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Modeling of Exposure to Carpet-Cleaning Chemicals Preceding Irritant-Induced Asthma in One Patient

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A 42-year-old woman experienced an acute asthma attack, seizures, and unconsciousness immediately after a carpet-cleaning and deodorizing job was conducted in her home. Exposure modeling estimates that she was exposed to approximately 3.4–17 mg/m^3 of sodium tripolyphosphate and more than 14 mg/m^3 volatile organic compounds immediately after the cleaning. I derived two separate exposure models for these estimates that evidenced good consistency of exposure estimates. Asthmatics and carpet-cleaning companies should be advised about safety during carpet-cleaning operations, including adequate warnings about excess risk for asthmatics, temporary removal from the home, reduced detergent levels within cleaners, and reduced overall levels of cleaning solutions used within the home. Further studies of carpet-cleaning exposures are indicated. *Key words*: asthma, carpet cleaning, exposure modeling, sodium tripolyphosphate, volatile organic compounds. *Environ Health Perspect* 108:911–913 (2000). [Online 10 August 2000] *http://ehpnet1.niehs.nih.gov/docs/2000/108p911-913lynch/abstract.html*

Case Presentation

A 42-year-old female hired a professional carpet-cleaning company to clean the carpets in her home. The carpet-cleaning solution used was a sodium tripolyphosphate (TSP) solution, which also contained low levels of dipropylene glycol methyl ether (DPGME) and various fragrance compounds, mixed with water. The solution was applied to the carpets and upholstery in the home with a high pressure application wand. During most of the carpet-cleaning activity, the female remained in a bedroom with the door closed, isolated from the living room, which was being cleaned. When she reentered the house after leaving temporarily, she noticed a damp smell and an associated chemical odor as the carpet cleaning was being completed. She began to experience respiratory distress and facial discomfort within 5 min of returning to the home; this was immediately followed by shortness of breath, an asthma attack, and cyanosis. A witness present during the event (a certified emergency medical technician) described the patient as being semiconscious and having what appeared to be petit mal seizures: her eyes rolled, her feet and arms tightened, her hands clenched, her feet postured downward in an arch, and her entire body shook. An ambulance was called by the witness. Upon arrival, emergency personnel attempted to intubate the patient but were unsuccessful due to airway swelling. She was transported to the local emergency room via ambulance and was finally intubated in the emergency room. She was diagnosed with anaphylactic shock with respiratory failure secondary to carpet cleaning. The seizures were considered to be due to hypoxic encephalopathy. After 18 days of hospitalization, she was released.

The patient had been diagnosed with asthma at age 19, though the condition did not prevent normal activities and exercise throughout her twenties. She was a self-reported smoker from her teenage years through age 37. During her thirties, the patient reported that heavy physical exercise was increasingly likely to induce asthma attacks, and by her early forties, she was using oral and inhaled bronchodilators 2–3 times per day, more often during the winter than other seasons. The patient is considered atopic.

Since the asthma attack that followed the carpet-cleaning exposure, she has experienced persistent nocturnal and exertional asthma with reduced responsiveness to bronchodilators. She is steroid dependent and maintains an epinephrine anaphylactic kit for emergency use. She reports breathing difficulty when exposed to odors and consistent nocturnal awakening due to breathing difficulty. She self-administers Albuterol nebulizer (Ivax Corp., Miami, FL) treatments 3 times daily and Azmacort (Aventis Pharma AG, Frankfurt, Germany), an inhaled steroid, each morning and evening.

In this paper I summarize the current understanding of irritant exposures and asthma, as well as asthma associated with carpet-cleaning operations, and describe modeling of the exposure to carpet-cleaning compounds potentially received by the victim described in this case, based upon two independent exposure-modeling approaches.

Discussion

Several studies linking the use of carpet-cleaning compounds to respiratory irritation and asthma among building occupants after carpet cleaning have been published over the past two decades. In 1982, Kreiss et al. (*1*) described two respiratory distress outbreaks associated with carpet cleaning. In one outbreak, employees of an office building experienced coughing, respiratory irritation, and difficulty breathing after the application of underdiluted carpet-cleaning compounds. In the other outbreak, employees and children of a day-care facility experienced respiratory irritation and breathing difficulty after carpet-cleaning activities. In 1983, a case of respiratory irritation and breathing difficulty was reported immediately after carpet-cleaning activities in a hospital clinic (*2*). Excessive respiratory irritation, coughing, and sneezing were also reported among conference participants following carpet cleaning in a motel (*3*). In each of these studies, recommendations were proposed for proper dilution of cleaning chemicals and for proper ventilation of rooms to be cleaned.

Chemical components and process description. According to the material safety data sheets, the carpet-cleaning solution used was a 90–95% TSP solution, which also contained low levels of DPGME and various fragrance compounds. None of the material safety data sheets report the components as

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allergens. This original powdered mixture was diluted to a 4% mixture in water before being introduced into the home. This material was further diluted to a 1 part in 30 mixture, using tap water at the home, and applied to the carpets and upholstery within the home using a high pressure application wand.

During application, high temperature water and cleaning chemicals are injected into the carpet via high pressure nozzles at the end of the application wand. Some of the moisture impacts the carpet surface and is absorbed or removed from the carpet via a vacuum system. The remaining moisture is either released into the air of the home as a mist, or remains in the carpet to dry over a 2–24-hr period. Approximately 8–40 gallons of diluted cleaning solution is applied within the home, 95% of which is removed and recaptured by the vacuum system.

Following the cleaning process, a deodorizer product containing approximately 2.1% glycol ethers and fragrance compounds was applied to the upholstery.

Irritant effects of chemicals used. TSP is an irritant powdered solid that may affect the skin and eyes. It injures cell tissue by alkaline caustic action, causing irritation of mucous membranes, with effects similar to those of lye (*4*). Because of respiratory hazards, the American Industrial Hygiene Association (AIHA) has established a recommended workplace environmental exposure level of 5 mg/m^3 over a 15-min period as the maximum exposure level for this material for industrial workers. Glycol ethers such as DPGME can cause irritation, burning, and coughing after inhalation exposure. The American Conference of Governmental Industrial Hygienists has established a threshold limit value of 100 ppm and a 15-min short-term exposure limit of 150 ppm for DPGME (*5*).

Irritant exposure and asthma. The relationship between irritant chemical exposure and induction of asthma attacks in asthmatics is well established. Irritant chemical exposure causes bronchial epithelium injury. Persons with asthma are more susceptible to irritant and volatile organic chemicals than nonasthmatics and show greater bronchial hyperresponsiveness to irritant exposures than nonasthmatics (*6*). Several studies indicated respiratory irritation due to exposure to low levels of volatile organic compounds. In 1986, Molhave et al. (*7*) found that exposures to between 5 and 25 mg/m^3 of volatile organic compounds resulted in eye, nose, and throat irritation. Exposure to 25 mg/m^3 organic compounds produces asthma-like symptoms in asthmatics, resulting in forced expiratory volumes of approximately 90% after 90-min exposures, and also produces reduced pulmonary flow rates among persons suffering from sick building syndrome (*8,9*).

Exposure Model 1: chemical composition of the mist as a function of increases in relative humidity. The specified dilution of the cleaning compound results in 37.9 mg TSP/gram of water as the 5 gallon premix solution. When further diluted by 30 additional gallons of water, the new TSP concentration is reduced to 1.26 mg TSP/gram of water as delivered to the carpet and mist released into room air. Assuming that the mist and moisture liberated into the air from the use of the cleaner results in an increase in the humidity within the room air, and that the increased airborne moisture contains dissolved TSP in the same concentrations as in the diluted cleaner, potential exposures to the victim can be projected based upon any increase in relative humidity within the home due to the release of the TSP-containing mist.

Relative humidity refers to the amount of moisture in the air as compared to the amount that the air could contain at saturation at the same temperature (*10*). Assuming that the temperature within the home at the start of the project was 70°F with a relative humidity of 30%, the amount of water that could be held in the air is approximately 32 grains of water per pound of dry air. If, as a result of the hot water mist liberated during the carpet-cleaning operation, the relative humidity increased to 50%, then a total of 56 grains of water per pound of dry air would be suspended. At 70% relative humidity, 76 grains/ft^3 would be contained within the air, and approximately 112 grains/ft^3 would be airborne at 100% relative humidity. Using the above information, the estimated exposure to TSP (in milligrams per cubic meter) can be computed by multiplying the changes in total moisture content in air from cleaning solution humidity by the room size over which the increased humidity occurs. Equations 1 and 2 display the specifics of this conversion process, using standard industrial hygiene conversion factors (*5,10,11*).

$$\begin{aligned}\text{Total moisture grams } H_2O/ft^3 &= (\text{grains } H_2O/\text{lb air}) \\ &\times (0.065 \text{ g } H_2O/\text{grain } H_2O) \\ &\times (0.075 \text{ lb air}/ft^3 \text{ air}) \end{aligned} \quad [1]$$

I computed an estimate of TSP exposure by multiplying the results obtained from Equation 1 (grams H_2O/ft^3 air) by the computed concentration of TSP per gram of water (1.26 mg TSP/gram H_2O), a conversion factor of 35.31 ft^3 air/m^3 of air (*11*), and the percent of new moisture added to air as a result of the cleaning process (new moisture refers to the percentage of total moisture added by the mist liberated during cleaning).

$$\begin{aligned}\text{Milligrams TSP}/m^3 \text{ air} &= (\text{grams } H_2O/ft^3) \\ &\times (1.26 \text{ mg TSP/gram } H_2O) \\ &\times (35.31 \text{ ft}^3/m^3) \\ &\times (\text{percent new moisture}) \end{aligned} \quad [2]$$

Based upon the above equations, the estimate of TSP exposure is shown to increase as a function of changes in relative humidity due to the liberation of mist from the carpet-cleaning procedure, as shown in Table 1.

Table 1 shows that even a modest increase in relative humidity posed by the carpet-cleaning solution mist results in significant increases in projected homeowner inhalation exposure to TSP. This increased exposure would occur immediately at the end of the cleaning job and during the 2- to 24-hr carpet drying period that follows, until room humidity levels return to normal. The range of estimated exposure based on this approach is 5–17 mg/m^3 of TSP; this is 1–3 times the recommended 15-min exposure limit for industrial workers.

Exposure Model 2: box model assuming that mist spreads evenly in air within the apartment. An alternative exposure estimate is based on a "box model" and uses assumptions about the volume of mist generated within the room. Using the 8–40 gallons of cleaning solution used, along with the 95% reported removal rate, I tested several assumptions regarding the fate of the 5% moisture left within the home. Because no actual measures of the mist fraction left within the home are available, the model was run using several assumed mist fractions (10, 25, and 50%) to establish a range of exposure possibilities. This information was applied in the following manner to estimate TSP exposure levels:

$$\begin{aligned}\text{mg TSP}/m^3 \text{ air} &= (\text{gallons of mist released/room volume } ft^3) \\ &\times (8.31 \text{ lb mist/gal mist}) \\ &\times (454 \text{ g mist/lb mist}) \\ &\times (1.26 \text{ mg TSP/g mist}) \\ &\times (35.31 \text{ ft}^3 \text{ air}/m^3 \text{ air}) \end{aligned} \quad [3]$$

Table 2 shows the range of estimated exposures to TSP based on the assumptions that 8–40 gal cleaner solution was used and that the approximate size of the living room plus other open areas of the apartment was 3,912 ft^3 (approximately 111 m^3).

Table 1. Estimated TSP and DPGME exposures experienced immediately after carpet cleaning based on increases in relative humidity (RH) levels.

Condition	Total grams H_2O/ft^3 air	Milligrams TSP/m^3 air
Normal (30% RH)	0.156	0
50% RH from cleaning	0.273	5.2
70% RH from cleaning	0.370	9.6
100% RH from cleaning	0.546	17.4

Table 2. Estimated exposure to TSP based on mist released in the living room and other open areas (assumed to be 3,912 ft^3).

Gallons cleaner used	Percent removed by wand	Percent of remaining solution as mist	Gallons of mist/cleaner in air	Exposure level mg TSP/m^3 air
8	95	10	0.08	3.4
8	95	25	0.1	4.3
8	95	50	0.2	8.6
40	95	10	0.2	9.0
40	95	25	0.5	21.5
40	95	50	1.0	43.0

This approach yields estimates of 3.4–43 mg/m^3 of TSP exposure, using the most conservative assumption that the mist spreads evenly throughout all open areas of the apartment. This exposure represents 0.7–8.6 times the recommended AIHA's 15-min maximum exposure recommendation of 5 mg/m^3 for workers.

Estimated volatile organic compound exposure from the deodorizing product. I also conducted mathematical modeling of the exposures to organic chemicals contained within the deodorizing product. According to the standard operating procedures, the technicians should apply approximately 1 gal for every 200 ft^2 of upholstery surface area, enough to penetrate carpets and padding in stained areas and produce a drying time of 2–24 hr. From the material safety data sheets and stated dilutions, every gallon of the deodorizer is estimated to contain approximately 2.1% glycol ether and fragrance organic compounds. From this, it can be estimated that every gallon of diluted deodorizer results in 10,139 mg volatile organic compounds being sprayed around the apartment as a mist. Assuming that 1.5 gal was used to cover the approximate 300 ft^2 of surface area treated within the home where the incident occurred, approximately 15,209 mg organic chemicals known to cause respiratory irritation was sprayed in the victim's apartment. If only 10–25% of this deodorizer was airborne due to the mist created during application, evaporation, and drying by the time the homeowner exited the bedroom, she would have been exposed to a mixture of organic chemicals ranging from 14 to 61 mg/m^3—far in excess of the 5–25 mg/m^3 shown by Molhave and colleagues (*7,12*) to cause respiratory irritation and asthma reactions among asthmatics and nonasthmatics.

Conclusions

Respiratory distress associated with carpet-cleaning activities has been reported in the literature for decades. The absence of exposure-monitoring data for carpet cleaning may be attributable to a perception of little danger associated with this activity and a high variability of the locations and types of cleaning performed, among other factors. The modeling conducted in this study demonstrates that significant exposures to TSP and volatile organic compounds may be possible during some carpet-cleaning activities where hot water mist is released into the room. The modeled exposures from this incident may approach levels considered to be of concern for workers, who are often more healthy than older adults or children. The two approaches used during modeling showed comparable estimates of exposure, with ranges overlapping between 5 and 17 mg/m^3 TSP exposure, which is 1.0–3.4 times the recommended short-term exposure limit for workers.

If the findings of this study are indicative of other exposures to carpet cleaners using a hot water mist cleaning method, then asthmatics who are susceptible to irritant-induced asthma attacks may be particularly at risk after carpet cleaning. Companies that perform carpet cleaning should provide asthmatics with specific warnings about potential risks before cleaning operations begin and take steps to minimize hazardous exposure to these individuals. Preventative steps may include *a*) reducing cleaning chemical concentrations used to reduce airborne exposures and residual solid cleaner in carpets after moisture has dried; *b*) reducing the total volume of water and cleaner used within asthmatics' homes; *c*) instructing the asthmatic to avoid returning to the home until all surfaces have dried; and *d*) ensuring the availability of a medicinal inhaler in case of an emergency. Modeling also suggests that asthmatics should not accept deodorizing treatments.

More detailed industrial hygiene studies are warranted for characterizing carpet-cleaning exposures. This information would be valuable not only to susceptible individuals and their attending physicians seeking to avoid harmful exposure but also to carpet cleaners and chemical manufacturers in developing appropriate hazard labeling and safety precautions for their workers.

References and Notes

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Editor's note: This issue's Grand Rounds in Environmental Medicine represents something of a departure from convention in that it was written by a nonphysician and deals in large part with modeling concentrations of chemicals in air. However, it is instructive. Lynch takes a case scenario that is relatively common in the clinical practice of occupational/environmental medicine—new onset of asthma in relation to chemical exposures—and analyzes the circumstances surrounding the use of chemical carpet shampoos to estimate the likely dose inhaled by the patient. This is not merely an exercise in industrial hygiene theory. The information provided (dose reconstruction) forms an essential part of the chain of causation that would allow a clinician to determine the likelihood that a particular chemical exposure is responsible for illnesses observed. In this case, Lynch's analysis also informs us of an underrecognized danger inherent in carpet shampooing that may ultimately assist in public health efforts to prevent future occurrences of chemically related exacerbations of asthma. Appreciation of the value of this kind of analysis is vital to the interdisciplinary discipline that is environmental medicine. We look forward to additional contributions from other disciplines in future Grand Rounds.