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Cleaning Efficacy of High-Efficiency Particulate Air-Filtered Vacuuming and “Dry Steam” Cleaning on Carpet

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Previous studies for lead exposure reduction have indicated the difficulty in reducing surface contamination of carpets with the use of regular vacuum cleaners. To find a solution, a household vacuum cleaner equipped with a high-efficiency particulate air (HEPA) filter and a dust finder indicator, and a “dry steam” cleaner previously reported effective in reducing dust mite allergens in carpets and mattresses were tested for effectiveness in reducing lead dust in carpets. Fifty homes of lead-exposed children were tested in New Jersey. A selected carpet in the living area of each home was tested with two interventions: half was cleaned by HEPA vacuuming twice (VAC-VAC) and the other half by dry steaming between the two HEPA vacuumings (VAC-DSC-VAC). Wipe and vacuum samples, representing surface dust and total dust collections, respectively, were taken before and after cleaning. The wipe and vacuum sample data indicated that both cleaning methods substantially reduced dust lead levels ($p < 0.001$). The mean percent reductions in lead loading were approximately 29% and 40% for the VAC-VAC and VAC-DSC-VAC interventions, respectively. The difference between the two postcleaning levels was statistically significant by wipe sampling ($p = 0.038$) but was marginally insignificant by vacuum sampling ($p = 0.072$). A subset of sample data collected before repeat vacuuming (VAC-DSC) suggested that repeat vacuuming after dry steam cleaning is unnecessary. In summary, slow and steady HEPA vacuuming with the help of a dust finder indicator reduces surface and overall lead dust in carpets, and dry steam cleaning further reduces surface lead contamination as compared with HEPA vacuuming alone.

Keywords carpet, HEPA, lead dust, steam cleaning, vacuum, wipe, sampling

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INTRODUCTION

In many urban areas of the United States, carpeted flooring stores large amounts of dust contaminated with lead and

other chemical substances,^(1–3) which are easily ingested by young children through the hand-to-mouth pathway. Contaminated house dust is considered a major source of childhood lead exposure because dust lead has been strongly associated with blood lead.^(4–11) To reduce residential exposure to lead dust embedded in carpets, appropriate carpet care is very important. Contaminated carpet, unfortunately, is not cleaned effectively due to difficulty removing dust from within the carpet pile (e.g., small particulate matter adheres to carpet fibers by electrostatic forces). With inadequate use of vacuum cleaners (e.g., infrequent use, poor implementation, failure to change vacuum bags and filters) or lack of ownership, dust accumulates over time, making carpet cleaning even more difficult.

A pilot study showed that repetitive vacuuming failed to reduce dust lead levels in the carpet significantly;⁽¹²⁾ several others demonstrated significant dust lead reductions,^(2,3,13) but the cleaning effectiveness had no effect on reductions in children's blood lead levels.^(13–15) A cleaning intervention study provided a reasonable explanation by showing that cleaning efficacy demonstrated by vacuum sampling was not achieved by surface wipe sampling.⁽¹⁶⁾

The study revealed that levels of lead dust deposited on the carpet surface (collected by the wipe sampling method) were not significantly lowered despite significant reduction for total lead dust from within the carpet (shown by the vacuum sample data). Thus, even after carpets were vacuumed recently, the surface lead remained as a source of lead exposure to young children. A cleaning method aiming at significantly reducing lead dust from the surface of carpet as well as within the pile is needed to reduce childhood lead exposure in the home.

Shampooing is considered the most intensive form of carpet care. However, professional cleaning aside, carpet shampooing using household hot water extraction cleaners has not been efficacious for lead reduction; instead, it allows the accumulation of additional contaminants that adhere to the carpet because of the wet surface.⁽¹⁷⁾ On the contrary, a “dry

steam" cleaner, used after regular vacuuming in an intervention study for asthmatic patients, further reduced levels of dust mite allergens in the carpet.⁽¹⁸⁾

The hot vapor injected into the carpet pile was believed to kill the mites and soften the dust, and an attached towel, acting like a mop, removed the loose dust from the surface. The carpet was reported to dry within 15 min; thus, concerns over the wet surface attracting dust were lessened. Based on these advantages, this technique was employed to reduce lead contamination in household carpets, and its effectiveness in comparison to vacuuming alone was evaluated.

METHODS

Cleaning protocol steps suggested by the U.S. Department of Housing and Urban Development (HUD) were used for interim control in housing of lead-based paint hazards⁽¹⁹⁾ (vacuuming-wet wash-repeat vacuuming) to test the efficacy of dry steam cleaning, which was in place of "wet wash." Thus, two cleaning protocols were applied on the same carpet for comparison: half was cleaned by a high-efficiency particulate air (HEPA) filtered vacuum cleaner only, and the other half was cleaned using a dry steam cleaner in addition to the same HEPA vacuuming.

Two pieces of cleaning equipment were used: (1) a Hoover upright HEPA vacuum cleaner with a dust finder indicator (U6446-900; Maytag Corp., Newton, Iowa), and (2) a dry steam cleaner (VaporJet 2400; VaporJet Technologies, Sandy, Utah). One study⁽³⁾ suggested that this type of HEPA vacuum cleaner would be effective in carpet cleaning. Its dust finder indicator detects the rate at which particles pass through a detector in the airstream and is equipped with red and green lights that indicate a rate of collection above and below, respectively, a preset threshold. The dry steam cleaner, used

in an intervention study for asthma,⁽¹⁸⁾ generated and ejected approximately 96% steam vapor of 212°F (100°C) from the cleaning head.

When in use, the cleaning head, tightly wrapped with a towel, was firmly pressed onto the carpet and steadily moved back and forth to let the attached towel pick up the loosened dust. When the contact side of the towel was soiled, the towel was rewrapped with a cleaning side in place. With the assistance of local health departments, participating homes were recruited from residences of lead-exposed children (blood lead levels >10 µg/dL) in northern New Jersey. The recruitment method and study protocols were approved by the Institutional Review Board of the University of Medicine and Dentistry of New Jersey. The eligible homes had at least one wall-to-wall carpet or area rug not smaller than 8 ft × 10 ft (2.44 m × 3.05 m). Fifty homes with one carpet tested per household were completed.

Testing was conducted following the procedures shown in Figure 1. Dust samples were collected by a wipe method (ASTM E1728-03)⁽²⁰⁾ and by a canister vacuuming method using a 2.78-ft² (~0.26 m²) template⁽²¹⁾ to evaluate the effectiveness of carpet cleaning on the surface and throughout the pile, respectively.⁽²²⁾ The location of precleaning sampling was chosen to cross the dividing line between two cleaning assignments so that any sampling bias would be minimal. When cleaning, the entire carpet was first vacuumed using the HEPA vacuum cleaner.

The vacuuming was performed twice in perpendicular directions until the dust finder indicator turned green over all sections of the rug, indicating the completion of dust removal. After vacuuming, the carpet was divided into two equal halves, and the left half was cleaned with a dry steam cleaner. After at least 15 min for drying, repeat vacuuming was performed over the entire carpet following the same HEPA vacuuming protocol. The purpose of repeat vacuuming was to pick up any remaining loose dust after dry steam cleaning.

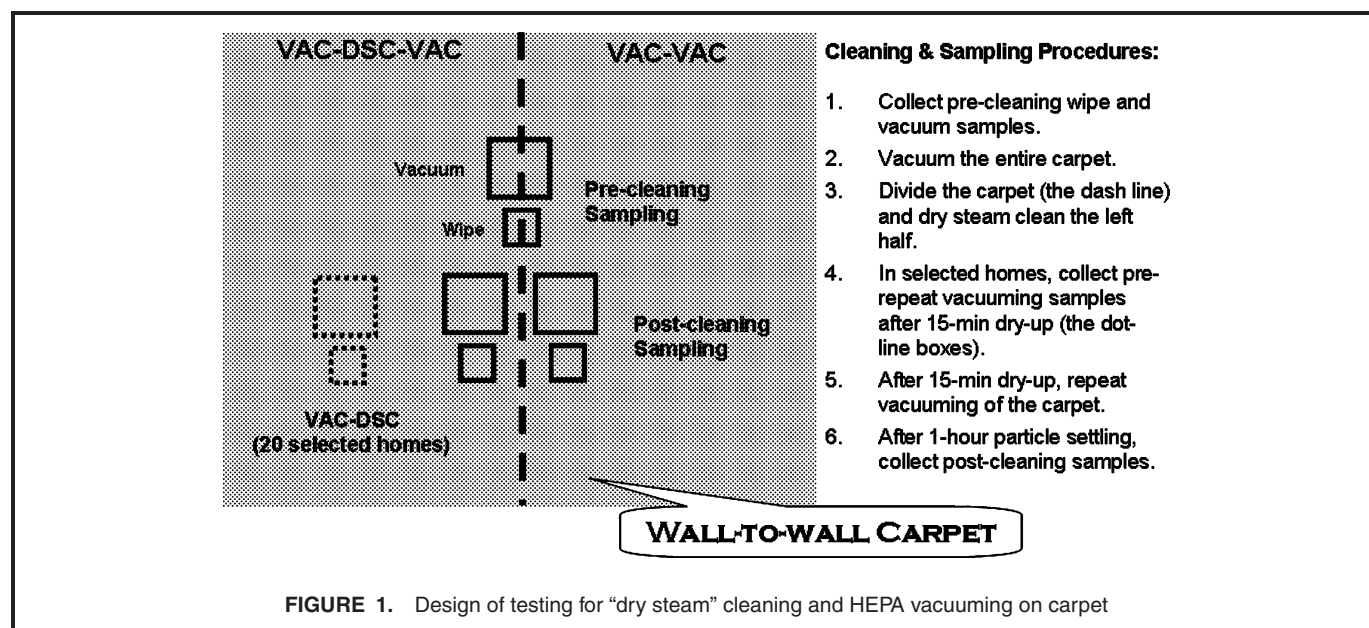


FIGURE 1. Design of testing for "dry steam" cleaning and HEPA vacuuming on carpet

TABLE I. Correlations Between Lead Loadings Derived from Wipe and Vacuum Sampling Methods

Cleaning Status	No. of Pairs	r	p
Precleaning (PRE)	50	0.75	<0.001
Postcleaning (VAC-VAC)	50	0.77	<0.001
Postcleaning (VAC-DSC-VAC)	50	0.59	<0.001

With these procedures, the left half of the carpet was cleaned in the sequence of vacuuming, dry steam cleaning and repeat vacuuming (VAC-DSC-VAC), and the right half with vacuuming and repeat vacuuming (VAC-VAC). To allow any suspended dust to settle, postcleaning sampling was performed 1 hr after the repeat vacuuming, as suggested by the HUD Guidelines.⁽¹⁹⁾ Postcleaning samples were collected for each of the two cleaning methods from nonoverlapping locations adjacent to the precleaning sampling location.

A subset of extra postcleaning samples was taken before repeat vacuuming in 20 out of 50 homes to evaluate the efficacy without repeat vacuuming. The second, fifth, seventh, and tenth of every 10 homes were assigned for the extra sampling. Duplicate samples were taken in 1 out of 10 houses for reproducibility check. Wipe and vacuum samples were digested with nitric acid in a microwave oven (MDS 2000; CEM Corp, Matthews, N.C.), and analyzed by graphite furnace atomic absorption spectrometer (Zeeman 5100; Perkin Elmer, Norwalk, Conn.).

Lead loading ($\mu\text{g}/\text{ft}^2$ or mg/m^2), which was widely used as index in exposure assessments of residential lead contamination,⁽²³⁾ was calculated to evaluate the cleaning efficacy, while lead concentration ($\mu\text{g}/\text{g}$) was derived to assess lead content in dust. All results were above the limits of detection of $0.5 \mu\text{g}/\text{ft}^2$ ($5.37 \times 10^{-3} \text{ mg}/\text{m}^2$) for lead loading and $1 \mu\text{g}/\text{g}$ for lead concentration. Details of sample analysis have been previously published.⁽¹⁶⁾

Both vacuum and wipe samples were identified carefully and stratified as PRE (before cleaning), VAC-VAC (after repeat HEPA vacuuming), and VAC-DSC-VAC (after initial

vacuuming, dry steam cleaning, and follow-up vacuuming). Paired t-tests were used to compare lead loadings between any two strata of the three. Pearson correlation analyses were conducted to find the associations between dust sampling methods. Lead loading data were log-transformed prior to any statistical tests due to the skewed shape of distribution, and the transformed data were found to be normal using Kolmogorov-Smirnov test ($p > 0.05$).

RESULTS

There were significant correlations between the wipe and vacuum sampling methods for pre/postcleaning, suggesting that both methods vary consistently with each other (Table I). The moderate correlation coefficients, however, reflected that the two methods showed dust lead levels in different extents (i.e., wipe sampling standing for surface dust collection and vacuum sampling for total dust sampling), as stated by Bai et al.⁽²²⁾

The duplicate samples showed very good agreement ($r > 0.9$, data not shown), indicating the consistency of sampling and spatial distribution of dust. Among the 50 recruited homes, high lead content in carpet dust ($>400 \mu\text{g}/\text{g}$) was detected in approximately half of them, and a high mean lead loading ($223 \mu\text{g}/\text{ft}^2$ or $2.40 \text{ mg}/\text{m}^2$, Table II) was observed from the dwellings, indicating that those houses were of concern with lead exposure and suitable for testing. Both cleaning protocols, repeat HEPA vacuuming (VAC-VAC), and HEPA vacuuming plus dry steam cleaning (VAC-DSC-VAC), resulted in significant reductions in lead loading ($p < 0.001$) (Table II), indicating that intensive vacuuming assisted by a dust finder indicator would reduce lead contamination.

The addition of dry steam cleaning removed further lead dust from the surface ($p = 0.038$, by wipe sampling) as well as from within the carpet pile ($p = 0.072$, by vacuum sampling); however, the latter was marginally insignificant. Based on both wipe and vacuum sampling, mean percent reductions from the baseline levels were approximately 29% and 40% for the VAC-VAC and VAC-DSC-VAC assignments, respectively. In contrast to wipe sample results, the vacuum

TABLE II. Pre- and Postcleaning Lead Loadings ($\mu\text{g}/\text{ft}^2$) for Carpet Cleaning Techniques by Wipe and Vacuum Sampling Methods

Cleaning Status	No.	GM	GSD	Mean Percent Reduction (95% CI)	p (vs. PRE)	p (vs. VAC-VAC)
Wipe Sampling						
PRE	50	9.43	3.4	—	—	—
VAC-VAC	50	5.65	3.7	29.4 (17.3, 41.6)	<0.001	—
VAC-DSC-VAC	50	4.64	3.7	40.4 (30.1, 50.8)	<0.001	0.038
Vacuum Sampling						
PRE	50	223	7.3	—	—	—
VAC-VAC	50	98.0	7.4	29.5 (3.0, 56.1)	<0.001	—
VAC-DSC-VAC	50	75.6	8.5	38.9 (19.6, 58.3)	<0.001	0.072

Notes: GM = geometric mean; GSD = geometric standard deviation; CI = confidence interval.

TABLE III. Subset of Lead Loadings ($\mu\text{g}/\text{ft}^2$) with Extra Testing for Dry Steam Cleaning Without Repeat HEPA Vacuuming

Cleaning Status	No.	GM	GSD	p (vs. VAC-VAC)	p (vs. VAC-DSC)
Wipe Sampling					
VAC-VAC	20	5.23	2.9	—	—
VAC-DSC	20	4.31	3.2	0.135	—
VAC-DSC-VAC	20	3.90	3.5	0.029	0.480
Vacuum Sampling					
VAC-VAC	20	79.3	6.8	—	—
VAC-DSC	20	57.1	7.0	0.177	—
VAC-DSC-VAC	20	64.6	6.1	0.366	0.503

sample data showed more variation in percent reductions, perhaps reflecting differences in the efficiency of dust removal from within the carpet pile of different carpet types.

In 20 homes, additional dust samples (termed as VAC-DSC) were collected from the side of the rug assigned to dry steam cleaning before repeat vacuuming (Figure 1). The comparisons between VAC-DSC and VAC-DSC-VAC were not statistically significant ($p = 0.480$ by wipe; 0.503 by vacuum), indicating that repeat vacuuming did not make much difference after dry steam cleaning (Table III).

It is interesting, in comparing the VAC-VAC and VAC-DSC results for those 20 available subset data, to evaluate the effectiveness of two cleaning procedures. Calculating from the geometric means in Table III, dry steam cleaning (VAC-DSC) yielded lead loadings that were 18% (wipe sampling) and 28% (vacuum sampling) lower than those found after repeat HEPA vacuuming (VAC-VAC).

These differences are equal to or larger than those found between VAC-VAC and VAC-DSC-VAC in Table II (11% for wipe data; 9.4% for vacuum data) but do not reach statistical significance possibly due to the smaller sample size. It appears, therefore, that dry steam cleaning did improve efficacy in carpet cleaning whether or not the carpet was cleaned by repetitive HEPA vacuuming.

The characteristics of the carpets may have affected cleaning efficacy. In 50 tested carpets, there were 32 and 18 carpets identified as level-loop and cut-pile, respectively. For

wipe sample data, level-loop carpets appeared to be more "cleanable" than cut-pile carpets, regardless of the cleaning protocol used (Table IV).

The difference in mean percent reduction between VAC-VAC and VAC-DSC-VAC was little for cut-pile carpets (3.5%), suggesting that the significant difference observed in surface loadings between two cleaning protocols (11%; $p = 0.038$, Table II) was largely attributable to level-loop carpets (15.3%). Unlike the wipe sample data, the vacuum sampling method, which yielded data with more variability, did not show any effects by carpet type. The impact of carpet wear was not examined because most of the carpets were in relatively good condition.

DISCUSSION

The issue of reducing lead contamination of household carpets in contaminated homes has been a vexing one. Several studies have shown that vacuuming removes substantial amounts of lead from carpets but may fail to reduce significantly the level of lead on the carpet surface, which is most accessible by direct contact.^(2,13,16) For instance, a recent study testing a variety of vacuum cleaners at a rate of $22.5 \text{ ft}^2/\text{min}$ ($2.09 \text{ m}^2/\text{min}$) showed that each removed a substantial amount of lead dust from the lead-contaminated carpet, and that vacuum style (e.g., upright, canister) or cost was not predictive of the amount of lead removed.⁽¹⁷⁾ HUD suggests that vacuuming,

TABLE IV. Percent Reductions in Lead Loading ($\mu\text{g}/\text{ft}^2$) for Different Carpet Types by Cleaning Protocol and Method of Sampling

Cleaning Status	Mean Percent Reduction (95% CI)		
	Level Loop (n = 32)	Cut Pile (n = 18)	p
Wipe Sampling			
VAC-VAC	35.0 (17.7, 52.2)	19.5 (4.37, 34.7)	0.171
VAC-DSC-VAC	50.3 (39.7, 60.8)	23.0 (2.29, 43.7)	0.021
Vacuum Sampling			
VAC-VAC	25.7 (−13.9, 65.3)	36.3 (8.77, 63.9)	0.652
VAC-DSC-VAC	40.7 (16.6, 64.8)	35.7 (−0.18, 71.6)	0.810

as part of interim controls, should be performed no faster than 10 ft²/min (0.93 m²/min);⁽¹⁹⁾ at this rate it takes 8 min to vacuum an 8 ft × 10 ft (7.44 m²) carpeted room.

Householders may be tempted to complete their vacuum cleaning faster; however, the dust finder indicator on the vacuum is helpful in encouraging the operator to continue vacuuming as long as substantial amounts of dust are being removed. In one home, a 180-ft² (16.7-m²) carpet was vacuumed for more than 45 min before the indicator turned green (i.e., clean), and this was about two times slower than the HUD-recommended rate. The long vacuuming time performed in this study not only significantly reduced dust embedded in the carpets but also resulted in significant reductions in surface lead dust, which was not observed in a previous cleaning intervention study.⁽¹⁶⁾ This is consistent with the findings of Roberts et al.⁽³⁾ who first reported the value of the dust finder indicator in this context.

Causser et al.⁽¹⁷⁾ conducted a series of carpet cleaning experiments and reported that height and density of carpet pile and carpet wear are important factors affecting vacuuming efficacy. Causser and colleagues found that carpet factors associated with more thorough dust removal included low pile height, low pile density, and less wear. In this study's testing, level-loop carpets were usually low height but densely piled, whereas cut-pile carpets tended to have high height with lower pile density. Possibly due to these competing characteristics of "cleanability," the two types of carpets did not differ significantly in percent reduction after HEPA vacuuming (VAC-VAC) determined by the vacuum sample analysis ($p = 0.652$).

However, reduction percentages measured by the surface wipe sampling were slightly higher for level-loop carpets, although the difference did not achieve statistical significance ($p = 0.171$) (Table IV). Because level-loop carpets have higher density, there would be a reduced velocity of airflow within the carpet pile as well as increased hindrance to the physical removal of particles. These results show that dry steam cleaning further reduces lead contamination on carpets beyond the reduction achieved with HEPA vacuuming alone. This was especially true for the lead-contaminated dust on the carpet surface. It is reasonable that dry steam cleaning is more effective in reducing dust on the surface than within the pile because the cleaning head wrapped with a towel contacts the upper part of carpet pile, acting like a floor mop.

In addition, height and density of carpet pile may also limit the penetration of steam vapor and, subsequently, decrease the capacity for removing lead-contaminated dust deep in the rug. For surface cleaning on different types of carpets, level-loop carpets showed higher mean percent reductions than cut-pile carpets when cleaned by dry steam cleaner as well as HEPA vacuum cleaner (Table IV). The characteristics of level-loop carpets may be more conducive to surface cleaning because the flatter surfaces are more suitable for mopping-style dry steam cleaning.

CONCLUSIONS

In this study, the reduction of lead loading on lead-contaminated carpets by HEPA vacuuming was substantially higher than in a number of previous reports. It is likely that the application of intensive vacuuming until the dust indicator signaled completion accounted for this improvement. Dry steam cleaning, applied after HEPA vacuuming, can remove further lead dust, especially from the carpet surface. The authors recommend that these cleaning methods be considered for incorporating into interim control guidance to reduce childhood lead exposure.

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