foods were placed on the floor and collected to represent food that a child might pick up off the floor to eat. Four standard food items had previously been identified from interviews with parents of inner city children as foods frequently eaten by hand by their children (Freeman et al., 1997). Cheese and apples were identified as items a child might eat after dropping them on the floor and were used to assess the contribution of floor lead to food. Hot dogs and bananas were selected for assessing the contribution of the children's handling on lead contamination of food. Each of the food samples handled by the children or placed on the floor was comparable in mass, weighing approximately 100 g. Floor foods were placed on the floor by the technician. The food was slid around an area of 100 cm^2 to represent a child trying to retrieve the food from the floor, and then placed in a ziplock bag.

During the second visit, the child broke a banana into small pieces and placed it in a ziplock bag. A standard floor food item, an American cheese slice, was placed on the floor by the field technician and collected. During the third visit, the duplicate diets that were collected over a 24-h period were taken from the home, and the child broke a hot dog into small pieces and placed it in a ziplock bag. The second standard floor food item, apple slices, was placed on the floor by the field technician and collected.

Field blank food samples were collected from approximately half of the homes based on a predetermined sampling schedule. These were 100-g segments of apples, bananas, hot dogs, and sliced cheese brought to home and placed in ziplock backs by the technician.

Several other foods were collected in the home. A portion of food identical to what was collected in the duplicate diet was set aside, which had been identified as foods that the child might pick up off the floor. This was placed on an area of the floor not used for the other standard floor foods or the floor wipe in the same manner as the standard apple and cheese foods, and then collected. Food items found on the floor in the homes were also collected for lead analysis if the parent thought that the food was something the child might pick up and eat. The lead content of the duplicate diet and the other foods are reported by Melnyk et al. (2000).

The questionnaire used in this study was described previously (Freeman et al., 1997). The questionnaire's primary focus was the child's hygiene and eating habits. Food-handling questions focused on where the child ate food, if the child would eat food that had fallen on the floor, the child's use of a baby bottle, the child's behavior with pets before or while eating, and if the child ate with his/her fingers. The hygiene questions addressed the frequency with which the child washed his/her hands, and specific situations when hand washing might occur such as before or after meals, or after coming indoors. The contribution of children's food handling and hygiene activities on food contamination and hand lead level was evaluated by comparing the activities of the child with the lead measures in the food, floor, and hand wipe samples.

Sample Analysis

All sample analyses were conducted at Research Triangle Institute using Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Food samples were homogenized and digested with concentrated nitric acid prior to analysis. Floor wipes and hand wipes were collected with the same sampling medium (Pathmark Quilted Unscented Baby Wipes®) and extracted in nitric acid prior to analysis (Pellizzari, 1998). Food field blanks were unhandled food samples, and hand wipe and floor blanks were unhandled sampling media (Baby Wipes®). Detection level for foods was 3.125 μg/kg, and for wipe media was 0.003 μg/sample.

Statistical Analysis

Statistical analysis was conducted using Systat® and SAS® programs. The contribution of children's food-handling and hygiene activities on hand lead level and food contamination was evaluated by comparing the reported activities of the child with the lead measures in the food, floor, and hand wipe samples. The distribution of lead in the various types of exposed samples was examined for normality using probability plots, and normality was tested using Kolmogorov–Smirnoff test. Lead concentrations in dust, food, and hand wipe samples were not normally distributed. Log transformations of lead measures produced approximately normal distributions for cheese, banana, hot dog lead, and hand wipe samples, but floor wipe and apple lead levels remained non-normally distributed. Statistical analyses were conducted using non-parametric tests with the measured values or parametric tests with log-transformed values when appropriate. Three categorical levels of hand lead were also developed so that the children with the highest and lowest exposure measures could be compared. Other categorical variables were created to test specific contributions of activities to lead exposure.

Results

Field Blank Measurements

To estimate the amount of lead on food items, floor wipes, and hand wipes that can be attributed to environmental contamination, an adjusted average lead value of the field blank/unexposed samples was subtracted from each handled or environmental sample. This is necessary because all of the sample items were found to contain some lead, with processed foods such as cheese and hot dogs having at least twice as much as the fruits (Table 1). Use of the average unexposed sample value was considered to be more conservative than using the median in calculating the attributed environmental contamination. The adjustment to the average unexposed samples was based on the distribution of values and removal of statistical outliers. An outlier was defined as more than three times the interquartile range from the median. Removal of outliers brought the mean lead levels on the blank/unexposed samples closer to the median, normalized the distribution for these samples and reduced the coefficient of variation, although it had little influence on either the median or interquartile range. No more than three samples were removed as outliers from any sample group. In addition, the hand wipe samples were adjusted to the surface area of the child's hand to provide a ng/cm^2 measure comparable to the floor wipe samples. The lead levels of the blank wipe medium (Baby Wipes®) were adjusted to the average surface area of the children's hand, 56 cm^2.

Table 1. Distribution of lead concentrations in unexposed food samples, and wipes used for floor and hands (median, mean, and SD, number of outliers removed).

Sample type	*n*	Median	Mean±SD	Outliers removed
Apple (μg/kg)	22	7.8	8.6±3.7	3
Banana (μg/kg)	39	4.7	5.8±3.5	2
Cheese (μg/kg)	20	15.4	15.1±5.2	3
Hot dog (μg/kg)	21	15.5	16.3±8.2	2
Wipe (μg/sample)	25	0.012	0.013±0.01	3

Table 2. Lead levels (mean, SD, median) in food samples (μg/kg) in contact with floor (apples and cheese) or handled by children (banana and hot dog), and wipe samples (ng/cm^2) from floor and hands for first visits.

Sample	*n*	Mean	SD	Median
Wipe samples				
Floor wipe (ng/cm^2)	48	30	80	7.4
Hand wipe (ng/cm^2)	45	23	65	5.2
Handled foods				
Banana (μg/kg)	44	26	34	43
Hot dog (μg/kg)	45	65	104	29
Floor foods				
Apple (μg/kg)	47	215	410	64
Cheese (μg/kg)	47	119	161	87

All measures were adjusted for blank unexposed sample lead levels and represent the lead that is attributable to environmental exposure.

Floor wipes and hand wipes were the same material and, therefore, a single wipe blank distribution was created, and the mean of this distribution (0.013 μg/sample) was subtracted from hand and floor wipe lead measurements to determine the environmental contribution from floor and hand wipes. Samples with no detectable lead were given the value of 1/2 the analytic detection limit.

Physical Characteristics of the Children

Mean age of the children at the time of the first visit was 26.5±5.8 months (range 15–52 months). Average body weight was 28±4.4 lb (range 18–39 lb). Hand surface areas of the children averaged 56.0±7.3 cm^2 for each hand. The hand surface area was significantly correlated with age of the child and body weight (age r=0.553, P<0.001; body weight r=0.444, P=0.004). The gender distributions of the children were 48% boys and 52% girls, and there were no statistically significant differences in the age, weight, or hand surface areas of the boys and girls. In subsequent analyses, hand size was used when calculating exposures.

Markers of Exposure

The primary markers of exposure in this study were the lead levels on the children's hands and lead levels in the food samples that they handled. The secondary markers of exposure were the lead levels on the floor and in floor food samples. None of the lead measures was normally distributed, and most lead measures in exposed samples approximated a log normal distribution (Table 2).

Lead loadings on floor wipes were similar to lead loadings on hand wipes (mean difference 7.2 ng/cm^2, P=0.320), and the values were correlated (Spearman ρ=0.324, P=0.030), suggesting that the child's hand lead levels resulted from exposure to lead in the home. Hand lead levels were significantly correlated with handled food lead levels (bananas r=0.436, P=0.004; hot dogs r=0.504, P=0.002). The lead levels on the floor foods, apples, and cheese were also correlated with one another (r=0.650, P<0.001), as well as correlated with floor lead levels (apple r=0.281, P=0.056; cheese r=0.417, P=0.004), suggesting that the floor dust containing lead is readily transferred to food when food comes in contact with the dust.

The relationship between floor lead levels and the handled food items, bananas, and hot dogs failed to show a consistent pattern. No significant correlation between floor lead levels and lead on bananas (r=0.118, P=0.447) was found, while a significant association was found between floor lead levels and lead on hot dogs (r=0.398, P=0.007). In addition, no significant association was found between hand lead levels and the amount of lead on floor foods (apple r=−0.155, P=0.303; cheese r=0.062, P=0.689). The lack of consistent associations across all media with the hand lead levels may be due to when, where, and how the hand contact occurred, and the frequency with which the child's hands were washed. Since children touch many objects and surfaces throughout the day, the levels of lead on the child's hands at any moment in time would not be expected to have a strong association with floor foods, unless the child had been in contact with the floor immediately prior to collection of the hand wipe sample.

Food-Handling Activities

As reported by caregivers, nearly all children in the study ate food with their fingers (Table 3). More than half of the children was reported to either eat food while sitting on the floor or eat food that had been on the floor. Almost half of the children was reported to get or fix their own food and to use a baby bottle. Less than one third of the children was reported to be given food by an older sibling.

Table 3. Percent positive responses reported by caregiver on food-handling behaviors of children and its relationship to hand lead levels.

	Percent positive responses			
	For all children	Hand lead level: Low	Medium	High
Eat food with fingers	93	85	100	100
Eat on the floor[a]	54	50	54	45
Eat food dropped on floor*	63	55	62	73
Get own food	41	35	38	45
Use baby bottle	50	50	54	50
Sibling gets food[b]	30	20	31	30
Child fists food[c]*	62	50	62	73
n	48	20	13	12

Low lead levels are less than 4.0 ng/cm^2, and high lead levels are greater than 18.0 ng/cm^2.
*Chi-square test; P=0.05, low versus high.
[a]Child eats food while sitting or lying on floor.
[b]Older sibling provides food for toddler.
[c]Toddler holds food with full palmer grasp rather than only with fingers.

Hand lead levels were divided into low, medium, and high loading categories, where low levels are less than 4.0 ng/cm^2 and high levels are greater than 18.0 ng/cm^2. The uneven size of the categories was due to the log normal distribution of the measured values, with the number of samples in the low category substantially larger than in the other two categories. Comparison of hand lead levels and food-handling activities found only two significant associations between these food-handling behaviors and hand lead levels. One of the clearest associations between children's behaviors and lead exposure came from a question asking how the children handled foods. If the child was reported to "fist" food, i.e., to wrap the food with the palm of the hand and fingers rather than hold it with the fingers, the lead levels on handled foods were significantly higher than if the child did not "fist" food (banana P=0.007; hot dog P=0.030), and children who were reported to fist foods tended to have higher hand lead levels. Children who were reported to eat food that had dropped on the floor also had higher hand lead levels. The other behaviors that were evaluated were just as likely to be reported for children with little lead on their hands as for children with high lead loadings.

Parents were given the opportunity to report specific foods that: their children ate with their fingers; would pick up and eat after the food had been on the floor; foods obtained independently by the child; and the foods that the child typically ate as snacks. Several broad categories were identified: fruit; crackers (crackers, cookies, bread, cake); meat (hot dogs, chicken, eggs, steak, etc.); pasta (macaroni, spaghetti, rice, grits, fires); chips (potato chips, cheese doodles, corn chips); candy; drinks; and "everything." While parents easily reported food items that their child ate with fingers or ate as snacks, some parents seemed limited in giving examples of foods that their child would eat after the foods had fallen on the floor, despite having reported that their child engaged in the activity.

Two categories of foods consumed as snacks were associated with elevated lead levels on food items. Consumption of candy as snacks was associated with floor food lead levels (cheese P=0.023; apple P=0.087), and candy as snacks was associated with lead in handled foods (banana P=0.042; hot dog P=0.084). In addition, chips as snack foods were associated with floor lead levels (P=0.052), apple lead levels (P=0.052), and lead levels in handled hot dogs (P=0.039).

Locations for Food Consumption

Parents were asked where their child ate meals and snacks, both in terms of the rooms in which the activity took place and whether it was conducted at a table, high chair, chair or couch, or while seated on the floor. The children differed substantially in where they ate meals and snacks. The majority of children (68%) were reported to eat meals in the kitchen, whereas 12% of the children was reported to eat meals in multiple locations. In contrast, only 25% of the children was reported to eat snacks in the kitchen, whereas 54% of the children was reported to eat snacks in multiple locations or "everywhere." Seventy-five percent of the children was reported to eat meals at a table or high chair, whereas only 28% of children ate snacks at a table or high chair. In addition, only 8% of children was reported to eat meals at multiple places, whereas 53% of the children was reported to eat snacks at multiple places. Multiple places included parents' report of "while walking around."

Hygiene Practices

Parents reported when their children were likely to wash hands: before or after meals; before or after snacks; after going to the bathroom; after coming indoors; or before going to bed. Parents were asked how frequently the children washed their hands each day. An additional scale of hand washing frequency was developed based on the number of occasions in which the parent said the child would wash his/her hands.

Parents typically reported that their children washed their hands approximately three to four times a day (mean 3.6±2.9, range 1–20). Using hand wash frequency based on the sum of reported occasions, the average hand washing frequency was similar, 3.9±1.8 occasions per day, and the two measures were correlated (r=0.504, P=0.001). The majority of children were reported to wash their hands before or after meals (Table 4), with 44% reporting washing hands both before and after meals, and 13% reporting no meal time hand washing. Fewer children were reported to wash before or after eating snacks.

Table 4. Hygiene habits of children and relationship to hand lead level.

Wash hands	Percent positive responses			
	All children	Hand lead level		
		Low	Medium	High
Before meals	65	60	85	55
After meals	65	60	62	75
Before snacks	30	35	31	27
After snacks*	33	25	38	45
After bathroom*	52	35	69	58
After outdoors*	65	54	62	82
Before bed	72	70	69	82
Both before/after meals	44	29	29	38
Not before/after meals	13	83	17	0
n	48	20	13	12

Percent of children with reported habit, and the percent of children who wash hands with low, medium, and high hand lead levels. Low lead levels are less than 4.0 ng/cm^2 and high lead levels are greater than 18.0 ng/cm^2.
*Chi-square test; P=0.05, low versus high.

Table 5. Contributions to hand lead levels and lead on handled foods evaluated through stepwise multiple regression.

Outcome measure	Contributions	Standard coefficient	P value
Hand lead	Floor lead	0.795	<0.001
	Do not hand wash after meals	0.161	0.067
	Eat food dropped on floor	0.152	0.082
		R^2=0.706	<0.001
Banana lead	Hand lead	0.563	<0.001
	Fist foods	0.303	0.023
		R^2=0.417	<0.001
Hot dog lead	Hand lead	0.421	0.001
	Fist foods	0.302	0.052
		R^2=0.304	<0.001

The hygiene habits of the children were compared to the levels of lead found on their hands, floor wipes, and in food samples. Hand washing frequency was weakly associated with the floor lead levels (r_s=0.224, P=0.062). Unexpectedly, a reverse association was found between hand washing frequency based on the number of washing occasions reported and hand lead level (r=0.479, P=0.001), with children who washed hands five or more times per day having higher hand lead levels than children reported to wash less frequently (χ^2 test, P=0.04). It was found that a larger proportion of the children who were reported to wash their hands in most events had higher hand lead loadings. Hand lead levels were higher among children who were reported to wash their hands after meals, after snacks, before going to bed, and after coming indoors. For three of the seven washing occasions, children with the highest hand lead levels were reported more likely to wash hands than children with low hand lead levels (χ_2 test, P<0.05).

Comparison of hand washing habits and lead levels on foods handled by children found little association between handled food lead levels and hand washing habits. Children who were reported to wash hands after being outside had marginally higher lead levels on bananas (χ^2 test, P=0.079), apples (χ^2 test, P=0.107), and cheese (χ^2 test, P=0.056) than did children reported not to wash hands after being outside.

Contributions to lead on hands and in handled food were evaluated in stepwise multiple regression models using variable whose associations were previously reported. The primary contribution to hand lead levels was floor lead levels, with minor secondary influences from two indicators of hygiene practices: eating food that had dropped on the floor and lack of hand washing after meals. In contrast, hand lead level and child fisting of food were the primary contributors to handled food lead for both hot dogs and bananas (Table 5). Thus, the greater the hand surface that contacts the food, the higher the lead transfer from hand to food and the higher the food lead levels. It should be noted that greater hand washing frequency was reported for children who do not pick up food that had dropped on the floor than for those who display this behavior (frequency of washing for pick up 3.5±1.9; do not pick up 4.5±1.4, $P=0.021$).

Venous blood samples were collected for a subset of children and analyzed for lead. There was no correlation between the hand lead levels or handled food lead levels and blood lead ($n=20$, hand–blood $r=0.052$; banana–blood $r=0.005$; hot dog–blood $r=0.148$).

Discussion

The potential for excess dietary exposure of children living in lead-laden homes was demonstrated in this study and was associated with two sources. First, lead-contaminated food was identified as a potential source of dietary exposure in this study. In homes with environmental lead, food that has fallen on the floor becomes contaminated. This was represented in this study by the cheese and apple segments placed on the floor. More than 60% of the children in this study was reported to eat food that had fallen on the floor. This is consistent with other surveys that found between 43% and 68% of toddlers reported to eat food that had been on the floor (Freeman et al., 1997). Second, children can contaminate the food they eat through transfer of leaded dust adhering to their hands and fingers. Nearly all of the children were reported to eat food with their fingers. As found in previous studies (Bornschein et al., 1985; Duggan et al., 1985), hand wipes of the children can contain measurable amounts of lead. When the children handled foods, the lead on their hands was transferred to the food items. In addition, the more hand surface areas came in contact with the food, as indicated by fisting behavior, the greater the contamination level on the food. If the child eats the food, as commonly occurs, he/she would ingest the lead adhering to the food. Hand washing before food handling and consumption therefore becomes important.

As has been previously shown with other children (Freeman et al., 1997; Reed et al., 1999), hand washing was an infrequent activity, and did not necessarily precede food consumption. Washing hands before or after eating snacks was reported by less than 50% of the children. At the same time, parents reported that snack consumption was an unstructured activity that could occur any place in the home.

The lack of significant correlation between the lead levels on hands and on food items handled by the children with blood lead levels is not surprising. The amount of lead that adheres to a child's fingers at any point in time is only a single episode of exposure during the child's daily life. Had multiple hand rinses been collected through the day and all the foods the child handled during the day been collected, perhaps an association with blood lead levels would have emerged.

The differences in lead levels in the various food samples may have been due to the adherence characteristics of the food items. Differences in lead concentrations across size fractions of dust particles have been reported (Que Hee et al., 1985; Wang et al., 1996). The size fraction of dust that adheres to the foods used in this study has not been evaluated. The lack of strong association between handled foods and floor lead levels is likely the result of a multistage process. Only a limited size fraction of dust particles in the environment adheres to the child's hand (Wang et al., 1996; Edwards and Lioy, 1999) and from that only a portion may be transferred to the food. At each step, the character of the lead particle size distribution will change from what was originally in the home environment. An additional factor is that environmental samples in this study were obtained from kitchen floors. This is not the only site in the home that the child contacts and may not represent the primary source of the child's residential exposure. It should be noted that in most lead studies, kitchen floors are not usually evaluated as a source of lead exposure. Environmental samples are typically obtained from window sills and window wells, areas that are primary sources of lead, or from carpets which are secondary sources or reservoirs of lead. One might think that the kitchen floor, because it can be easily cleaned, would not be a source of lead exposure. This study shows that the kitchen may be a source of exposure in homes with residential lead contamination.

Lead exposure models have, for the most part, overlooked incidental food contamination as a pathway of lead exposure (Succop et al., 1998). This study found that food dropped on the floor accumulates substantial amounts of lead and that simply handling food with unwashed hands can contaminate it. In combination with inadequate hygiene, poor food-handling habits, and unstructured eating arrangements, this may be a major pathway of exposure for young children living in high-lead environments.

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