

# Inactivation of Dust Mites, Dust Mite Allergen, and Mold from Carpet

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*Carpet is known to be a reservoir for biological contaminants, such as dust mites, dust mite allergen, and mold, if it is not kept clean. The accumulation of these contaminants in carpet might trigger allergies or asthma symptoms in both children and adults. The purpose of this study is to compare methods for removal of dust mites, dust mite allergens, and mold from carpet. Carpets were artificially worn to simulate 1 to 2 years of wear in a four-person household. The worn carpets were inoculated together with a common indoor mold (*Cladosporium* species) and house dust mites and incubated for 6 weeks to allow time for dust mite growth on the carpet. The carpets were randomly assigned to one of the four treatment groups. Available treatment regimens for controlling carpet contaminants were evaluated through a literature review and experimentation. Four moderately low-hazard, non-destructive methods were selected as treatments: vacuuming, steam-vapor, Neem oil (a natural tree extract), and benzalkonium chloride (a quaternary ammonium compound). Steam vapor treatment demonstrated the greatest dust mite population reduction ( $p < 0.05$ ) when compared to other methods. The two physical methods, steam vapor and vacuuming, have no statistically significant efficacy in inactivating dust mite allergens ( $p = 0.084$ ), but have higher efficacy when compared to the chemical method on dust mite allergens ( $p = 0.002$ ). There is no statistically significant difference in the efficacy for reducing mold in carpet ( $p > 0.05$ ) for both physical and chemical methods. The steam-vapor treatment effectively killed dust mites and denatured dust mite allergen in the laboratory environment.*

**Keywords** allergen, carpet, dust mite, mold/fungi, Neem oil, steam cleaning, vacuuming

## INTRODUCTION

Asthma is one of the top allergen-mediated chronic diseases<sup>(1,2)</sup> and house-dust mites,<sup>(1,3–9)</sup> molds,<sup>(1,5,10–14)</sup> and associated allergens are widely recognized as key contributors to the onset of asthmatic attacks, rhinitis, and atopic dermatitis. In 2010 in the United States there were approximately 25 million people who had asthma.<sup>(15–18)</sup>

Exposure to indoor allergens can increase the risk of developing an asthma-related disease,<sup>(19,20)</sup> but more and more evidence shows that allergen exposure increases exacerbation of existing asthma.<sup>(18)</sup> Carpet is widely used as floorcovering in the United States, both residentially and commercially, due to its acoustic characteristics, thermal insulation, and slip-resistant properties.<sup>(21,22)</sup> However, carpet can be a reservoir for many contaminants if not kept clean.<sup>(23)</sup> According to the National Survey of Lead and Allergens in Housing, pet allergens, such as cat and dog allergens, are among the most common carpet contaminants,<sup>(18)</sup> followed by house dust mites, dust mite allergens, bacteria, and fungi.<sup>(6,24–32)</sup> As such, it is essential to consider the potential health risk associated with exposure to carpet-sourced pollutants, specifically for people who suffer from allergen-mediated disease.

The relationship between carpet and asthma exacerbation is complex. Prior studies examining this relationship have reported conflicting results.<sup>(6,27,33–35)</sup> Researchers indicate that human activities, such as vacuuming and walking, can release and re-suspend microbes or allergens in carpet, which can trigger allergic or asthmatic reactions among sensitized children and adults.<sup>(6,24,31)</sup> Mold spores are ubiquitous, making it impossible to maintain a spore-free carpet. However, minimizing dust mite and mold levels in carpet is essential to reducing the

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allergen burden on newborn infants and young children.<sup>(32)</sup> The prevalence of high allergen burden is usually in families with lower socioeconomic status according to study by Salo et al.<sup>(18)</sup>

Minimizing carpet pollutants should reduce the risk of exposures, leading to fewer asthma and allergy exacerbations, but the best method for doing so has not been determined. Carpet pollutants could be treated using chemicals to reduce the risk of aerosolization/exposure, but residual from chemicals also raises human health concerns.<sup>(36)</sup> Therefore, it is important to find alternate solutions to minimize dust mites and mold in carpet with either non-toxic chemicals or no chemicals at all.

Mitigation techniques to control dust mite and dust mite allergens consist of either physical methods, such as vacuuming or steam cleaning, or chemical treatment with acaricides, such as benzyl benzoate,<sup>(29,37–39)</sup> disodium octaborate tetrahydrate,<sup>(40,41)</sup> and tannic acid.<sup>(8,37,42,43)</sup> Vacuuming alone or in combination with very hot water has been found to be effective at killing mites and removing allergens,<sup>(9)</sup> but some investigators have found that vacuuming removes dust mites' natural predators, cheyletus mites,<sup>(44)</sup> which produces more dust mites.<sup>(45,46)</sup> Two studies have examined the impact of steam cleaning on allergen removal from carpet. Colloff et al. found that steam cleaning reduces 87% of dust mite allergens in inoculated carpet samples, but the study did not assess actual reductions in dust mites.<sup>(47)</sup> Vojta et al.<sup>(9)</sup> reported that dry-steam cleaning plus vacuuming resulted in a significant persistent reduction in dust mite allergen that lasted for up to 8 weeks.

Approximately 20 chemical compounds have been tested for fungicidal and acaricidal activity in carpets, with varying degrees of effectiveness evident. Among the chemical compounds studied previously, two were chosen for this study based on four criteria: a) toxicity, b) potential for carpet damage, c) indoor air quality impacts and/or flammability, and d) effectiveness against fungi, dust mites, or dust mite allergens. Human epidemiological and animal studies were reviewed to determine the toxicity of each chemical. The chemicals were tested on carpet samples to assess for texture and color change in the untreated carpet.

Flammability, respiratory irritation, and odor were assessed using information from the Material Safety Data Sheets (MSDS). Chemical safety and effectiveness against fungi, dust mites or dust mite allergen were assessed using searches in Toxline and Medline databases as well as the carpet industry online journal, the *International E-Journal of Flooring Sciences*.<sup>(48)</sup> Based on a risk assessment<sup>(49–51)</sup> method, a score was assigned for each compound based on the criteria addressed. From this process, the two best candidate compounds were selected for this study: i) Neem Oil, a natural plant extract, and ii) benzalkonium chloride, a quaternary ammonium compound.<sup>(52)</sup> These two chemical compounds have a comparatively low toxicity risk, limited potential to damage carpet, and potential to kill fungi and dust mites or denature dust mite allergens. However, neither chemical treatment is

currently registered for use as a carpet pesticide. Although there is no significant epidemiological evidence, there are some case reports of benzyl ammonium chloride (BAC) acting as an asthmagen when sprayed on hard surfaces.<sup>(53–56)</sup>

The objective of this study was to examine the efficacy of four carpet treatment methods: i) vacuum, ii) steam-vapor, iii) natural plant extract (Neem oil), and iv) benzalkonium chloride (active ingredient in Lysol disinfectant spray) for deactivating dust mites, dust mite allergens, and fungi from carpet. To evaluate three general questions:

- Are green chemical-free physical methods superior to basic vacuuming?
- Are green-chemical free methods superior to select chemical method?
- Is Neem oil superior to benzalkonium chloride?

The following specific hypotheses were tested:

- Steam-vapor is more effective than vacuuming
- Steam-vapor is more effective than Neem oil or benzalkonium
- Neem oil is more effective than benzalkonium chloride.

## METHODS

Four carpet treatments were evaluated for removal of fungi, dust mites, and dust mite allergens (Der f1) from carpet. *Cladosporium* was chosen as the indicator fungal species for this study because it is one of the most common molds found in both indoor and outdoor environments<sup>(11,25,57–60)</sup> and it has easy microscopic identification due to its ubiquity and distinct morphology. *Cladosporium* species is grown on DG-18 media and is olive green in color, with a defined round shape colony after 5 to 7 days incubation at 25°C.<sup>(25,61–63)</sup> *Dermatophagoides farinae* (*D. farinae*) was chosen as the dust mite indicator for this study because it is one of the two most common species of house dust mites worldwide, and it is the species that is predominantly found in drier regions, such as the midwestern United States where this study took place.<sup>(64)</sup>

The experimental design consisted of four treatment regimens applied to carpet samples: i) vacuuming, ii) steam vapor, iii) Neem oil, and iv) benzalkonium chloride (the active ingredient contained in Lysol disinfectant spray). The outcome variables included percent reduction in fungal colony-forming units, percent reduction in dust mite counts (% mite mortality vs. control), and percent reduction in allergen concentration ( $\mu\text{g/g}$ ) compared to control carpet samples that received no treatment. A total of 60 carpet samples were prepared. Each of the 4 treatment groups was randomly assigned 10 carpet samples, and the remaining 20 samples were designated as untreated controls.

## Carpet Specification and Preparation

The carpets used in this study were nylon carpet with 3.175 mm (0.125") gauge fiber with 9.144 mm (0.36") pile height (manufactured by Shaw Industrial, Dalton, Ga.). These



**FIGURE 1.** Hexapod-carpet wearing machine

were cut into separate pieces of 20 cm by 46 cm (8" × 18"). To simulate lightly worn carpet with 1–2 years of wear in a four-person household, two carpets (20 cm x 46 cm) were artificially worn in a hexapod (Figure 1) for 2000 revolutions.<sup>(65)</sup> After the carpets were artificially worn, the carpet was cut using a carpet-core razor blade to 7.6 cm (3") diameter. With a gloved finger, 0.1 g nutrient<sup>(65)</sup> was embedded into the middle of the round carpet sample. The nutrient<sup>(65)</sup> consisted of powdered wheat germ, granulated yeast, gold fish food, and freeze-dried daphnia. This formula was able to support dust mite populations for more than one month. The carpet samples were heated in a muffle furnace for 2 h at 80°C to inhibit mold growth contamination on the mite food.

### Mold Suspension

Mold inoculum was prepared by adding 20 mL of 0.05% Tween-20 into a Petri plate that had established pure cultures of *Cladosporium*. A sterile loop was used to dislodge a slurry of mold spores from the Petri plate. The slurry was transferred into a sterile 400 mL Stomacher Bag (Seward, Bohemia, N.Y.), and 80 mL 0.05% Tween-20 was added to bring the final inoculum volume to 100mL. The Stomacher Bag was placed in a laboratory circulator (Seward Stomacher 400 Circulator,

Brinkmann Instruments, London U.K.) for 5 min at 200 rpm, to extract and evenly mix the mold spores.

### Mold and dust mites inoculation

The prepared mold spore suspension was loaded into a pump sprayer. The sprayer was pressurized with a 15-pump prior to release. The nozzle of the sprayer was placed 20 cm away from the carpet samples at a height of 18 cm, and pointed parallel to the surface. Each carpet sample was sprayed for 4 sec with the mold spore suspension, and the sprayer was depressurized after each carpet sample. The carpet was then air dried for 2 h, and 50 dust mites (40 female and 10 male) were transferred onto the middle of the carpet. The carpet was then incubated for 6 weeks at 25°C, 75% relative humidity (RH).

### Treatment

After incubation, the test carpet samples were randomly assigned to one of the four treatment methods or to the control group. Control carpet samples received no treatment. The test carpets were placed into a 91 cm × 41 cm template made with the same carpet, with a 7.6 cm diameter hole cut off to receive the test carpet, and both were secured to the floor with

double-sided tape. The function of the template is to maintain the pressure drop when vacuuming. The machine used for the vacuum intervention was an off-the-shelf Bissell Powerforce vacuum cleaner (Model 3522-1, Bissell Inc., Walker, Mich.). Each carpet assigned to the vacuum intervention was vacuumed for 4 passes at a rate of 55 cm/s (1.8 ft/s).

A dry steam vapor machine designed for residential use (LadyBug 2300, Advanced Vapor Technologies, Edmonds, Wash.) was selected for the steam treatment intervention. The temperature measured at the steam head was 95°C; the carpet temperature was 83°C. The steamer head was placed directly over the carpet sample for 15 sec, simulating 4 passes of steam vapor treatment at 2 cm/s.

The volume of the chemical treatments was standardized to deliver approximately 0.5 g of solution to the target area of the carpet. Preliminary data (not shown) indicated that 1 one-sec application of benzalkonium chloride aerosol spray and six pumps of Neem oil spray were sufficient to deliver equal mass quantities of the treatment. The mechanism of timing the benzalkonium chloride aerosol spray (a countdown timer) was devised to ensure consistent spray volumes across the ten treatment samples. An auditory signal indicated start and stop event. Neem oil was obtained from an off-the-shelf ready-to-use product (Mites Out!, Bioforce USA, Ghent, NY) that comes in a 100 mL spray pump container. The sprayer was placed 5 cm away from the test carpet and angled at 45°. The carpet was sprayed with Neem oil six times (0.5 g of Neem oil, as determined in preliminary testing) and allowed to dry for 2 h at room temperature.

An aerosol can of Lysol disinfectant spray (540 g) was used for the benzalkonium chloride intervention because this chemical is the active ingredient found in Lysol household spray, a common disinfectant application in homes. The can was placed 10 cm away from the test carpet and angled at 45°, spraying continuously with benzalkonium chloride for 1 sec in a circular motion (0.5 g of benzalkonium chloride), and left to dry for 2 h at room temperature.

### Dust Mite Quantification

The heat escape method, which relies on the natural movement of dust mites away from heat, was used to count dust mite in carpets.<sup>(29,38,39,47,65)</sup> Heat of 50°C was applied to the bottom of the carpet, driving living dust mites toward the top of the carpet pile. Dust mites driven to the surface were trapped on sticky tape applied to the surface of the carpet, allowing an evaluation of the number of live mites in the carpet.<sup>(66)</sup>

### Dust Mite Allergen and Mold Quantification

Allergen and mold spores were harvested from the carpet sample after treatment using a High-Volume Small Surface Sampler (HVS3) with a pre-weighed collection bottle.<sup>(24)</sup> Dust mite allergens and mold spores were extracted from the collection bottles using phosphate-buffered saline solution with Tween 20 (PBS-T). The extract was then analyzed for both allergens and mold. Quantification of dust mite allergens (*Der f 1*) was based on Chapman et al.'s process, using

the enzyme linked immunosorbent assays (ELISA) kit from Indoor Biotechnologies, Inc. (Charlottesville, Virginia)<sup>(67,68)</sup> Mold was quantified by taking a 0.1 mL volume of extract and plating it on DG-18 media, followed by incubation at 25°C and 75%RH in an environmental chamber for 7 days. To increase reliability and efficiency of fungi quantification, an aCOLyte colony counting system with SuperCount software (Synbiosis, Frederick, Md.) was used.

### Statistical Analysis

The Statistical Package for the Social Sciences (SPSS) (IBM Corporation, Armonk, NY) 20.0 was used for all analyses. Independent two-sample t-tests were conducted to assess differences between each of the four interventions and the control group for all three outcome measures—dust mite count, dust mite allergens, and mold colony-forming unit (CFU). The hypotheses were tested using an analysis of variance (ANOVA), with the four treatment methods as independent variables, and percent reductions over the control for dust mite count, dust mite allergens, and mold CFU as dependent variables. A critical p-value of .05 was used for all analyses.

## RESULTS

The mean and standard deviation (SD) for dust mite count, mite allergen level, and mold count for control samples were 302 ± 262 dust mites, 442.4 ± 349.9 µg/g allergen, and 125 ± 167 CFU of mold, respectively (Table I). After vacuuming, there was no significant differences from the control for dust mites (279 ± 346,  $p=0.838$ ), mite allergen (246.2 ± 225.5 µg/g,  $p = 0.134$ ), and mold (143 ± 208 CFU,  $p = 0.787$ ), respectively. After steam-vapor treatment, there was significant differences from the control, respectively for dust mites (5 ± 4,  $p < 0.001$ ), mite allergen (98.3 ± 114.5 µg/g,  $p = 0.005$ ), and mold (27 ± 23 CFU,  $p = 0.007$ ). After Neem oil application, there were no significant differences from the control, for dust mites (199 ± 187,  $p = 0.219$ ), mite allergen (289.2 ± 247.5 µg/g,  $p = 0.225$ ), and mold (86 ± 143 CFU,  $p = 0.488$ ), respectively. After benzalkonium chloride treatment, there were no significant differences from the control for dust mites (384 ± 254,  $p = 0.426$ ), mite allergen (325.4 ± 209.8 µg/g,  $p = 0.339$ ), and mold (318 ± 782 CFU,  $p = 0.459$ ), respectively. The t-test analyses indicated that only the steam-vapor method significantly decreased the bio-load compared to the control group ( $p < 0.05$ ).

Figure 2 shows the mean and the 95% confidence interval (CI) of the percent reduction of bio-contaminants on carpet by treatment methods. Table II summarizes the percent reduction of all three common contaminants in carpet by treatment type, and annotates the significant results of our hypotheses.

Vacuuming removed 48.4 ± 42.4% of dust mites, 50.8 ± 37.3% of dust mite allergens, and 49.7 ± 40.7% of mold (Table II). When compared to steam for dust mite removal, there was a significant difference in treatment performance ( $p = 0.008$ ), where vacuuming is less effective than steam in reducing dust mite counts. On the other hand, there is no

**TABLE I. t-test of Treatment over Control**

| Treatment (n=60)       | Dust mite (counts/sample) |         | Dust mite allergen ( $\mu\text{g/g}$ ) |         | Mold (CFU/mL) |         |
|------------------------|---------------------------|---------|----------------------------------------|---------|---------------|---------|
|                        | Mean $\pm$ SD             | p-value | Mean $\pm$ SD                          | p-value | Mean $\pm$ SD | p-value |
| Control (no treatment) | 302 $\pm$ 262             |         | 442.4 $\pm$ 349.9                      |         | 125 $\pm$ 147 |         |
| Vacuum                 | 279 $\pm$ 346             | 0.838   | 246.2 $\pm$ 225.5                      | 0.134   | 143 $\pm$ 208 | 0.787   |
| Steam vapor            | 5 $\pm$ 4                 | < 0.001 | 98.3 $\pm$ 114.5                       | 0.005   | 27 $\pm$ 23   | 0.007   |
| Neem oil               | 199 $\pm$ 187             | 0.219   | 289.2 $\pm$ 247.5                      | 0.225   | 86 $\pm$ 143  | 0.488   |
| Benzalkonium chloride  | 384 $\pm$ 254             | 0.426   | 325.4 $\pm$ 209.8                      | 0.339   | 318 $\pm$ 782 | 0.459   |

Notes: Control (n = 21), vacuum (n = 9), Steam-vapor (n = 10), Neem oil (n = 10), Benzalkonium chloride (n = 10).

statistically significant difference, in the percent reduction of dust mite allergens, between vacuuming and steam treatment ( $p = 0.084$ ). As for mold reduction, there is also no significant difference between the efficiency of vacuuming and steam or other treatments ( $p > 0.05$ ).

Steam treatment removed  $98.4 \pm 0.9\%$  of dust mites,  $75.6 \pm 31.0\%$  of dust mite allergens, and  $64.9 \pm 37.5\%$  of mold (Table II). The results demonstrated that steam is superior in killing dust mites when compared to vacuuming ( $p < 0.001$ ) and to the two chemical methods combined ( $p = 0.044$ ). In terms of ability to reduce dust mite allergens, steam and vacuuming have no statistically significant difference ( $p = 0.084$ ). The results indicated that the steam method is able to remove significantly more allergens than both the Neem oil treatment and the benzalkonium chloride treatment combined ( $p = 0.002$ ). There are no statistically significant differences in percent mold reduction when comparing steam to all other methods ( $p > 0.05$ ).

Neem oil was not statistically effective in the removal of dust mite allergens or mold ( $p > 0.05$ ), but was statistically effective for dust mite reduction when compared to benzalkonium chloride ( $p = 0.044$ ) (Table II). The Neem oil treatment removed  $48.3 \pm 34.0\%$  dust mites,  $39.6 \pm 28.9\%$  of dust mite allergens, and  $54.8 \pm 32.2\%$  of mold. The benzalkonium chloride treatment removed  $18.3 \pm 27.4\%$  of dust mites,

$34.5 \pm 23.3\%$  of dust mite allergens, and  $50.7 \pm 41.6\%$  of mold.

## DISCUSSION

Dry-vacuuming is the most common method of cleaning carpet, and, in our study, it removed on average 50% of dust mites, dust mite allergens, and mold. This study sought to identify other carpet cleaning methods that perform better than regular vacuuming alone. The steam vapor method performed much more effectively in reducing mite populations than other methods. The steam vapor method was also more effective than Neem oil, benzalkonium chloride, and vacuuming in denaturing dust mite allergens from the test carpet. This study agreed with findings from Vojta et al. that steam reduced dust mite allergen levels after a single application.<sup>(9)</sup> This study is also in agreement with findings from Colloff et al. (1995) that the steam vapor method reduced more than 87% of dust mites in inoculated carpet.<sup>(47)</sup>

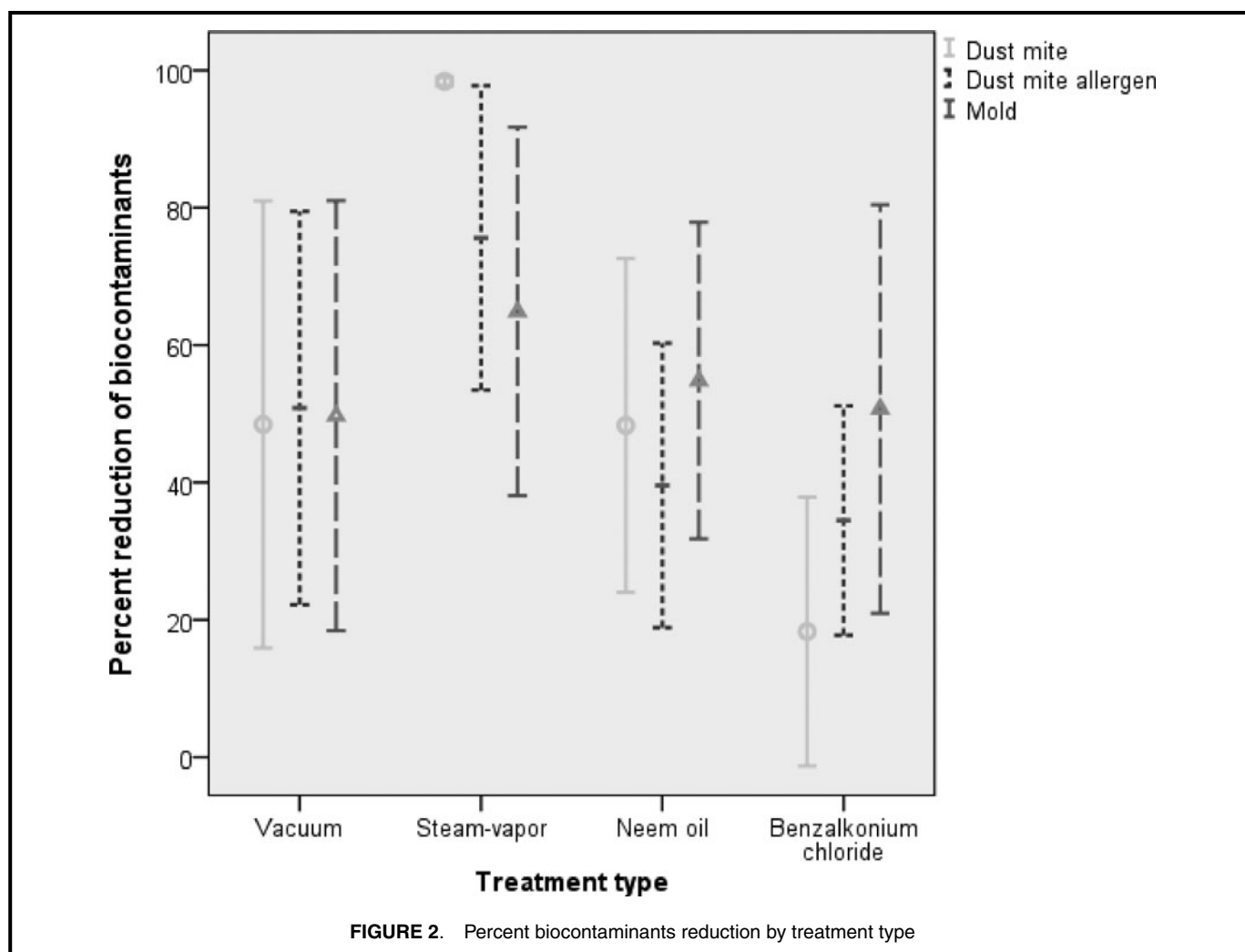
Although Neem oil was relatively effective in reducing dust mite population when compared to benzalkonium chloride, its percent dust mite reduction was approximately the same as regular vacuuming. There was no statistically significant difference for percent reduction of dust mite allergens or mold for carpet treated with Neem oil versus vacuuming alone.

**TABLE II. Percent Removal by Treatments**

| Treatment             | Dust mite (% reduction) |      | Dust mite allergen (% reduction) |      | Mold (% reduction) |      |
|-----------------------|-------------------------|------|----------------------------------|------|--------------------|------|
|                       | Mean                    | SD   | Mean                             | SD   | Mean               | SD   |
| Vacuum                | 48.4                    | 42.4 | 50.8                             | 37.3 | 49.7               | 40.7 |
| Steam vapor           | 98.4*†                  | 00.9 | 75.6†                            | 31.0 | 64.9               | 37.5 |
| Neem oil              | 48.3‡                   | 34.0 | 39.6                             | 28.9 | 54.8               | 32.2 |
| Benzalkonium chloride | 18.3‡                   | 27.4 | 34.5                             | 23.3 | 50.7               | 41.6 |

Hypotheses tested with ANOVA for pairs of comparison listed below:

- Steam vs. vacuum ( $p < 0.05$ )
- Steam vs. Neem oil & Benzalkonium chloride ( $p < 0.05$ )
- Neem oil vs. Benzalkonium chloride ( $p < 0.05$ )



Benzalkonium chloride seemed to be the least effective in reducing dust mite populations and dust mite allergens on carpet. It has the lowest percent mold reduction on carpet but it was not statistically significant when compared to the other test methods in this study. We speculate that the ineffectiveness of benzalkonium chloride could be partially due to the spray delivery format, as the spray may not have completely penetrated the entire carpet pile. Dust mites tend to live deeper in the carpet pile, and therefore the chemical may not have come into contact with them. Mold spores were inoculated onto the carpet at the beginning of the experiment, and the growth occurred on both the top of and deep within the carpet. We believe the low percentage of mold reduction was also partially due to the spray delivery format because the number of mold spores was reduced significantly using this compound when found in pure cultures.

Future studies of bio-contaminant control in carpet may benefit from improvement of new test methods in inoculation of mold spores onto carpets, as there is no standard protocol to inoculate them evenly. Variability in the data that may have obscured differences among mold treatments was likely due to the mold inoculation technique. We had to limit the amount

of liquid that could be introduced onto the carpet samples in this study so that it would not be too wet for the dust mites to thrive. To simulate the habitat of dust mites and mold in carpet, inoculations volume from 0.25 to 2 mL at 0.25 mL increments were tested during a preliminary experiment, and 0.5 mL inoculum was deemed the minimum amount to be properly delivered by the sprayer, and yet not soak our carpet sample.

To address the problem of evenly inoculating mold on carpet with minimal liquid, a pressurized spray bottle system and the mold suspension were sprayed onto the carpet for four sec. This spray inoculation of mold yielded consistent results for volume output onto the carpet. However, the inconsistency in CFU counts in the carpets might be attributed to the pump sprayer or clumping of the spores that affected deposition on the carpet. More research on mold inoculation onto carpet is needed to address this inconsistency.

The ability of Neem oil and benzalkonium chloride to penetrate the carpet where mold often lodges may also have contributed to the variability of the results that obscured differences among treatments. These compounds are not designed for porous surface applications, such as carpet, but rather

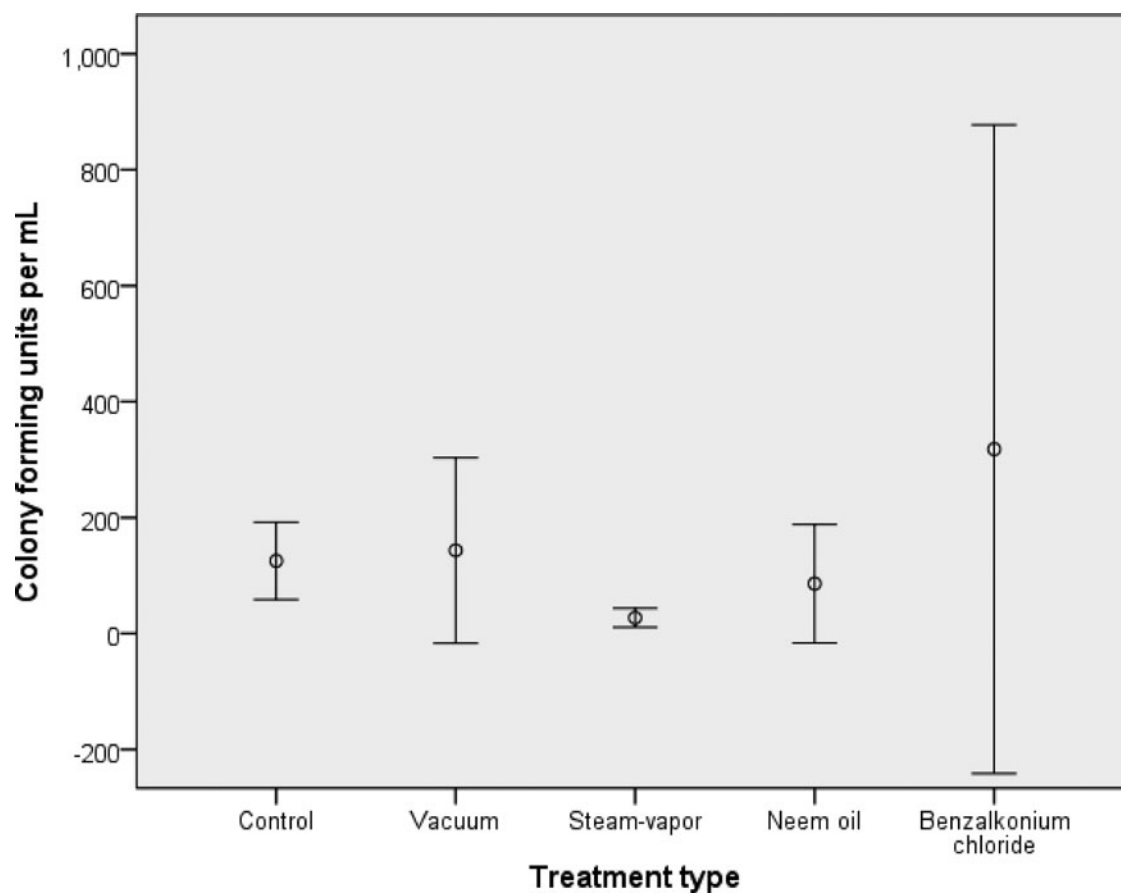


**FIGURE 3.** Number of mold colony-forming unit per mL after carpet treatment

for hard and smooth surfaces. However, at the concentrations they were used, they will not discolor carpet and in the test environment not drown the dust mites in the carpet. Since this experiment was conducted, many of the Lysol disinfectant sprays no longer contain benzalkonium chloride. We discourage readers from using this laboratory approach of spraying benzalkonium chloride onto carpet since this was a laboratory pilot study and not a field investigation.

Steam-vapor or dry-steam utilizes steam for cleaning with <6% water content.<sup>(69)</sup> A steam vapor machine differs from the commonly known “steam cleaner” which is a hot-water carpet shampooing machine. Steam was demonstrated to be effective in reducing dust mite populations.<sup>(9,69)</sup> Because of its high temperature, it has the ability to soften and loosen sticky dust, and it can effectively remove polycyclic aromatic hydrocarbons (PAHs)<sup>(69)</sup> and leaded dust from carpet,<sup>(70)</sup> particularly when used in conjunction with HEPA vacuuming. Although there were no significant differences among treatment methods when carpet was evaluated for percent reduction of mold, we believe that the steam vapor could be more effective than other methods based on the CFU result in Figure 3. Our visual observations of mold in Petri plates from samples treated with steam vapor had consistently lower CFUs when compared to samples treated by the other three methods.

Independent samples t-tests were conducted to compare the mean CFU of each treatment method to the control. Steam treatment was the only treatment exhibiting a significant reduction in mold ( $p = 0.007$ ). The use of steam, however, will require further studies to confirm its application in carpet. Steam shows significant potential, as it is non-toxic and appears to be effective at reducing mold, dust mites, and dust mite allergens in carpet. Additional research is needed to evaluate the effects of steam vapor on other common indoor mold species, such as aspergillus, alternaria, and penicillium, before blanket recommendations can be made regarding the use of steam vapor as a stand-alone mold remediation tool. Furthermore, there are multitudes of steam vapor machines available, and each machine varies in steam output. A cost-benefit analysis using steam as a mold remediation tool needs to be done to include cost of electricity and cost for labor and time to complete the remediation.

## CONCLUSION

The aim of this study was to explore and evaluate various carpet treatment methods against common contaminants found in carpet, such as dust mites, dust mite allergens, and mold. The steam-vapor treatment effectively killed dust mites,

denatured dust mite allergens, and is potentially effective in reducing mold in the laboratory environment; whether it maintains this efficiency when applied in the field is still unknown. The ability to minimize environmental asthma triggers is now the foundation of a holistic approach to reducing asthma severity, which incorporates both environmental controls and appropriate and timely medication.

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