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The Effect of Dust Lead Control on Blood Lead in Toddlers: A Randomized Trial

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ABSTRACT. *Background.* Contaminated household dust is believed to be a major source of exposure for most children with elevated blood lead levels. To determine if a vigorous dust clean-up effort would reduce this exposure we conducted a randomized controlled field trial.

Methods. We randomized 113 urban children between the ages of 6 and 36 months: 56 children to a lead dust intervention composed of maternal education and biweekly assistance with household cleaning and 57 children to a control group. Household cleaning was done by two trained lay workers who focused their efforts on wet mopping of floors, damp-sponging of walls and horizontal surfaces, and vacuuming with a high-efficiency particle accumulating vacuum. Household dust lead levels, child blood lead levels, and maternal knowledge of lead poisoning and sources of exposure were measured before and after the intervention.

Results. Ninety-nine children were successfully followed for 12 ± 3 months: 46 children in the lead group and 53 children in the control group. Age and blood lead were similar in the two groups at baseline and averaged 20 months and $12.0 \mu\text{g}/\text{dL}$, respectively. Blood lead fell 17% in the intervention group and did not change among controls. Household dust and dust lead measures also fell significantly in the intervention group. Children in homes cleaned 20 or more times throughout the year had an average blood lead reduction of 34%.

Conclusions. Regular home cleaning, accompanied by maternal education, is a safe and partially effective intervention that should be recommended for the large majority of lead-exposed children for whom, unfortunately, removal to lead-safe housing is not an option. *Pediatrics* 1999;103:551–555; lead, dust, randomized trial, children.

ABBREVIATION. CDC, Centers for Disease Control.

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Timothy J. Buckley was with the US Environmental Protection Agency at the time this work was initiated.

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A number of epidemiologic studies provide evidence that excessive lead exposure in early childhood is associated with compromised cognitive¹ and behavioral,^{2,3} outcomes. The major prospective studies suggest that cognitive deficit after age 5 years is predicted as well by a blood lead level at 2 to 3 years as by any subsequent levels.^{4–7} Consistency across studies, extensive control of confounding variables, and support from experimental animal work,^{8,9} suggest that the associations are causal in nature. As a result, the Centers for Disease Control (CDC)¹⁰ has lowered its recommended upper limit of acceptable blood lead levels in children to $10 \mu\text{g}/\text{dL}$. The CDC, the American Academy of Pediatrics,¹¹ and the US Preventive Services Task Force¹² all recommend that, at a minimum, young children living in high-risk communities be screened with blood lead determinations.

Approximately 95% of children with lead exposure that is excessive by the CDC standards have a blood lead level between 10 and $25 \mu\text{g}/\text{dL}$ ¹³ and do not meet currently accepted criteria for chelation therapy. Most authorities recommend environmental and educational interventions for these youngsters and their families, but there is very little evidence that these activities, as conducted in many US cities, are effective. Many communities require only partial abatements and exert little control over the amount of lead-contaminated dust that may be liberated by such activities. Relocation to lead-safe housing, which presumably would be effective,^{14,15} is not an option for most children in this blood lead range. In a quasi-randomized trial involving 14 intervention homes and 35 control homes, Charney et al¹⁶ showed that careful control of lead-contaminated dust after abatement would reduce blood lead levels by 18% in children with high initial values (mean = $39 \mu\text{g}/\text{dL}$), but there has been no clear evidence that this strategy will help children with lower levels of exposure. Without evidence supporting an available and effective intervention, the rationale for screening is compromised.

To seek such evidence we conducted a randomized controlled trial to evaluate the effect of an intervention consisting of maternal education and household dust control measures on blood lead in young children at risk of excessive lead exposure.

METHODS

We visited 211 families in and around Jersey City, NJ, who responded to posters and door hangers about the study or were

referred to us by the municipal lead poisoning prevention program, local health care providers, or word of mouth, and who had a child between the ages of 6 months and 3 years. We evaluated their homes for the presence of lead paint with a portable radiograph fluorescence detector and conducted a baseline interview including demographic information and questions testing the responsible adult's knowledge of lead poisoning and lead sources. The responsible adult (nearly always the mother) had to speak English or Spanish to continue in the study. Dust wipe samples were collected from uncarpeted perimeter floor locations in the kitchen and another room frequented by the index child. If time permitted, additional samples were collected from interior window sills. When carpets were present, vacuum samples were collected from those thought most likely to be used as play locations. Families were questioned about parental occupational and avocational lead exposures, but potential exposure from these sources was rare.

Families were provided with basic information about lead poisoning but were excluded from the study if: a) we found no lead paint in the home ($n = 32$); b) the home was in such structural disrepair or was so disorganized that it could not be cleaned effectively ($n = 18$); c) there was evidence of illicit drug use, firearms, or other major safety concerns ($n = 7$); d) the index child was in regular day care ($n = 7$); e) the family was not interested in participating ($n = 27$); or f) the family could not be recontacted or refused to allow a baseline blood lead sample to be drawn ($n = 7$).

Consenting families ($n = 113$) were randomly assigned to a lead exposure reduction group ($n = 56$) or to an accident prevention (control) group ($n = 57$). Families assigned to the lead intervention group were asked to cooperate with a cleaning program in which two study staff members recruited from the community and provided with a short course on appropriate cleaning methods visited every 2 weeks to clean up potentially lead-contaminated dust. These visits typically lasted ~2 hours. Floors and carpets were vacuumed with a high-efficiency particle accumulating vacuum cleaner (Nilfisk Model GS80, Nilfisk of America, Inc, Malvern, PA) and walls, horizontal surfaces, and uncarpeted areas of floor were wet-wiped or mopped with detergent solution. The household detergent selected (Spic and Span, Proctor and Gamble, Cincinnati, OH) was low in phosphate (<0.1%) in conformance with New Jersey state law. As noted below, the willingness of the families to cooperate with this cleaning program varied considerably. Approximately 30% of the families moved during the study period, but the moves were usually local so that, for most, the assigned intervention could be maintained. Six lead intervention families asked for more frequent visits. These requests were accommodated if the schedule permitted. On average these homes were cleaned every 8 to 13 days.

Families in the accident prevention group (controls) were informed about identified lead paint hazards in their homes and received routine information about lead exposure at the time of enrollment. These participants were given home safety items such as fire extinguishers, smoke detectors, safety latches for cupboards, and first aid kits. They did not receive biweekly visits and most contact during the study year was concerned with scheduling educational sessions and assessments of blood lead and dust lead. Incentives offered by the project were an important factor in maintaining participation by members of both groups.

We invited caretakers in both groups to attend 4 to 5 educational sessions during the 1-year intervention. These 1-hour sessions were held separately for the lead and accident groups in the study offices where play facilities for children were provided. They usually involved groups of two to five women. Information about lead and how to limit the child's exposure were presented by a study staff member with an active effort to engage the participants. During most of the study, flip charts were used to emphasize important points, but in the lead group this was replaced by a specially devised educational card game in the last year. A few educational sessions were conducted in the homes of individual participants who did not come to the group sessions.

The protocol called for final assessments of blood lead and dust lead after 1 year of intervention. Because of the frequent moves and changing circumstances of the enrolled families, it was not possible in all cases to adhere strictly to this plan. Final blood lead levels were obtained at 12 ± 3 months in 99 of the 113 index children.

We used the LWW Sampler to collect dust samples because it

allows separate quantification of total dust and lead content per surface area.¹⁷ In side-by-side comparisons this sampler yields lead loading estimates that are lower¹⁸ than the widely used wipe method recommended by the US Department of Housing and Urban Development.¹⁹ Venous blood samples were collected using vacuum collection tubes and butterfly needles from lots that had been tested for lead contamination. Samples were held in the refrigerator and were shipped by overnight carrier to the Nutritional Biochemistry Branch, Center for Environmental Health, CDC in Atlanta for analysis by published methods.²⁰

A randomization sequence composed of permuted blocks of variable length was used to allocate consenting families in equal numbers to the lead and accident interventions. Assignments were kept in sequentially numbered, sealed, opaque envelopes. When a family's eligibility and willingness to participate were confirmed, the next envelope was opened to determine the assignment. Of 114 envelopes opened, only 1 was for a family who then refused to participate. We used a one-sided significance level to test the primary hypothesis. All other significance tests are two-sided. Because the dust lead distributions were highly skewed, significance tests were conducted on the log-transformed data and geometric means are reported.

RESULTS

The analyses presented here are for the 99 children for whom we were able to obtain a final blood lead determination 12 ± 3 months after the baseline blood lead: 46 in the lead group and 53 in the accident group. The median elapsed time between initial and final blood lead tests was 361 days in the lead group and 370 days in the accident group. As shown in Table 1, the two groups were quite similar with respect to age, ethnic background, number of children living in the home, and proportion speaking English. The mothers also scored similarly on a baseline test of their knowledge of lead poisoning.

The families in the intervention group varied considerably in their willingness to cooperate with the study protocol. The number of cleaning visits completed ranged from 0 to 42 with a median of 17. The number of health education sessions completed before the final blood lead sample was drawn ranged from one to five with a median of three.

Household dust levels and dust lead levels, measured as weight per m² of surface area, are shown in Table 2 for all homes in each group where samples were obtained. Vacuum samples were only obtained in homes with carpets. If more than one sample of a given type (floor, sill, vacuum) was obtained at the same visit, a single geometric mean of the like samples was used to represent the house. Geometric

TABLE 1. Characteristics of Children and Their Families by Study Group

Characteristic	Lead Intervention ($n = 46$)	Control ($n = 53$)
	Mean Values	
Age of mother (y)	28.6	27.0
Age of index child (y)	1.7	1.6
Number of children in home	2.5	2.6
Number rooms in home	4.3	4.6
	Percentages	
High school graduate (mother)	59	59
Living with partner	63	47
African ancestry	46	49
Latino	13	19
English speaking (mother)	91	89
Rental unit	83	87
Peeling paint ≥ 1 room	59	64

TABLE 2. Household Dust Analyses*

Dust Measurement	Lead Intervention	Control
Geometric Mean Values		
Dust loadings (g/m ²)		
Initial values		
Floor wipes	0.414 (42)	0.424 (42)
Sill wipes	0.757 (39)	0.829 (40)
Vacuum	8.440 (27)	7.352 (28)
Final values		
Floor wipes	0.378 (40)	0.395 (45)
Sill wipes	0.380 (36)	0.578 (40)†
Vacuum	3.040 (22)	7.933 (27)‡
Lead loadings (mg/m ²)		
Initial values		
Floor wipes	0.237 (42)	0.275 (42)
Sill wipes	0.810 (39)	0.661 (40)
Vacuum	5.053 (27)	5.018 (28)
Final values		
Floor wipes	0.163 (40)	0.207 (45)
Sill wipes	0.263 (36)	0.522 (40)‡
Vacuum	1.618 (22)	2.307 (27)

* Number of observations shown in parentheses. Some families moved during the study so that the final values are not necessarily from the same houses as the initial values. Significance of differences between intervention and control groups was calculated by *t* test on the log-transformed data and is shown as: † *P* < .10; ‡ *P* < .05.

means across the houses in each study group were then calculated and are presented in Table 2.

At baseline the dust levels and lead loadings were quite comparable in the two groups (Table 2). Because much more dust is extracted from a carpet than can be obtained from a hard surface on a floor or window sill, the vacuum loadings are much higher than those for the floors and sills. Levels for sills were higher than for floors.

By the end of the study the dust levels and lead loadings were lower in the lead intervention group for all three sample types.²¹ Compared with the initial levels the floor loadings did not change much. However, both dust loadings and lead loadings on sills and carpets were down by 50% or more in the lead group whereas more modest and inconsistent changes were seen in the accident group. For reasons that are not clear there was a substantial drop in carpet lead loading in the accident group that narrowed the difference between lead and accident homes for that measure (Table 2).

As shown in Table 3, blood lead levels at baseline were slightly higher in the lead intervention group than in the control group, although the difference was not statistically significant. At the end of the intervention mean blood lead had fallen by 2.1 μg/dL (0.10 μmol/L; 17%) in the intervention group,

TABLE 3. Children’s Blood Lead Levels by Study Group

	Lead Intervention (<i>n</i> = 46)		Control (<i>n</i> = 53)	
	Mean	SD	Mean	SD
At baseline (μg/dL)*	12.4	5.7	11.6	6.2
At follow-up (μg/dL)	10.3	5.6	11.6	7.6
Change (μg/dL)	-2.1	5.7	0.1	6.3
% Change	-17%		+1%	

Abbreviation: SD, standard deviation.

* 1 μg/dL blood lead = 0.0483 μmol/L.

whereas it rose by 0.1 μg/dL (0.005 μmol/L) in the control group (*P* < .05, one-sided). Adjustment for baseline blood lead in a regression model provided an estimated intervention effect of 1.9 μg/dL (0.09 μmol/L; *P* < .05, one-sided).

The intervention seemed to reduce the chance of sustaining an increase in blood lead. Four lead group children and 9 accident group children experienced increases of 5 μg/dL (0.24 μmol/L) or more during the year; 1 lead group child and 4 accident group children sustained increases of 10 μg/dL (0.48 μmol/L) or more. At the conclusion of the study, 6 (13%) of the lead group children and 13 (25%) of the accident group children had lead levels >15 μg/dL (0.72 μmol/L). Conversely, 26% of the lead group and 19% of the accident group children sustained decreases in blood lead of 5 μg/dL (0.24 μmol/L) or more.

In the lead intervention group, children whose families cooperated fully with the study protocol enjoyed more benefit than did those from less compliant families. A useful index of the degree of cooperation was the number of times we were able to complete home cleaning visits. As shown in Fig 1, there was no change in blood lead levels in children in the intervention group whose homes were cleaned <10 times, whereas there was an average 34% drop in blood lead in children whose homes were cleaned 20 or more times. Table 4 shows that the former had more home contamination at outset, as measured by window sill lead loading, and that the percentage decline in this measure during the study was less than in the homes that were cleaned more regularly.

We searched for evidence that our educational effort contributed to the decline of blood lead. There was no relation between the maternal score on a baseline test of knowledge of lead poisoning and the child’s initial blood lead level or the subsequent change in blood lead level. Nor was the number of educational sessions attended related to the decline in blood lead level. However, when knowledge of lead poisoning was assessed at the end of the intervention period, there was a statistically significant increase in knowledge in the intervention group as a whole, whether compared with the baseline scores or to the mothers in the control group. Children whose mothers scored greater than the median on the final knowledge evaluation averaged a 3.9 μg/dL (0.19

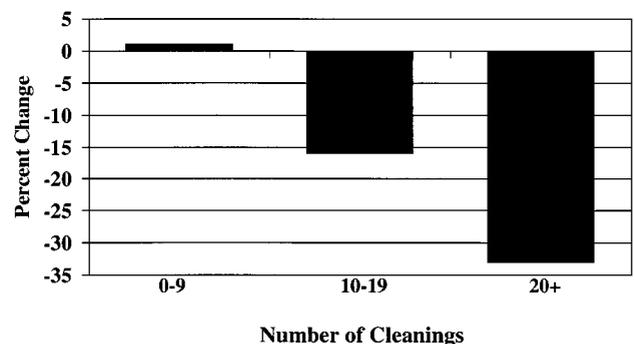


Fig 1. Mean change in blood lead among children in the intervention group by number of cleaning visits.

TABLE 4. Selected Mean Characteristics of Families in Final Lead Group by Number of Cleanings*

Number of Cleanings	Enrollment Age (Mo)	Initial Blood Lead ($\mu\text{g}/\text{dL}$)	Final Blood Lead ($\mu\text{g}/\text{dL}$)	Change in Blood Lead ($\mu\text{g}/\text{dL}$)	Sill Lead Loading	
					Beginning	% Decline
<10	20.6 (11)	13.6 (11)	13.8 (11)	0.2 (11)	1.07 (9)	51%
10–19	19.8 (19)	12.5 (19)	10.5 (19)	–2.0 (19)	.75 (15)	61%
20+	21.2 (16)	11.6 (16)	7.7 (16)	–3.9 (16)	.73 (15)	78%

* Table shows mean values with numbers of observations in parentheses. Sill lead loadings (mg/m^2) are shown as the geometric means because of their skewed distribution. Some families moved during the study so that final sill lead loadings are not necessarily from the same house as the initial ones.

$\mu\text{mol}/\text{L}$) decline in blood lead level whereas those whose mothers scored below the median averaged only a 0.2 $\mu\text{g}/\text{dL}$ (0.01 $\mu\text{mol}/\text{L}$) decline ($P < .05$). However, the relation between this final knowledge score and lead change was nonlinear with the Pearson and Spearman correlations being 0.05 (not significant) and 0.20 (not significant), respectively. When blood lead change in the intervention group was regressed on initial blood lead, number of cleanings, and final knowledge score in a multiple regression model, the first two were highly significant predictors ($P < .01$), but the last was not ($P > .5$).

DISCUSSION

This randomized trial demonstrated that an intervention composed of maternal education and household cleaning will reduce the lead exposure of children living in contaminated urban housing. The overall 17% reduction in blood lead achieved in the intervention group is similar to the 18% reduction found by Charney et al¹⁶ in somewhat older children whose homes were cleaned in a similar manner after abatement. The children in Charney's study had much higher blood lead levels than those that we enrolled. In contrast to these studies, a randomized trial of high-efficiency particle accumulating vacuuming every 6 weeks in smelter town homes (without wet mopping) produced only a minimal and nonsignificant reduction in blood lead levels of 0.3 $\mu\text{g}/\text{dL}$ (0.14 $\mu\text{mol}/\text{L}$).²² The mean lead levels in these children were comparable to those that we studied, but the housing stock was relatively clean and well maintained.

It was not possible, within budgetary constraints, to design this trial with separate intervention groups that would have distinguished clearly between the effect of maternal education alone and the effect of maternal education combined with the cleaning protocol. Only the combined strategy was tested. The cleaning team was encouraged to provide education to mothers in the course of their visits, and one of the major foci of the educational effort was on cleaning. Education was included because it is unlikely that a community agency would provide families with assistance in cleaning without making an educational effort.

The literature on the effect of education alone on blood lead in children is mixed. The only randomized trial provided both education and cleaning supplies to urban families and found no effect on blood lead in toddlers.²³ Studies that have reported favor-

able results have been subject to bias from regression to the mean, seasonal change in blood lead, and/or the decline in blood lead that is usually seen in the later preschool years.²⁴ In our study, multiple regression analysis suggested that if maternal knowledge at the end of this study had any explanatory power, it operated primarily through cooperation with the cleaning protocol. As a practical matter, many of the participating families had no vacuum cleaners and some did not have buckets and mops. Thus, in this setting provision of materials necessary for cleaning would need to be added to an education protocol.²³

The average 17% reduction in blood lead in the lead intervention group may be viewed as a conservative estimate of what cleaning can achieve because it was clearly diminished by the lack of change in the homes of the less cooperative families. Nevertheless, it was sufficient to reduce the number of children with blood lead levels greater than the CDC action level of 15 $\mu\text{g}/\text{dL}$ (0.72 $\mu\text{mol}/\text{L}$) by one half. Cooperating families achieved substantially larger reductions. There is no comparable evidence that legally ordered abatements, as conducted in most US inner cities, are as effective for children with lead levels in the 10 to 30 $\mu\text{g}/\text{dL}$ (0.48–1.44 $\mu\text{mol}/\text{L}$) range.

The intervention conducted for this project can be implemented by motivated householders or by lay workers with very modest training. It differs from abatement in that it does not require the permission or cooperation of landlords and has little potential to cause harm if done badly. However, as implemented in our project, the intervention required 5 person-hours per home visit, which, if fully salaried, would be too expensive for most health departments. Exploration of ways to reduce costs and to find alternative funding mechanisms are needed to develop public health policy around this approach. A somewhat simpler cleaning protocol than we used might be justified, and a recent research initiative from the Department of Housing and Urban Development should help to identify suitable compromises.

The majority of children with blood lead levels that are excessive by CDC standards are not suitable candidates for chelation, nor is there a consensus on legal mandates for abatement at blood lead levels $<20 \mu\text{g}/\text{dL}$. Although some authorities have recommended household cleaning for these children, its efficacy has never been clearly demonstrated at these modest exposure levels. We believe the results of this trial make it clear that many of these children can be helped with a cleaning program that physicians can

confidently recommend and that at least some families will be willing and able to undertake. This evidence lends credence to the utility of lead screening in the many communities where exposure to this toxin continues to be a problem.

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