Assessment of Cleaning to Control Lead Dust in Homes of Children with Moderate Lead Poisoning: Treatment of Lead-Exposed Children Trial

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In this article we describe the assessment and control of lead dust exposure in the Treatment of Lead-exposed Children (TLC) Trial, a clinical trial of the effects of oral chelation on developmental end points in urban children with moderately elevated blood lead levels. To reduce potential lead exposure from settled dust or deteriorated paint during the drug treatment phase of the trial, the homes of 765 (98%) of the randomized children (both active and placebo drug treatment groups) were professionally cleaned. Lead dust measurements were made in a sample of 213 homes before and after cleaning. Geometric mean dust lead loadings before cleaning were 43, 29, 308, and 707 µg/ft^2 in the kitchen floor, playroom floor, playroom windowsill, and playroom window well samples respectively. Following cleaning, floor dust lead loadings were reduced on average 32% for paired floor samples (p < 0.0001), 66% for windowsills (p < 0.0001), and 93% for window wells (p < 0.0001). Cleaning was most effective for 146 homes with precleaning dust lead levels above the recommended clearance levels, with average reductions of 44%, 74%, and 93% for floors (p < 0.0001), windowsills (p < 0.0001), and window wells (p < 0.0001), respectively. Despite these substantial reductions in dust lead loadings, a single professional cleaning did not reduce the lead loadings of all dust samples to levels below current federal standards for lead in residential dust. Attainment of dust levels below current standards will require more intensive cleaning and lead hazard reduction strategies. *Key words:* chelation, cleanup, dustwipe, environmental exposure, lead dust, lead poisoning, prevention and control. *Environ Health Perspect* 110:A773–A779 (2002). [Online 12 November 2002]
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Childhood lead poisoning is an entirely preventable condition; however, exposure to lead remains a primary environmental health concern. Despite the removal of lead from gasoline and residential paint in the United States beginning in the 1970s, millions of young children remain at risk for lead poisoning (*1*). Lead in paint and house dust are by far the most common sources of exposure in U.S. children (*2–4*). Risk factors for elevated blood lead levels in children reflect these sources and include residence in older homes, low family income, minority race, and residence in large urban areas (*5*).

Among children undergoing pharmacologic treatment for lead poisoning, chelation might cause lead to be more readily absorbed (*6*). In a small study of adult volunteers, gastrointestinal absorption of lead was enhanced by oral chelation with succimer (*7*). However, in animals the oral administration of succimer was not associated with a risk for increased gastrointestinal lead absorption (*8,9*). Before 1991, all drugs labeled for lead chelation were administered parenterally, and children being treated usually were hospitalized and thus removed from sources of environmental exposure in their homes during treatment. For children being treated for elevated blood lead levels with oral chelation (succimer) on an outpatient basis, continued environmental exposure during treatment is a concern. Reduction of the child's environmental exposure to lead remains the most important factor in the management of pediatric plumbism, even for children receiving pharmacologic treatment.

Low-technology household cleanup strategies can be effective in lowering lead dust levels (*10*), at least in the short term (*11*). These strategies also have been effective in reducing children's blood lead levels (*12–14*), but these benefits may be short-lived (*15*). It is unclear whether cleaning alone can produce a lead-safe environment, and the frequency and intensity of the cleaning interventions necessary are not known.

The Treatment of Lead-exposed Children (TLC) Trial is a multisite, placebo-controlled, double-blind, randomized clinical trial of the effect of succimer on developmental outcomes in children with moderately elevated blood lead levels (20–44 µg/dL). The primary goal of the TLC trial was to compare the effects of chelation with succimer versus placebo therapy on developmental status 36 months after initiation of treatment (*16*).

Children assigned to an active or a placebo drug received up to three courses of treatment for up to 6 months. The TLC Trial environmental intervention was designed to use interim control measures during treatment to substantially reduce the children's exposure to potential lead hazards from deteriorated household paint and dust. All children were assumed to have been exposed to lead in their homes. The TLC trial did not attempt to undertake comprehensive lead paint abatement activities, nor did it substitute for lead paint abatement activities required by local health departments or enforcement agencies (*17–23*). TLC activities were carried out independently of and in addition to local activities, although TLC environmental inspectors established working relationships with local environmental health inspectors. Thus, TLC participants' homes received more thorough dust control via professional cleanup than they would have received with normal care in their communities.

In this article we describe the TLC environmental intervention and quantify the effectiveness of this professional cleaning using analyses of interior dustwipe measurements made in a sample of homes in each TLC Trial center before and after cleaning.

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Methods

Children were enrolled between August 1994 and January 1997 at four clinical centers located in Baltimore, Maryland; Cincinnati/Columbus, Ohio; Newark, New Jersey; and Philadelphia, Pennsylvania. A detailed description of the design and recruitment of the TLC trial has been published elsewhere (*24*). The study protocol was approved by the institutional review boards at each of the clinical centers (Johns Hopkins University Hospital/Kennedy Krieger Institute, University of Cincinnati Medical Center, Children's Hospital of Columbus, University of Medicine and Dentistry of New Jersey, Children's Hospital of Philadelphia) plus the data coordinating center at Harvard School of Public Health, the central blood laboratory at the Centers for Disease Control and Prevention, and the National Institute of Environmental Health Sciences. Informed consent was obtained from a parent or primary caregiver for all eligible subjects before participation. To be eligible, a child had to be between 12 and 33 months of age and have a blood lead level between 20 and 44 µg/dL. A total of 1,854 children were referred for initial screening at the clinical centers as potential participants in the trial. Of these, 735 were excluded for confirmatory blood leads out of range (n = 651), other medical conditions (n = 27), and withdrawal (n = 57).

Home assessment. Before a second clinic screening visit, all eligible children (n = 1,119) were scheduled to receive an inspection of their primary and secondary residences (n = 2,026) for visual evaluation of potential lead hazards by trained TLC personnel. Typically, residential units were two- to three-story, single- or multiple-family houses built before 1950 and located in low-income, inner-city neighborhoods. Most were two- or three-bedroom units of approximately 900 ft^2.

The amount of work required to clean the residential dwelling unit and common areas (halls, stairs, porches) was estimated. The child's access to each area was considered in the environmental assessment and cleanup plan. The potential for lead exposure was assessed visually based on condition of painted surfaces, accessibility of nonintact painted surfaces, condition of painted substrates (i.e., wood, plaster, metal, drywall), potential difficulties in cleaning surfaces, and overall structural integrity of both the interior and exterior of the dwelling. It was assumed that all of these children were exposed to lead in their homes, so lead in paint was not measured. Housing conditions that would not permit effective cleaning of lead dust led to exclusion. On the basis of home assessment, children (n = 56) were excluded if the child's primary residence was judged "not cleanable" with lead hazards too great to be adequately cleaned and the child could not be relocated to lead-safe housing (n = 43); TLC staff felt the child's residence was unsafe for study personnel to visit (n = 9); the child spent significant amounts of time (> 24 hr per week) in two or more residences or day care (n = 2); or there were other reasons related to the child's total home environment (n = 2). Families of excluded children were referred to the local health department for appropriate follow-up based on the child's blood lead level.

During the home inspection, the environmental intervention and the family's role in the process was described. In a limited number of cases, TLC clinical centers attempted to relocate families into lead-safe housing. The Baltimore clinical center relocated families living in houses in poor condition to houses in better condition.

Environmental intervention. All clinical centers followed common procedures for the visual assessment of hazards using a standardized protocol based on U.S. Housing and Urban Development (HUD) guidelines (*25*) and for the minimum environmental cleanup intervention (*26*). As resources permitted, individual centers provided environmental intervention beyond the common core activities. Each center met or exceeded applicable local, state, and federal guidelines for the management of children with lead toxicity (*27*).

For children meeting eligibility criteria, a second home visit for professional home cleaning to reduce lead dust and paint chips was scheduled to occur before randomization or, in a small number of cases (n = 37), within one week after start of treatment. Precleaning dustwipe samples were collected in a sample of homes. The primary residence (and a secondary residence, if applicable) of enrolled children was professionally cleaned. The study child and other small children were requested to be out of the house during the cleaning, but this was not always feasible. The homes of 765 (98%) of the 780 randomized children were cleaned; 15 families refused the environmental cleanup intervention following initiation of treatment.

Contractors performed the cleanup at all clinical centers except in Newark, where staff were hired to carry out the intervention. Each cleaning crew consisted of two or more individuals trained using the U.S. Environmental Protection Agency (EPA) Residential Lead-Based Paint Abatement Model Training Course (*28*). Two centers (Baltimore and Cincinnati) had substantial field experience in residential lead dust cleanup, but the experience in the other two centers was limited. Homes were cleaned beginning with rooms located furthest from the entrance to prevent recontamination. The child's family was asked to place household belongings in plastic bags to prevent contamination with lead-containing dust. Furnishings and movable rugs were moved temporarily to other locations within the unit. Contamination control procedures ensured that any removed furnishings, waste water, and dust were handled appropriately onsite and during transport to designated disposal sites.

All horizontal surfaces (e.g., floors, windowsills, tops of baseboards) were vacuumed with cleaners (Nilfisk model GS-80 industrial vacuum; Nilfisk America, Malvern, PA) equipped with high-efficiency particulate air (HEPA) filters and an approved beater bar (for carpets) (Kenmore model 116; Sears, Roebuck and Co., Chicago, IL). Upholstered furniture was vacuumed. Other dust traps (e.g., venetian blinds, cold air return registers, radiators) and walls were vacuumed if accessible. Families were encouraged to dispose of deteriorated carpets. Fixed carpets (wall-to-wall) were vacuumed three times at the rate of 3 min/yard^2 each time. If there was no carpeting, the floor was vacuumed at the rate of 1 min/yard^2. Uncarpeted floors and horizontal surfaces then were damp mopped using a two-bucket cleaning method. Trisodium phosphate (TSP), a high-phosphate detergent, was mixed with water as a cleaning solution in one bucket, and the second bucket contained clean rinse water. The mop was dipped into the cleaning solution bucket, wrung lightly to remove excess, and applied to surfaces. Before repeating the procedure for the next section, the mop was rinsed in the clean rinse water bucket to collect soiled solution from the floor (or other surface), separating dirt from the cleaning solution. The water in both buckets was changed after cleaning approximately every 75 to 100 ft^2 of floor and after each room was completed. For rinsing surfaces, both buckets were changed to clean water. Using a new (clean) mop, the entire surface is mopped again with clean water using the same procedure. At the time of the design and implementation of our cleaning intervention, the U.S. EPA recommended the use of TSP to clean lead-contaminated surfaces. However, the U.S. EPA no longer recommends the use of this detergent (*29*).

Window wells (troughs), if accessible, were vacuumed to remove paint chips and dust, scrubbed clean with a damp sponge or brush using the two-bucket system, and, after drying, vacuumed a second time. Families were encouraged to wash curtains and dispose of vinyl miniblinds, a potential lead hazard for children (*30*). Common areas such as hallways, stairs, porches, and other exterior entryways were cleaned using the same procedures. All accessible surfaces with deteriorated paint were vacuumed to remove loose paint. Particular attention was given to deteriorated painted surfaces on porches, including ceilings.

Each family was given educational information and materials about lead poisoning and prevention of further lead exposure. Entryway mats were provided to reduce tracking of lead into the home. The importance of regular cleaning was reviewed with families during clinic visits. Families were given cleaning materials (e.g., bucket, sponges, detergent) to encourage on-going cleaning to control lead dust. TLC home assessors performed postintervention visual inspection for quality assurance and collected dustwipe samples in a subset of homes.

Minor repairs/paint stabilization. Where deterioration of painted surfaces was localized to one or two areas (e.g., windowsills or frames), in-place management was carried out (e.g., application of duct tape, contact paper, or paint) until the owner could provide more complete abatement. Limited paint stabilization was also applied to the common areas, with the permission of the building owner or manager. The Baltimore clinical center had access to state loan funds for some landlords to perform more extensive hazard remediation.

Parents were instructed to limit children's access to these stabilized areas, to reinspect the repaired areas frequently, and to contact the TLC representative if the surface(s) deteriorated further or if the owner/landlord performed repairs or repainting. Parents/guardians were asked about any new repairs or renovations at each clinic visit. If the families of enrolled children moved during the trial, the new residence was assessed and cleaned using the same procedures. Children with more than two usual residences were excluded, but homes were cleaned whenever the child moved or major repairs or renovations occurred.

Dust sampling methods. Pre- and postintervention dustwipe samples were collected from the first 25 homes at each center plus a sample of approximately one in 10 homes thereafter. Preintervention dustwipes were collected at the initial home assessment or before cleaning on the day of intervention. Median time from preintervention dustwipe to the cleaning intervention was 4 days (mean, 13 days). The postintervention sample was collected as soon as possible after completion of the cleanup activities (70% on the same day; 96% within 7 days).

Dustwipe samples were collected using the HUD wipe method (*25*). A defined 1-foot^2 sampling template was laid out on the kitchen and child's bedroom or playroom floor. This predefined area was wiped with a premoistened baby wipe (Little Ones Baby Wipes Lightly Scented; American Fare/Kmart Corp., Troy, MI) chosen for documented durability under field use and acceptable recovery rates. The windowsill above the playroom floor sample was similarly wiped and measured. In Baltimore, window wells were sampled using similar methods. Areas of the windowsill and window well samples were individually measured for each sample. The collected dust samples, including any paint chips, were folded in the baby wipe and placed in a nonsterilized screw-top polyethylene centrifuge tube (50 mL size). Visual presence of paint chips was noted. The area sampled, material of the surface, and surface conditions were recorded.

Laboratory analysis. All dustwipe samples from each of the clinical centers were sent to Azimuth Laboratories (Charleston, SC) or to University of Cincinnati Environmental Laboratory for analysis by flame atomic absorption spectrometry (Perkin-Elmer 3100; Perkin-Elmer, Wellesley, MA) using a modified-NIOSH 7082 method (*31*). Blinded standard reference materials from National Institute of Standards and Technology (NIST; SRM #2583 Trace elements in indoor dust) (range, 53–94 µg per sample; n = 16) and field blanks (n = 243) were analyzed for quality control/quality assurance purposes. Median recovery of standard reference material was 85% (range, 79–88%). Median field blank contained 0.0 µg lead (mean, –1.4 µg), with one sample above 25 µg.

Data analysis. We assessed the effectiveness of cleaning in the 213 homes with paired pre- and postintervention dustwipe lead measurements. Characteristics of the sampled versus nonsampled homes were tabulated. If a child had more than one residence reported, the characteristics of the first home assessed were considered.

Laboratory measurements of lead loadings were obtained for all samples. Truncation of lead measurements at the laboratory analytic limit of detection has the unintended result of producing biased sample means and population statistics. Although various statistical corrections have been proposed for this bias, using the actual laboratory measurements for all samples provides a direct, unbiased result estimate (*32–34*). For that reason, the actual laboratory measurements were analyzed for all dustwipe samples.

Dust lead loadings are reported as mass of lead collected divided by sample area (µg/ft^2). The lead loadings were highly positively skewed and were log-transformed. Values less than 1 µg/ft^2 were set to 1 µg/ft^2 before log transformation. The exponential of the mean and standard deviations of the log-transformed data (geometric mean and geometric standard deviation) are reported. The change in dust lead loadings was evaluated as the difference between the pairs of pre- and postintervention log-transformed lead loadings and reported as percent reduction [i.e., 100 times (1 minus the exponential of the postcleaning minus the precleaning log-transformed lead loading)]. Ninety-five percent confidence intervals (CI) were calculated assuming a normal distribution about the log-mean. Statistical significance was assessed by paired t-tests and reported by p-values. The percentage of pre- and post-intervention lead loadings above the EPA residential dust lead clearance standards (*35*) were tabulated. All statistical analyses were carried out using SAS version 8 (*36*).

Kitchen and playroom floor samples were combined to assess the influence of surface characteristics. Windowsill and window well

Table 1. Baseline housing characteristics.[a]

Characteristics	Randomized only	Homes with dustwipe pairs: Baltimore	Cincinnati	Newark	Philadelphia	All
No. homes	780	42	40	95	36	213
Building type (%)						
Single family	15	7	18	11	9	11
Multifamily house	27	3	30	57	9	34
Multifamily apartment	22	15	48	32	11	30
Row house	35	75	5	0	20	24
Other	2	0	0	0	51	1
Problems with home (%)						
Heating system	8	8	10	5	9	7
Plumbing leaks	23	15	35	29	17	26
Roof leaks	24	13	23	18	34	21
Structural	25	15	10	20	41	21
Rats	18	5	3	12	20	10
Peeling/chipping paint	83	53	65	95	77	78
Overall maintenance (%)						
Good	29	67	23	44	31	42
Fair	48	23	50	49	57	45
Poor	23	10	28	7	12	13
Potential lead exposure (%)						
Low	29	59	30	53	34	46
Moderate	48	23	42	44	54	42
High	23	18	28	3	12	12
House cleanable (%)	94	95	100	100	94	98

[a]As reported by TLC inspector for homes of all randomized children (n = 780), homes with dustwipe pairs by center (n = 213), and homes with dustwipe pairs combined (n = 213).

samples were considered separately. Floor and window conditions were characterized as "intact," with "minor problems," or "deteriorated." Floor materials were classified into three broad categories: carpeted (carpet or any fiber covering), linoleum (linoleum, tile, or other smooth surfaces including stone or brick), and wood (finished, painted, or bare). Window materials were categorized into wood, metal or vinyl, and other.

We assessed whether the 146 homes that would have triggered an intervention based on the U.S. EPA clearance standards (*35*) would have benefited from the cleanup intervention. Homes above the U.S. EPA standard were defined by having any floor dustwipe measurement of 40 µg/ft^2 or higher, a windowsill measurement of 250 µg/ft^2 or higher, or a window trough (well) measurement of 400 µg/ft^2 or higher.

Results

Housing characteristics. The homes of the randomized children (n = 780) were generally in below average condition with fair (48%) to poor (23%) maintenance (Table 1). Chipping and/or peeling paint was observed in 83% of these homes. Approximately one quarter of the homes of randomized children showed evidence of water damage from plumbing (23%) or roof (24%) leaks which can lead to paint failure, either by deterioration of the paint or of the substrate. Seventy-one percent (71%) were assessed as having moderate to high potential for lead exposure, but 94% were assessed as cleanable.

Homes of the 344 nonrandomized children (data not shown) were similar to those of randomized children in terms of building type, age, poor overall maintenance (72% fair or poor), and potential for lead exposure (69% moderate or high). A lower fraction of these homes (82%) were assessed as cleanable. A total of 213 homes of randomized children had paired dustwipe measurements before and after environmental cleanup. These homes were similar to the total sample of homes of randomized children (Table 1).

Cost of intervention. While each center organized the environmental intervention to conform to local standards, local practice, and available resources, the intervention for each child was designed to meet minimum common standards across the TLC Centers. Average total labor and materials costs were estimated for each center based on total expenditures for cleaning divided by the number of homes cleaned. The average estimated cost of each cleanup was $340 per home in Cincinnati, $675 in Baltimore, $291 in Newark, and $1,140 in Philadelphia. Labor, materials, or total costs of the professional cleaning were not recorded for individual homes.

Floor dust lead loadings. A total of 189 homes had paired kitchen floor dustwipe measurements before and after environmental cleanup (Table 2). The 10th to 90th percentiles of kitchen dustwipe lead loadings (4 and 350 µg/ft^2, respectively) ranged over two orders of magnitude, but were symmetric on the logarithmic scale (Figure 1). Before environmental intervention, the geometric mean kitchen floor lead dust loading was 43 µg/ft^2. After the environmental intervention, the geometric mean kitchen floor lead dust loading was reduced to 26 µg/ft^2. Thus, the postcleaning dustwipe lead loading was reduced on average by 40% compared to the precleaning value (95% CI, 24–52%; p < 0.00001). Postcleaning lead dust levels were lower than precleaning levels for 67% of the paired floor samples and were reduced by one-half or more in 40% of the samples. Fifty-two percent of the precleaning kitchen floor samples were greater than or equal to the U.S. EPA clearance standard of 40 µg/ft^2, and 39% were still above the standards after cleaning.

Paired playroom floor dustwipe samples were collected in 181 homes (Figure 1). Precleaning playroom floor dustwipe lead loadings had a lower geometric mean (29 µg/ft^2) than the kitchen floor samples (Table 2), but slightly larger variance [geometric standard deviation (GSD) 6.3]. Postcleaning playroom floor lead dust loadings were reduced by an average 24% (95% CI 6–39%) compared to precleaning values (p = 0.01362). Forty-two percent of the precleaning and 38% of the postcleaning playroom floor dustwipe samples were above the U.S. EPA clearance standards.

The kitchen and playroom floor samples were pooled so that effects of floor material, condition and center, could be considered. The lowest geometric mean loadings (Table 2) were measured on carpeted floors (13 µg/ft^2), with higher lead loadings for linoleum or tiled surfaces (33 µg/ft^2), and the highest levels for wood surfaces (79 µg/ft^2). The effectiveness of cleaning was similar for

Table 2. Floor dustwipe measurements before and after cleaning intervention stratified by condition before cleanup and center.

Variable	No. pairs	Precleaning GM (GSD)	Postcleaning GM (GSD)	Percent reduction Mean (95% CI)	p-Value[a]	< 40 µg Pb/ft^2 (%)[b] Pre	Post
Floor							
All pairs	370	35 (5.8)	24 (5.7)	32 (21–42)	< 0.0001	53	61
Location							
Kitchen	189	43 (5.7)	26 (5.7)	40 (24–52)	< 0.0001	48	61
Playroom	181	29 (6.3)	22 (7.3)	24 (6–39)	0.01362	58	62
Material							
Carpet	74	13 (5.0)	10 (5.4)	24 (2–41)	0.0355	76	80
Linoleum	194	33 (5.5)	22 (5.7)	34 (17–48)	0.0003	56	63
Wood	100	79 (5.5)	54 (7.0)	32 (5–51)	0.0226	31	44
Condition							
Intact	315	29 (5.6)	21 (6.4)	27 (13–38)	0.0005	58	64
Minor	39	101 (5.0)	40 (5.4)	61 (37–75)	0.0001	26	49
Deteriorated	12	187 (5.8)	123 (3.4)	34 (−8–60)	0.0979	17	17
Paint chips							
No	337	32 (5.8)	23 (6.3)	30 (17–41)	< 0.0001	50	75
Yes	29	98 (5.2)	51 (7.1)	47 (10–69)	0.0190	55	63
U.S. EPA guideline[c]							
Below	104	7 (3.2)	7 (4.8)	–9 (−38–18)	0.5413	100	87
Above	266	67 (4.8)	38 (5.9)	44 (32–54)	< 0.0001	35	52
Center							
Baltimore	83	41 (4.9)	19 (4.7)	54 (38–65)	< 0.0001	47	75
Cincinnati	80	21 (5.3)	11 (4.8)	48 (31–61)	< 0.0001	66	83
Newark	138	45 (6.5)	38 (7.0)	15 (−12–35)	0.2462	46	46
Philadelphia	69	32 (6.9)	29 (7.9)	9 (−41–41)	0.6873	59	51

Abbreviations: GM, geometric mean; GSD, geometric standard deviation; Post, postcleaning; Pre, precleaning.
[a]p-Value from t-test of equality of sample means. [b]U.S. EPA residential clearance standard for lead-in-dust equal to 40 µg Pb/ft^2 for floors (*35*). [c]Above U.S. EPA residential clearance standards for lead-in-dust for any floor sample, windowsill, or window well.

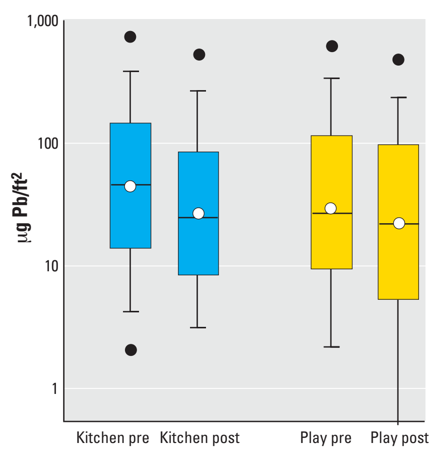

Figure 1. Boxplots of pre- and postcleaning paired kitchen (n = 189) and playroom (n = 181) floor dustwipe lead levels (µg/ft^2). Boxes indicate 25th, 50th, and 75th percentiles; bars, 10th and 90th percentiles; filled circles, 5th and 95th percentiles; open circles, geometric mean.

wood (32% reduction) and linoleum (34% reduction) surfaces, and somewhat less for carpeted surfaces (24% reduction). There was not a statistically significant difference in effectiveness between any of these surfaces.

There was a gradient in the floor dust lead loadings with reported condition of the floor (Table 2). Precleaning floor dust lead geometric mean loadings were highest from "deteriorated" surfaces (187 µg/ft^2) compared to surfaces with "minor" problems (101 µg/ft^2) or to the "intact" floors (29 µg/ft^2). In terms of percentage reduction in lead loading, cleaning was most effective for floors with "minor" condition problems (61% reduction), although there was no statistically significant difference in cleaning effectiveness by floor condition. Excluding carpeted floors did not change this observation (data not shown). Paint chips were reported to be present in 29 (8%) of the precleaning and five (< 2%) of the postcleaning dustwipe floor samples. However, exclusion of these samples did not substantially change the means or the post/precleaning ratios (data not shown).

Two hundred sixty-six paired floor dustwipe samples were collected in 138 homes with precleaning measurements (floor, windowsill, or window well) above the U.S. EPA clearance standards. Postcleaning floor dustwipe measurements were by an average 44% (95% CI, 32–54%) compared to the precleaning loadings (Table 2). Among the 104 paired floor samples from the 78 homes meeting the U.S. EPA clearance standards, there was little effect of cleaning (average –9% reduction; 95% CI, ⁻38–18%).

Precleaning dust lead geometric mean loadings were lowest in Cincinnati (and Columbus), with higher levels in Philadelphia, Baltimore, and Newark (Table 2). Cleaning was most effective in Baltimore (54% reduction) and Cincinnati (48% reduction). There were only modest improvements in floor dust lead loadings in Newark (15% reduction) and Philadelphia (9% reduction). Regression analyses adjusting for floor surface material and condition did not explain these differences among centers (data not shown). Cleaning was more effective in all centers in homes that had precleaning dust lead loadings above the U.S. EPA standards: Baltimore (40%; 95% CI, 29–55%), Cincinnati (41%; 95% CI, 27–60%), Philadelphia (71%; 95% CI, 42–119%), and Newark (74%; 95% CI, 53–104%).

Playroom window dust lead loadings. Windowsill dustwipe measurements were collected in 119 homes both before and after environmental cleanup (Figure 2). Geometric mean lead loading (Table 3) dropped substantially from 308 µg/ft^2 before cleaning to 105 µg/ft^2 after cleaning (66% reduction; 95% CI, 53–75%). Windowsill dust lead loadings were reduced by one-half or more in 55% of the homes. Forty-seven percent of the homes had windowsill lead loading less than 250 µg/ft^2 before cleaning, versus 62% after cleaning.

Precleaning dustwipe geometric mean loadings for intact windowsills were

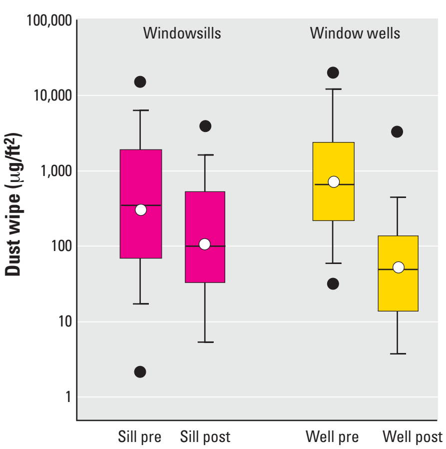

Figure 2. Boxplots of pre- and postcleaning paired windowsill (n = 119) and window well (n = 33) dustwipe lead levels (µg/ft^2). Boxes indicate 25th, 50th, and 75th percentiles; bars, 10th and 90th percentile; filled circles, 5th and 95th percentiles; open circles, geometric mean.

Table 3. Playroom windowsill dustwipe measurements before and after cleanup intervention stratified by condition before cleanup and center.

Variable	No. pairs	Precleaning GM (GSD)	Postcleaning GM (GSD)	Percent reduction Mean (95% CI)	p-Value[a]	< 250 µg Pb/ft^2 (%)[b] Pre	Post
Windowsills							
All pairs	119	308 (11.7)	105 (9.4)	66 (53–75)	< 0.0001	47	62
Material							
Wood	105	390 (11.2)	137 (8.8)	65 (51–75)	< 0.0001	44	58
Metal	6	33 (3.1)	14 (3.4)	58 (18–78)	0.0104	100	100
Other[c]	8	76 (14.0)	15 (8.3)	80 (8–95)		50	88
Condition							
Intact	74	189 (13.3)	73 (10.6)	61 (44–73)	< 0.0001	53	68
Minor	29	637 (7.5)	159 (6.0)	75 (48–88)	0.0002	38	55
Deteriorated	13	1,022 (8.1)	335 (9.3)	67 (9–88)	0.0331	31	46
Paint chips							
No	73	177 (10.2)	68 (9.6)	62 (44–74)	< 0.0001	55	71
Yes	43	799 (12.0)	223 (8.1)	72 (53–84)	< 0.0001	33	47
U.S. EPA guideline[d]							
Below	35	23 (5.7)	15 (6.5)	35 (⁻1–56)	0.0358	100	94
Above	84	914 (6.1)	238 (6.3)	74 (61–83)	< 0.0001	25	49
Center							
Baltimore	5	40 (7.2)	8 (5.8)	79 (⁻179–98)	0.2373	80	100
Cincinnati	40	179 (16.0)	52 (8.7)	71 (12–90)	0.0282	58	73
Newark	43	377 (10.0)	127 (9.4)	66 (11–87)	0.0282	42	56
Philadelphia	31	654 (7.5)	303 (5.7)	54 (⁻20–82)	0.1129	35	52

Abbreviations: GM, geometric mean; GSD, geometric standard deviation; Post, postcleaning; Pre, precleaning.
[a]p-Value from t-test of equality of sample means. [b]U.S. EPA residential clearance standard for lead-in-dust equal to 250 µg Pb/ft2 for windowsills (*35*). [c]Other materials include: brick, stone, slate, or marble (4); panelled (1); vinyl (1); sheetrock (1); unspecified (1). [d]Above U.S. EPA residential clearance standards for lead-in-dust for any floor sample, windowsill, or window well.

Table 4. Playroom window well dustwipe measurements before and after cleanup intervention stratified by condition before cleanup (Baltimore center only).

Variable	No. pairs	Precleaning GM (GSD)	Postcleaning GM (GSD)	Percent reduction Mean (95% CI)	p-Value[a]	< 400 µg Pb/ft^2 (%)[b] Pre	Post
Window wells							
All pairs	33	707 (6.2)	53 (8.4)	93 (85–96)	< 0.0001	42	91
Material							
Wood	20	756 (6.6)	61 (6.1)	92 (78–97)	< 0.0001	40	90
Metal	13	638 (6.1)	42 (13.4)	93 (82–98)	< 0.0001	46	92
Condition							
Intact	31	634 (6.2)	51 (8.9)	92 (85–96)	< 0.0001	45	90
Minor	2	3,804 (2.2)	84 (2.7)	98 (97–98)	< 0.0001	0	100
Paint chips							
No	31	622 (6.1)	46 (7.8)	93 (84–96)	< 0.0001	45	94
Yes	2	5,126 (3.3)	390 (24)	92 (⁻17–100)	0.0647	0	50
U.S. EPA Guideline[c]							
Below	5	82 (2.8)	8 (11.2)	90 (⁻16–99)	0.0661	100	100
Above	28	1,038 (5.3)	73 (6.9)	93 (85–97)	< 0.0001	32	89
Center							
Baltimore	33	707 (6.2)	53 (8.4)	93 (85–96)	< 0.0001	42	91

Abbreviations: GM, geometric mean; GSD, geometric standard deviation; Post, postcleaning; Pre, precleaning.
[a]p-Value from t-test of equality of sample means. [b]U.S. EPA residential clearance standard for lead-in-dust equal to 400 µg Pb/ft^2 for window wells (troughs) (*35*). [c]Above U.S. EPA residential clearance standards for lead-in-dust for any floor sample, windowsill, or window well.

189 µg/ft^2 (Table 3). These precleaning loadings were 2.5 times higher if there were minor problems (637 µg/ft^2) and more than 5 times higher if windowsills were deteriorated (1,022 µg/ft^2). The fraction of homes with pre-intervention window dustwipe measurements less than 250 µg/ft^2 were 53%, 38%, and 31% respectively for intact, minor, and deteriorated windows. Postcleaning windowsill geometric mean lead loadings were reduced on average by 61%, 75%, and 67% respectively for intact, minor problem, and deteriorated. Postcleaning loadings were still less than 250 µg/ft^2 in 68% of the homes with intact windows, 55% with minor problems, and 46% with deteriorated windows. There was no statistically significant difference in the percent reductions between centers.

Windowsill cleaning was more effective (74% reduction; 95% CI, 61–83%) in the 84 homes with precleaning dust-lead loadings above the U.S. EPA clearance standards (windowsill, window well, or either floor samples) compared to the 35 homes below the clearance standard (35% reduction; 95% CI, –1 to 56%).

Window well dustwipe measurements were collected in 33 homes in Baltimore before and after environmental cleanup (Table 4). Geometric mean lead loading dropped from 707 µg/ft^2 before cleaning to 53 µg/ft^2 after cleaning (93% reduction; 95% CI, 85–96%). All but one home had a reduction in window well lead dust loadings after cleaning and 89% had a reduction of one half or more. Forty-two percent of the homes had window well lead loading below 400 µg/ft^2 before and 91% after cleaning. Cleaning was equally effective for homes above and below the clearance standards before the intervention.

Discussion

The homes of the children participating in this study were generally in substandard condition. Most (83%) had peeling or chipping paint evident, and overall maintenance was characterized as fair or poor in 71%. The environmental intervention was undertaken to ensure that the child's exposure to lead dust in the home was minimized during the treatment phase of the study. Homes of 98% of the randomized children were professionally cleaned. All study children were assumed to be exposed to lead in their homes; however, they may have been exposed to unidentified sources of lead outside of the home.

The U.S. EPA established new clearance standards for lead in residential dust for floors, windowsills, and window wells in January 2001, almost 4 years after the completion of this environmental cleanup protocol. The precleaning dustwipe lead loadings for any floor or window sample were above these new U.S. EPA clearance standards for 69% of the homes sampled. The geometric mean precleaning dustwipe lead for the kitchen floor (43 µg/ft^2), playroom windowsill (308 µg/ft^2), and playroom window well (707 µg/ft^2) samples were above the clearance standard. The environmental intervention was most effective for windows, where geometric mean sill loadings were reduced by two-thirds and well loadings by more than 90%. Nevertheless, window dust lead loadings still did not meet the revised U.S. EPA clearance standards after the environmental intervention for 38% of the windowsill and 9% of the window well samples.

Overall, cleaning was most effective at the clinical centers with the most experience with lead dust removal (Baltimore and Cincinnati). Cleaning effectiveness—as assessed by the percent reduction in dust loading or by the fraction of homes above the clearance standard—was greater in homes with higher lead loadings initially. Random measurement error would produce a reduction in mean of repeated dust samples among initially high-exposure homes (regression to the mean). However, this does not explain the observed overall reduction in postcleaning mean dust lead. The environmental intervention was more effective for floors that were initially above the U.S. EPA clearance standard, reducing the geometric mean levels by almost half. Cleaning made no difference for floors that initially met the U.S. EPA standard. Thirty-nine percent of the floor samples were above the clearance standard postcleaning and there was no significant improvement in the number of homes with floor samples meeting this standard after cleaning. Nevertheless, for those homes initially within the U.S. EPA standards for windows, there was a significant improvement for windowsill and well samples after cleaning. Not all postcleaning samples were collected immediately after the cleaning intervention, thus allowing time for lead dust to reaccumulate. In a stratified analysis of postcleaning samples collected on the same day as the cleaning, versus on a later day, there was no significant difference in cleaning effectiveness.

Hilts and colleagues (*37*) reported limited efficacy of repeated cleanings (every 6 weeks) with HEPA vacuums in a heavily contaminated area near a lead smelter. On average, lead loadings declined by about 50% immediately after vacuuming and the homes recontaminated within 2.5–3 weeks, indicating that more frequent vacuuming may be beneficial. In a randomized intervention trial in Jersey City, New Jersey, biweekly professional cleanings significantly reduced levels of lead dust in inner-city homes of children with low to moderate lead exposure (*38*).

In this study, initially 146 (69%) of the 213 homes with paired dustwipe samples were above the U.S. EPA clearance standards for at least one floor or window sample. After the professional cleaning 101 (69%) of these 146 homes had at least one dustwipe sample above the clearance standards. This suggests that in these inner-city homes repeated cleaning and more aggressive lead hazard reduction strategies are required to reduce environmental exposures. Although we found substantial differences in precleaning dust levels by substrate and condition, we found no differences in cleaning effectiveness by these characteristics. Moreover, professional cleaning and in-place management would not have met the current U.S. EPA clearance standards in 54% of the homes where they were applied. These interim control measurements are no substitute for abatement and other long-term strategies to remove sources of lead exposure. In Baltimore, houses that received new replacement windows, floor treatments to make them smooth and more easily cleanable, and other repairs besides professional cleaning were more likely to meet current recommended clearance standards (*10*). Other long-term strategies include encapsulation or removal of lead-based paint according to published protocols (*25,28*).

Dust lead loadings were significantly reduced in a cohort of children living in inner-city housing with a thorough lead dust cleaning intervention. What remains unclear is how long the intervention will maintain dust lead at reduced levels and what effect, if any, the reduction of dust lead will have on blood lead levels in the short and long terms. The level of maintenance required will vary on several factors, including hazard control strategy used, levels of lead in the interior and exterior dust and soil, condition and type of surfaces in home, feasibility of the intervention, and the frequency, duration, and intensity of the cleaning effort. Effective exposure reduction may be achieved only with substantial lead hazard control.

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