A Pilot Study Examining Changes in Dust Lead Loading on Walls and Ceilings after Lead Hazard Control Interventions

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The U.S. Department of Housing and Urban Development (HUD) guidelines on lead hazard control instruct contractors to clean floors, windows, walls, ceilings, and other horizontal surfaces to remove lead-contaminated dust and debris after lead interventions are conducted. This dust removal activity adds costs to each project. The need to clean floors and windows is well documented in the HUD guidelines. However, there is substantially less documentation to support the recommendation to clean walls and ceilings. We examined whether it is necessary to clean walls and ceilings after lead hazard control (LHC) interventions by comparing dust lead loadings measured on these surfaces before an LHC intervention to dust lead loadings after the intervention. Twenty-two dwelling units undergoing substantial LHC measures consistent with the HUD guidelines were enrolled in the study. There was a significant increase in dust lead loading on walls and ceilings between the pre- and postintervention. The change in wall dust lead loading was substantial and created potentially harmful lead exposures. Although statistically significant, the change in ceiling dust lead loading was minimal and the postintervention dust lead loadings were far below the existing federal floor dust lead clearance standard. These results strongly support the recommendations in the HUD guidelines to clean walls after LHC interventions and do not provide sufficient justification to alter the current recommendation to clean ceilings after lead work. ***Key words*****: lead dust, lead hazards, lead paint, lead poisoning, wall and ceiling dust lead.**
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Children living in housing with deteriorated lead-based paint and lead in household dust are at risk of having elevated blood lead levels (*1*). Current lead hazard control (LHC) strategies are designed to control lead-based paint hazards such as deteriorated lead-based paint and lead-contaminated dust through a variety of interventions. One essential element of all lead hazard control projects is to remove lead-contaminated dust and debris by cleaning at the end of the project. Several studies have demonstrated the importance of cleaning lead-contaminated dust after lead hazard reduction work to achieve low dust lead loadings and reductions in the blood lead levels of the resident children (*2,3*). Conversely, studies have documented increases in the blood lead levels of children after LHC work when precautions are not taken to contain lead dust and debris (*4,5*).

Over a decade ago, researchers (*3*) concluded that

> if, in our zeal to remove lead-based paint, we fail to clean up after ourselves, we could be increasing the quantity of bioavailable lead in the child's environment.

A more recent comprehensive review of both published and unpublished studies examining the effectiveness of lead hazard control interventions (*6*) concluded,

> regardless of the method used, however, neither abatement nor interim control measures can be considered "safe" until the dwelling has been thoroughly cleaned and passed clearance testing.

Clearance testing includes *a*) a visual assessment of a dwelling unit to ensure that LHC activities were completed and that no dust or debris is present, and *b*) the collection of dust lead loading samples to assure that the levels are below applicable standards. Collectively, these studies led the Department of Housing and Urban Development (HUD) in its Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing (HUD guidelines) (*7*) to recommend that upon completion of LHC interventions, contractors perform cleaning procedures necessary to meet dust clearance levels on floors, window sills, and window troughs. The HUD guidelines also recommend that contractors thoroughly clean all walls, ceilings, and other horizontal surfaces (e.g., kitchen counters).

Although there is clear evidence to support the need to clean floors and windows after lead interventions, less is known about the amount of lead-contaminated dust that adheres to walls and ceilings after such work. We undertook this pilot study to characterize dust lead loading on walls and ceilings before LHC activities and immediately after such an intervention but before cleaning or repainting. The study evaluated whether dust lead loading on walls and/or ceilings increased substantially because of the LHC intervention. Postintervention dust lead loadings were also compared to applicable federal standards and thresholds to assess if these lead loadings represented a health hazard warranting dust removal. We also examined the effectiveness of several streamlined cleaning techniques aimed at reducing lead dust loading on walls and ceilings after lead hazard control interventions.

Methods

Dwelling units enrolled. Twenty-two dwelling units in the state of Vermont were enrolled in the study. All study dwelling units underwent LHC work supported by a grant from the HUD Lead-Based Paint Hazard Control grant program (*8*) and participated in the national evaluation of this grant program. The Evaluation of the HUD Lead-Based Paint Hazard Control Grant program is the largest and most comprehensive study of lead hazard control in housing ever initiated. The overall purpose of the evaluation is to measure the relative cost and effectiveness of the various methods used by state and local governments grantees to reduce lead-based paint hazards in housing. Data collection began in 1994 and is still continuing. Additional information on the evaluation can be found on the HUD web site (*8*). The Vermont Housing and Conservation Board (Montpelier, VT) managed the work. All 22 dwelling units underwent lead hazard control interventions designed to make the dwelling unit lead-safe (i.e., all lead-based paint hazards as defined by the HUD guidelines were controlled or eliminated).

Units undergoing LHC work between February 1996 and April 1997 were enrolled in the study if:

- Substantially deteriorated lead-based paint ($\geq$ 2 ft^2) or lead-contaminated dust on floors, window sills, or window troughs was identified during preintervention sampling. Federal guidelines (*7,9*) set thresholds for lead-contaminated dust at levels $\geq$ 100 µg/ft^2 for floors, $\geq$ 500 µg/ft^2 for window sills, and $\geq$ 800 µg/ft^2 for window troughs.

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- Window replacement or window treatment in combination with paint stabilization was performed to control the lead-based paint hazards. Paint stabilization is the process of repainting surfaces coated with lead-based paint that includes the proper removal of deteriorated paint and priming. Window treatment entails eliminating friction and impact surfaces on windows through the removal of paint or the enclosure of certain window components.

Preintervention data collected. We obtained baseline data on the housing characteristics of each dwelling unit and the resident household through a questionnaire at the time of enrollment. Data were also collected on the types and costs of LHC work and general rehabilitation work conducted subsequent to the lead work.

We measured paint lead loading on walls, ceilings, and other building components using an X-ray fluorescence analyzer. Before the intervention, we obtained dust wipe samples to measure lead loading from the floors, window sills, and window troughs. We collected floor dust samples in one to three of the following locations: interior entry, kitchen, child's playroom (or living room), or youngest child's bedroom (or smallest bedroom). Window samples (sill or trough) were collected in one to three of the following locations: kitchen, child's playroom or living room, youngest child's bedroom, or next youngest child's bedroom (*10*). One composite wall and one composite ceiling sample were collected in one room where preparation for paint stabilization and window replacement or treatment was scheduled to take place. Each composite consisted of four dust wipe subsamples. We collected ceiling subsamples in each of four quadrants. One wall subsample was collected from the midpoint of each of the four walls, at approximately 3–4 ft off the ground. Samples were not collected from surfaces with deteriorated paint, surfaces that might be damaged by sampling, or from walls slated for demolition during the lead hazard work. In these cases, the subsample was collected from an area of the wall with intact paint nearest the specified sample location.

Description of lead hazard control work. Surface preparation for paint stabilization occurred in all study dwelling units. This entailed wet scraping and sanding areas of deteriorated paint and preparing surfaces for repainting. Windows were either replaced or treated to eliminate lead-containing surfaces that were subject to friction or impact. Treatment involved removing paint or enclosing certain window components (e.g., covering window troughs with aluminum coil stock). Contractors removed visible debris during daily cleaning activities; however, no special efforts were made to clean walls and ceilings. In 11 dwelling units, general rehabilitation work was conducted immediately after the lead hazard control work. All units met dust clearance standards used by the HUD Lead Hazard Control Grant Program (*8*) before residents were allowed to occupy the unit. The HUD program required that dust lead loadings be below 100 µg/ft^2 on floors, 500 µg/ft^2 on window sills, and 800 µg/ft^2 on window troughs (*7*).

Postintervention data collected. We measured dust lead loading on walls and ceilings after the lead intervention. A different sampling protocol was followed for the 11 dwelling units where only LHC work occurred versus the 11 dwelling units that also underwent subsequent general rehabilitation. In the 11 dwelling units where only LHC work occurred, the contractor was required to remove visible debris to pass a visual clearance before the postintervention dust samples were collected. Dust containment measures remained in place (e.g., plastic on floors) and walls and ceilings were not cleaned before collecting the postintervention dust samples. The lead loading measured in these dwelling units provides useful information about the amount of lead-contaminated dust that adheres to walls and ceilings during the lead interventions.

In the remaining 11 dwelling units, general rehabilitation work occurred immediately after the lead hazard control work. General rehabilitation activities began once the dwelling unit had undergone a general cleaning and passed a visual assessment (i.e., no visible dust or debris). The general cleaning included some cleaning of walls and ceilings. Two cleaning methods were used by contractors to remove dust: wiping surfaces with a feather duster misted with trisodium phosphate (TSP) and vacuuming surfaces with a machine equipped with a high-efficiency particulate air (HEPA) filter. Technicians collected dust lead loading measurements after this cleaning occurred and before the general rehabilitation activities began. Because cleaning occurred, the lead dust loading observed in these dwelling units is not representative of the immediate postintervention lead loading after LHC interventions. However, the data are useful to explore the potential effectiveness of alternative and relatively streamlined cleaning methods for removing lead-contaminated dust.

We collected postintervention samples at least 1 hr, but not longer than 3 days, after the LHC work was completed. One composite dust sample was collected in the study room from the walls and one composite sample was collected from the ceilings. Technicians followed the same protocol used to collect preintervention samples.

Laboratory analyses of dust samples. We submitted dust samples to a laboratory recognized by the U.S. Environment Protection Agency (EPA) under the National Lead Laboratory Accreditation Program (NLLAP) for analysis. To be recognized by the EPA under the NLLAP, laboratories participate in the Environmental Lead Proficiency Analytic Testing (ELPAT) program and are accredited and audited by the American Industrial Hygiene Association (AIHA; Fairfax, VA). Although the laboratory used in this study successfully participates in the ELPAT program, its accreditation is for single surface wipes only. Currently, there are no programs accredited for the analysis of composite wipe samples.

In this study, composite wipe samples were taken on walls and ceilings and single surface wipe samples were taken on floors, sills, and troughs. Composite dust samples were digested using a modified version of EPA method SW-846 (*11*). We analyzed sample digestates by flame atomic absorption. The detection limit was < 2 µg/sample for composite wipes and 10 µg/sample for single wipes. Quality control consisted of submitting single wipe and composite wipe blind blank samples and blind samples spiked with known quantities of lead to the laboratory. During this study's sample analysis period, the laboratory was also analyzing single wipe samples from the national evaluation. The national evaluation quality control (QC) criteria (*10*) state that during a period of time, the vast majority of analyzed QC samples must fall between 80 and 120% recovery. The laboratory achieved a recovery rate of 80–126% for the spiked single and composite samples.

Results

Preintervention dwelling unit characteristics and conditions. Seventeen dwelling units were constructed before 1910, and the remaining five dwelling units were constructed between 1910 and 1919. Eighteen of the dwelling units were in buildings with three or more dwelling units, three were duplexes, and one was a single-family home. Fifteen of the dwelling units were occupied and seven were vacant at the time of the preintervention assessment.

Lead-based paint (defined as paint with lead levels ≥ 1 mg/cm^2) was present in all of the dwelling units and 95% of these units had substantially deteriorated (≥ 2 ft^2) lead-based paint. Median dust lead loadings were 22 µg/ft^2 for bare floors, 21 µg/ft^2 for carpeted floors, 266 µg/ft^2 for window sills, and 5,455 µg/ft^2 for window troughs. As shown in Table 1, we found lead-contaminated dust in excess of the current federal guidelines (*7,9*) in all window troughs, 50% of the window sills, 36% of the bare floors, and 9% of the carpeted floors. Standards recently proposed by the EPA (*12*) would lower the threshold for hazardous levels of lead-contaminated dust on window sills and floors. Applying these proposed standards to the preintervention data increased the number of dwelling units with at least one sample in excess of the standard (Table 1). Dwelling unit conditions were similar among dwelling units, regardless of whether general rehabilitation work was slated to follow the lead work.

Preintervention study room conditions. Lead-based paint was present in all study rooms and 58% of the study rooms had substantially deteriorated (≥ 2 ft^2) lead-based paint. The majority of the walls were in good condition (77%) and 86% of the ceilings were in good condition (i.e., < 0.5 ft^2 deteriorated paint). Twenty-three percent of the ceilings had lead-based paint and 5% of the ceilings had substantially deteriorated lead-based paint. Twenty-five percent of the walls had lead-based paint; however, none of this paint was substantially deteriorated. We measured paint lead loading on walls, ceilings, windows, trim/doors, and other surfaces in each study room. We calculated the mean paint lead loading for each type of building component in each room. Table 2 presents descriptive statistics for the mean paint lead loading by component system.

The median wall and ceiling dust lead loading were 3.5 and 2 µg/ft^2, respectively. The maximum loading was also low, 17 µg/ft^2 for walls and 9 µg/ft^2 for ceilings. Although there is no federal standard for lead dust hazards on these surfaces, the loadings are far below the most stringent existing hazard threshold for lead-contaminated dust on any surface (i.e., HUD has established 40 µg/ft^2 as its standard for lead dust hazards on floors in federally assisted housing (*13*) (Tables 3 and 4).

Lead hazard control interventions. Window treatments (either window replacement or window repairs) in conjunction with preparation for paint stabilization or enclosure occurred in all 22 study dwelling units. The mean lead hazard control cost was $4,878, with costs ranging from $1,663 to $11,774. All walls and ceilings were in good condition after the lead intervention.

Postintervention dust lead loading in dwelling units with no cleaning. There was a significant increase in dust lead loading on walls from pre- to post-LHC intervention (Wilcoxon signed rank $p < 0.001$). The median increase on walls was 32 µg/ft^2. The maximum preintervention wall lead loading was 17 µg/ft^2; the maximum postintervention lead loading was 243 µg/ft^2 (Table 3). Figure 1 presents a frequency distribution of postintervention dust lead loading on walls. The increase in dust lead loading on ceilings after the lead intervention was also statistically significant; the median increase was 1 µg/ft^2 (Wilcoxon signed rank $p = 0.008$). Tables 3 and 4 present descriptive statistics for dust lead loading on walls and ceilings before and after the lead interventions.

Postintervention dust lead loading in dwelling units with limited cleaning. In 11 dwelling units, the walls and ceilings were cleaned to remove visible dust and debris after the LHC work. Two general cleaning methods were used by contractors to remove dust. In five units, surfaces were wiped with a feather duster misted with TSP. In six units, surfaces were vacuumed using a machine equipped with a HEPA filter.

Wall dust lead loading measured after these cleaning efforts is presented in Table 3. Based on a Wilcoxon signed rank test, we concluded that there was no significant difference in the change in dust lead loading from preintervention to postcleaning be-tween the two cleaning procedures on walls ($p = 0.783$) and ceilings ($p = 0.168$). Hence, the two cleaning groups were combined (Tables 3 and 4).

Using this combined model, we observed a significant increase in dust lead loading on walls from pre- to postintervention (median 4

Table 1. Preintervention median dust lead loading and number of dwelling units that exceed current[a] and proposed[b] dust lead standards.

Sample type	Dwelling units (*n*)	Median dust loading (µg/ft^2)	Dwelling units with at least one sample exceeding federal standards: Current (%)	Proposed (%)
Bare floor	22	22	36	41
Carpeted floors	11	21	9	18
Window sills	22	266	50	55
Window trough	22	5,455	100	NA

[a]Current standards in EPA (*9*) and HUD (*7*) guidelines are 100 µg/ft^2 for floors, 500 µg/ft^2 for window sills, and 800 µg/ft^2 for window troughs. [b]The EPA proposed hazard identification standards (*12*) are 50 µg/ft^2 for bare floors and 250 µg/ft^2 for window sills. No standards were proposed for carpeted floors or window troughs. Although no standard was proposed for carpeted floors, the current bare floor standard was applied to these surfaces (*9*).

Table 2. Preintervention paint lead loading (mg/cm^2) in study rooms.

Component system	Rooms (*n*)	Minimum	25th percentile	Median	75th percentile	95th percentile	Maximum
Walls	20	< 0.1	< 0.1	< 0.1	0.9	12.4	19.3
Ceiling	22	< 0.1	< 0.1	< 0.1	0.9	8.3	18.3
Window	22	0.2	1.5	3.7	8.9	20.2	24.6
Trim/door	22	< 0.1	0.1	0.4	6.3	15.4	16.5
Other	12	< 0.1	0.1	0.4	1.6	11.1	11.1
All	22	0.1	0.6	2.3	6.6	13.4	15.8

Table 3. Wall dust lead loading (µg/ft^2) before and after lead hazard control interventions.

Phase	Cleaning procedure	Samples (*n*)	Min	25th percentile	Median	75th percentile	95th percentile	Max	SD
Preintervention	Cleaning	11	2	3	4	6	7	7	1.7
Postintervention	Cleaning	11	1	3	9	13	28	28	9.1
Change[a]	Cleaning	11	-3	0	4	7	22	22	8.3
Preintervention	No cleaning	11	1	2	2	10	17	17	5.7
Postintervention	No cleaning	11	13	21	49	86	243	243	76.6
Change[a]	No cleaning	11	-1	16	32	85	241	241	79.1
Preintervention	All	22	1	2	3.5	6	14	17	4.1

Abbreviations: max, maximum; min, minimum.
[a]Change represents the difference in dust lead loading in a study room. Pre- and postintervention samples were matched to determine the change.

Table 4. Ceiling dust lead loading (µg/ft^2) before and after lead hazard control interventions.

Phase	Cleaning procedure	Samples (*n*)	Min	25th percentile	Median	75th percentile	95th percentile	Max	SD
Preintervention	Cleaning	11	1	1	4	5	9	9	2.4
Postintervention	Cleaning	11	1	2	3	7	13	13	3.6
Change[a]	Cleaning	11	-5	-3	-1	6	7	7	4.3
Preintervention	No cleaning	10	1	1	1	2	3	3	0.7
Postintervention	No cleaning	10	1	2	2.5	5	26	26	9.6
Change[a]	No cleaning	10	0	0	1	3	24	24	9.5
Preintervention	All	21	1	1	2	4	9	9	2.1

Abbreviations: max, maximum; min, minimum.
[a]Change represents the difference in dust lead loading in a study room. Pre- and postintervention samples were matched to determine the change.

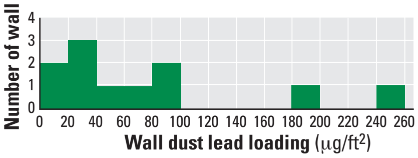

Figure 1. Frequency distribution of postintervention dust lead loading on walls (no cleaning).

µg/ft^2; Wilcoxon signed rank p = 0.010). No significant increase was observed on ceilings (Wilcoxon signed rank p = 0.163). In fact, we found a decrease of 1 µg/ft^2.

Discussion and Conclusions

The data from this study demonstrate that wall and ceiling dust lead loadings before LHC interventions are generally lower than the dust lead loading on either floors or window sills in the same dwelling units. Even in dwelling units with hazardous levels of lead-contaminated dust, wall and ceiling lead loadings are generally low. The median wall lead loading was 3.5 µg/ft^2 (range 1–17 µg/ft^2) and the median ceiling lead loading was 2 (range 1–9 µg/ft^2) in study dwelling units even though 36% of bare floors and 50% of window sills sampled had dust lead loadings that exceed thresholds in the HUD guidelines (*7*). The SD was 4.1 µg/ft^2 for walls and 2.1 µg/ft^2 for ceilings (Tables 3 and 4). This low SD suggests consistent dust lead loading on these surfaces.

Lead dust loading observed after lead hazard interventions indicates that such work (i.e., window replacement or treatment in conjunction with surface preparation for paint stabilization) can substantially increase dust lead loading on walls. Although there is no current standard to evaluate the health risk posed to young children from exposure to lead-contaminated dust on walls, these results strongly suggest that the lead hazard control work performed in this study could place children at increased risk for exposure to lead. Several exposure scenarios are possible. Lead dust on walls could fall to the floor, where a young child is likely to crawl or where it would come in contact with toys. A child could also touch walls during daily activities. In both scenarios a child's hands or toys can become contaminated with lead dust and ingestion of lead-contaminated dust is likely because young children often put their hands and toys in their mouths.

We used the floor lead hazard standard as one possible reference point because of the lack of a lead hazard standard for walls or ceilings and because of the possible exposure scenarios for children. This comparison is conservative because it is unlikely that a child's exposure to lead dust on walls or ceilings would be as intense as exposure on floors, where crawling and play activities occur. The current EPA threshold for lead dust hazards on floors is 100 µg/ft^2 (*9*) and the agency's proposed hazard standard is 50 µg/ft^2 (*12*). The recently promulgated HUD regulations for lead hazard evaluation and control in federally assisted housing established a standard of 40 µg/ft^2 (*13*).

The median increase in dust lead loading on walls in units that were not cleaned after the intervention was 32 µg/ft^2. The maximum postintervention lead loading on walls in these units was 243 µg/ft^2, representing a 241-µg/ft^2 maximum increase in dust lead loading. This level is approximately 2.5 times the current EPA threshold for floors (100 µg/ft^2) and 6 times greater than the new HUD standard for lead-contaminated dust hazards on floors in federally assisted housing (40 µg/ft^2) (*13*). The increase in lead loading occurs across the distribution of the data. Even at the 25th percentile, the increase in dust lead was 16 µg/ft^2 and the maximum was 21 µg/ft^2 (Table 3).

The study results document a striking increase in lead-contaminated dust on a surface that is accessible to young children. The observed increased in lead loading on walls, considered in conjunction with recent research suggesting the harmful health consequences of dust lead loadings previously considered safe (*14*), support the current HUD guideline (*7*) recommendation to clean walls after LHC. Although it is possible that subsequent repainting of walls could make the lead-contaminated dust less accessible to children, data were not collected to explore this possibility. Even if trapped lead-contaminated dust was repainted, exposure to lead in dust could still occur between the time the LHC work took place and the final repainting was completed.

Although the increase in dust lead loading on ceilings was also statistically significant, the change may not be practically significant because the postintervention lead loading is very low. The postintervention median ceiling lead loading (3 µg/ft^2) is less than one-thirtieth of the EPA current threshold for lead-contaminated dust on floors (100 µg/ft^2) (*9*) and less than one-tenth of the proposed EPA standard of 50 µg/ft^2 (*12*) or the recently promulgated HUD standard of 40 µg/ft^2 for lead hazard control in federally assisted housing (*13*). However, given the small sample size and the range of postintervention dust lead loading on ceilings, the data are not sufficient to justify eliminating the current recommendation in the HUD guidelines to clean ceilings (*7*).

The study results also suggest that although it is likely that substantial increases in dust lead loading can be observed on walls after lead hazard control work, cleaning techniques that are less extensive than those currently recommended in the HUD guidelines (*7*) can reduce this loading. The HUD guidelines recommend a three-step cleaning process—vacuum with a machine equipped with a HEPA filter, wet wash with a detergent, and vacuum with a HEPA-filtered vacuum. The maximum dust lead loading on walls after simple cleaning procedures was 28 µg/ft^2, whereas the maximum lead loading on walls that were not cleaned was 243 µg/ft^2. The cleaning method in this study involved either vacuuming with a HEPA-filtered machine or wiping down the wall with a feather duster misted with TSP.

Given the small sample size and wide range of possible cleaning protocols, additional research is needed to document the effectiveness of low-cost cleaning techniques that reduce lead-contaminated dust on walls and ceilings to acceptable levels.

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