Characterization of occupational exposures to cleaning products used for common cleaning tasks–a pilot study on hospital cleaners

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ABSTRACT

Background: In recent years, cleaning has been identified as an occupational risk because of an increased incidence of reported respiratory effects, such as asthma and asthma-like symptoms among cleaning workers. Due to the lack of workplace exposure data and systematic occupational hygiene analyses, it is not clear which cleaning–related exposures induce or aggravate asthma and other respiratory effects. Currently, there is a need for systematic evaluation of cleaning products ingredients and their exposures in the workplace. The objectives of this work were to: a) identify cleaning product hazardous ingredients in relation to respiratory and skin irritation and sensitization; and b) assess the potential for inhalation and skin exposures during common cleaning tasks.

Methods: We identified and prioritized hazardous ingredients in cleaning products commonly used in several hospitals in Massachusetts. Methods included workplace interviews, reviews of product Materials Safety Data Sheets, reviews of the scientific literature related to adverse health effects on humans, reviews of physico-chemical properties of cleaning ingredients, and occupational hygiene observational analyses. Qualitative assessment of airborne exposures and semi-quantitative assessment of dermal exposures were conducted to assess the potential for airborne and dermal exposures during product applications.

Results: Cleaning products used for common cleaning tasks were mixtures of many chemicals, including respiratory and dermal irritants and sensitizers. Examples include quaternary ammonium compounds, 2-butoxyethanol, and ethanolamines. Workers performing cleaning tasks are at risk of inhalation exposures to volatile organic compounds (VOC) vapors and aerosols generated from product spraying. Dermal exposure to hazardous ingredients occurs mostly through hands.

Conclusions: Cleaning products are mixtures of many hazardous chemical ingredients that may impact workers health through air and dermal exposures. Because cleaning exposures are a function of both product formulations and product application procedures, combination of product evaluation with workplace exposure data is necessary to develop strategies for protecting workers from cleaning hazards. This task based assessment allows classification of cleaning tasks in different exposure categories, a strategy that can be employed by epidemiological investigations of the impact of cleaning on health. The methods presented here can be used by occupational and environmental health practitioners to identify interventions to improve health.

BACKGROUND

Cleaning products have become an indispensable part of our modern lives. They are used on a daily basis in nearly all workplaces and homes. In recent years, cleaning has been identified as an occupational risk, because of an increased incidence of asthma and asthma-like symptoms among cleaning workers [1-7]. Adverse effects on skin, such as occupational hand dermatitis, have also been reported by few studies of hospital cleaning workers [8, 9]. Results from epidemiological investigations support the hypothesis that exposure to cleaning products are related to the development and/or exacerbation of respiratory symptoms, including asthma [10-17]. The design of existing epidemiological studies has not allowed identification of agents responsible for asthma and other reported respiratory symptoms. These studies have used broad definition of exposures such as “job titles” and “product type”. It is critical that further epidemiological investigations employ better exposure metrics on assessing exposures to cleaning agents. Rosenman 2006 and Nielsen 2007 in their recent reviews of cleaning agents responsible for asthma emphasize the need for further research to understand the mechanism of asthma and other respiratory symptoms among cleaners.

Workplace exposure assessment is necessary to identify specific ingredients used in the workplace and to study the exposure-response relationships. The main objective of this work was to characterize workplace exposures to cleaning products used for common cleaning tasks is hospitals. We have identified a set of cleaning products used for common cleaning tasks; evaluated the products’ hazardous ingredients in relation to respiratory and skin irritation and sensitization; and assessed the potential for inhalation and skin exposures during common cleaning tasks.

We selected hospitals to study cleaning exposures given the results of a recent surveillance report that identified cleaning products as one of the leading causes of occupational asthma among health care workers [3]. Additionally, we hypothesized that hospital cleaning workers may be at higher exposure risk compared to other groups of cleaners because: a) hospitals use a wide range of products including disinfectants, a toxicologically important group of chemicals in cleaning products[1]; and b) the frequency of the cleaning activities has increased rapidly in hospitals in order to ensure compliance with existing regulations and guidelines for protecting patients and workers from infectious diseases[18].

This paper reports data on potential hazardous ingredients comprising products used everyday for common cleaning tasks in hospitals and identifies cleaning tasks that are associated with higher potential for exposures during product applications. The results of this work can be useful for epidemiologic studies for developing better exposure metrics to relate to health effects. Furthermore, the results are important for development of effective interventions in the workplace.

METHODS

Cleaning products and their hazardous ingredients

a) Evaluation of product lines and identification of chemical ingredients

Information on major products lines and brand names of cleaning products was obtained by interviewing environmental services representatives of six hospitals in Eastern Massachusetts. Hospitals selected represent a full range of in-patient and outpatient services and were located in several cities. They included three large sized urban teaching hospitals, one medium sized urban hospital, and two medium sized suburban hospitals.

Workers' interviews and observational surveys were conducted to identify the products used daily and the associated cleaning tasks. Material Safety Data Sheets (MSDSs) of the products were collected on site or obtained by the manufacturers' web sites. MSDSs of both the concentrated form and ready to use (RTU) form of all products were reviewed. The concentrated forms were evaluated even when only the RTU form was actually used in order to identify ingredients of the mixture with concentrations of less than 1% by weight, that are not reported from the MSDSs of RTU products. Information collected from MSDSs included hazardous ingredients as listed, their concentration in the mixture and chemical abstract services (CAS) numbers.

b. Determination of hazardous ingredients

A list of chemical ingredients identified from MSDSs was created. Because cleaners were mixtures of many ingredients, a set of criteria was developed to prioritize ingredients for further exposure assessment evaluation. An ingredient was considered to be more hazardous if: 1) it occurred frequently in multiple cleaning products, 2) it was a sensitizer or irritant to respiratory system or skin; 3) it occurred at higher concentrations compared to other ingredients in the product, 4) had higher potential to become airborne compared to other mixture ingredients.

Health effects and physical-chemical properties of the ingredients were researched using several tools including online Toxicological Data Network (Toxnet) such as Hazardous Substances Data Bank (HSDB) and ChemIDplus [19]; the ACGIH 2006 TLVs and BEIs booklet [20] , the NIOSH pocket guide to chemical hazards [21]. In addition, literature searches on human adverse health effects of exposures to the ingredients were conducted. Based on the previously defined criteria, the most hazardous ingredients were then identified for further evaluation of the potential for inhalation and dermal exposures in the workplace.

Assessment of the potential for inhalation and dermal exposures

a. Identification of common cleaning tasks

Industrial hygiene worksite observation, interviews with workers, and videotaping of cleaning tasks were performed in three hospitals. Observations and interviews were performed for several hours while the workers were performing the tasks. Process flow charts were developed to identify cleaning tasks, which were used as a unit of exposure analyses. A "task" was defined as a cleaning activity that required application of one single product. Examples of common cleaning tasks performed include floor cleaning, mirror cleaning, toilet bowl cleaning, counter cleaning and floor care tasks.

b. Qualitative assessment of inhalation exposures

The potential for inhalation exposures to hazardous chemical ingredients for each task was evaluated qualitatively by investigating three important determinants of airborne exposures: the exposure intensity, duration and frequency.

$$\textit{Potential for inhalation exposures/task} = \textit{Airborne Exposure Intensity}_{\textit{Task}} * \textit{Task Duration} * \textit{Task Frequency}$$

Intensity of exposure to a chemical ingredient was considered directly proportional to the volatility of the hazardous chemical ingredients and its concentration in the product. Ingredients' boiling point data were collected through literature searches; concentration data were obtained from MSDSs review; and product consumption data were obtained by workers interviews. Task frequency, duration and the cleaning product application method (spraying, wiping, mopping) were assessed via workplace observations, videotaping and interviews of the workers. Considering these determinants of exposure, cleaning tasks were classified in three exposure categories: low, medium, and high.

c. Semi-qualitative assessment of dermal exposures

The Dermal Exposure Assessment Method (DREAM), a validated semi-quantitative method for assessing dermal exposures, was applied to assess the potential for dermal exposure from common cleaning tasks [22-24] . The DREAM method is based on the conceptual model developed by Schneider that considers three major mechanisms by which the contaminant can contact the skin: emission, deposition and transfer[25]..

Emission is the transport of substances from primary sources to the skin in the form of vapors or particles that can happen through splashing, spilling etc. Deposition is the transport from air to the skin and it is dependent on the deposition velocity, concentration of the chemical in air and area of the skin contact. Transfer is the transport of substances by direct contact with skin for example from contaminated working tools[22].

The DREAM method has two major parts. The first part, the *inventory,* includes a structured questionnaire designed to collect data on six levels: company, department, agent, job, tasks and exposure module. The second part, *evaluation*, involves assessment of the potential dermal exposure for each task using the following equation:

$$\textit{Skin-}P_{TASK} = \Sigma\, \textit{Skin-}P_{BP} \qquad (A)$$

where : Skin-P_{TASK} = Potential dermal exposure per task

Skin-P_{BP} = Potential dermal exposure/ body part

The potential skin exposure for each task is estimated as sum of potential skin exposure for 9 body parts: head, hands, upper arms, lower arms, torso front, torso back, lower body part, lower legs, and feet. Then, the potential exposure for each body part is estimated as sum of the three major exposure routes: emission, deposition and transfer as follows:

$$\textit{Skin-}P_{BP} = E_{BP} + D_{BP} + T_{BP} \qquad (B)$$

where: E_{BP} -exposure/body part through emission

D_{BP} -exposure/body part through deposition

T_{BP} -exposure/body part through transfer

The exposure potential for each route is estimated using the following equations:

$$E_{BP} = P_E * I_E * E_I * ER$$

$$D_{BP} = P_D * I_D * E_I * ER \qquad (C)$$

$$T_{BP} = P_T * I_T * E_I * ER$$

where: P= exposure probability

I=exposure intensity

E_I=intrinsic emission

ER=exposure route factor

The main elements of the last set equations (C) are the probability (P) and the intensity (I) of exposure. The probability is assigned a value of 0; 1; 3; or 10 based on the frequency of the occurrence of exposure route. The intensity is also categorized in four categories and assigned values between 0; 1; 3 or 10. The intensity of emission and deposition is defined as amount of the agent on clothing and for transfer is defined as contaminated level of the surface. Another element in these equations is the "intrinsic emission" that accounts for physical and chemical properties of agents. For more details on how the intensity, probability and intrinsic emission values are assigned the reader can refer to the DREAM method.

Using these equations, we estimated the potential total body skin exposure per task (Skin-P_{TASK}) for a set of common cleaning tasks: toilet bowl cleaning, sink cleaning, mirror cleaning, floor cleaning with traditional method and floor cleaning with microfiber mops. In the paper we present step by step estimations for two cleaning tasks. Based on the value of the Skin-P_{TASK}, cleaning tasks were classified in different exposure categories as defined by DREAM: "no exposure"; "very low exposure"; "moderate exposure"; and "extremely high exposure". Additionally, body parts with the highest potential for dermal exposures were identified by comparing the DREAM estimates for different body parts.

RESULTS

Hazardous ingredients in cleaning products

The major product lines used for common cleaning tasks included general purpose cleaners, glass cleaners, washroom cleaners, and floor care products. Examples of products and their ingredients are given in Table 1. A list of chemical ingredients identified from MSDSs is given in Table 2. The most frequent ingredients (that occurred in more than three products) are highlighted in bold on the table.

Hazardous ingredients identified based on the previously expanded criteria, included: quaternary ammonium chlorides or "quats", glycol ethers such as 2-butoxyethanol, ethanolamine, several alcohols such as benzyl alcohol, ammonia and several phenols. Table 3 presents a summary of ingredients' chemical and physical properties, health effects of their inhalation and dermal exposures, and the purpose of the application in cleaning products.

Description of common cleaning tasks in hospitals

Common cleaning tasks identified included: preparation of cleaning solutions, floor cleaning, window cleaning, mirror cleaning, toilet bowl cleaning, sink cleaning, and floor care tasks (buffing, waxing and stripping).

Preparation of cleaning solutions: Cleaning solutions were prepared in the preparation room and were later transported to each floor using a cart. In most of the cases, solutions were prepared using an automated dispensing system. Concentrated cleaning products were diluted to the ready to use (RTU) form at a certain dilution rate. The dilution rate differed from one product to another, for example the dilution rate was higher for floor cleaners (rate =3 gallon/min) compared to glass cleaners (rate =1 gallon/min). Only floor care products such as floor strippers were prepared by manual mixing.

Floor cleaning tasks: Two methods of floor cleaning were observed: a) wet mop cleaning and b) microfiber mop cleaning. The traditional method involved dipping the mop into a bucket filled with cleaning solutions. The second involved the use of the microfiber cloths that were soaked in cleaning solution, used attached to a handle, and send to laundry after one usage. Floor cleaning was performed daily and its duration varied by the size of the room. For example, patient room cleaning required about 5-10 minutes and hallway floor cleaning required several hours.

Window/mirror/glass cleaning tasks: During these tasks the product was sprayed and then wiped with the paper towel. The frequency of window cleaning was lower compared to other tasks. Windows were cleaned as needed and mostly in the main areas or hallways with glass doors. Bathroom mirrors were cleaned daily using glass cleaners.

Bathroom cleaning tasks: Bathroom cleaning involved several cleaning tasks such as: sink cleaning, mirror cleaning, toilet bowl cleaning, and floor cleaning and required application of many products, specific for each task. For mirror and sink cleaning the product was sprayed and wiped with paper towel. During toilet bowl cleaning the product was sprayed into the toilet bowl, followed by brushing with a toilet cleaning brush. In general, bathrooms were cleaned two times per day. The average cleaning time varied from 10-15 minutes.

Floor care tasks (stripping, waxing buffing): During stripping the floor stripper was applied and left to reside on the floor for about 10 minutes. Then, the old floor finish and the residue of the stripper were removed by using a stripping and a wet vacuum machine. Floor waxing was performed after stripping by mopping the protective coat on the floor. After waxing the floor was left for about 20-40 minutes to dry, depending on the indoor air temperature and humidity. Fans were usually used to speed up this drying process. Floor stripping was performed twice a year and in cases when floors were worn or scratched. Floor buffing was needed more frequently, and was performed by spraying the solution and finishing the localized area with a buffing machine.

Patients room cleaning: Patient room cleaning involved combination of several cleaning tasks, such as floor, counters and bathroom cleaning tasks. An example of a patient room cleaning flow chart is given in Figure 1. The workers were responsible for cleaning a certain number of patient rooms (in one case 22 rooms) during the work shift.

Inhalation exposures potential

Qualitative exposure assessment of inhalation exposures resulted in classification of cleaning tasks into three major exposure groups: low, medium, and high exposures.

Low exposure category: Tasks classified in this exposure category include floor cleaning tasks. Floor cleaning generates low concentrations of VOC in the air, mainly because floor products were more diluted compared to other products. The important hazardous ingredients in floor cleaning products are quats, which are not volatile compounds. Additionally, because floor cleaning does not involve product spraying, the risk of inhalation to aerosol particles is very low. Despite their longer duration compare to other tasks, considering their lower exposure intensity, floor cleaning these tasks can be classified in the low inhalation exposure category.

Medium exposure category: Tasks classified in this exposure category include: window and mirror cleaning; sink cleaning; counter cleaning; and toilet bowl cleaning. The potential for inhalation exposures during these tasks is higher compared to floor cleaning tasks because: a) the intensity of hazardous VOC in the air is higher due to the higher concentrations of volatile ingredients in the diluted products; and b) product spraying may facilitate exposures to aerosols and other non-volatile ingredients such as quats, commonly found in products used for these tasks. Workers performing these tasks are continuously exposed to VOC and aerosols during the workday.

High exposure category: We classified in this category "the combination tasks", which include patient room and bathroom cleaning tasks. Due to the continuous application of many products after each other, the potential for inhalation exposures can be higher compared to when the tasks are performed separately. The shadowed boxes in Figure 1 show tasks that potentially generate higher airborne exposures. Because these are small volume environments, it is possible that VOC airborne can increase at a short period of time exposing the worker to inhalation risks.

The other group of tasks classified in this category includes floor care tasks, such as stripping, waxing and buffing. The potential for inhalation exposures from this tasks is higher compared to other tasks because: a) of the higher airborne exposure intensity, due to the higher VOC concentrations in the bulk product; b) they include specific activities such as the use of stripping and buffing machines, which can facilitate dust and particle re-suspension in the air that can potentially be inhaled; and c) the application of fans to speed up floor drying increases the intensity of exposures to VOC. Quantitative exposure assessment is necessary the evaluate the risk of particle inhalation during floor care tasks. Overall, although less frequent, these tasks may contribute to high acute exposure levels that can be related to irritation mechanism of asthma and other respiratory symptoms among cleaning workers.

Dermal exposures potential

Two *examples* of step by step estimations of potential skin exposures for mirror and floor cleaning are given in Table 4 and 5. The results of DREAM for five cleaning tasks are presented in a graph given in Figure 2. This graph presents the total body potential skin exposure for five tasks along with contribution of three exposure routes emission, deposition and transfer for each task. The results of individual body part contribution to the potential total body dermal exposure / task for the five cleaning task evaluated is presented in Figure 3.

According to the DREAM categories, cleaning tasks create moderate (such as in floor cleaning tasks) and high potential for dermal exposure (such as in mirror/window cleaning, sink cleaning and toilet bowl cleaning tasks). The graph in Figure 3 shows that "emission" route contributes more to the overall exposure compared to "transfer" and "deposition" routes. That can be related to the spraying activities, that generate liquid particles with aerodynamic diameter >100 µm that potentially reach the skin. The contribution of the deposition was found to be higher during sink cleaning. Quantitative measures of airborne exposures are needed to explain different contributions of deposition for different tasks. Transfer contributes more during floor cleaning, probably due to the continuous hand contact with the mop handle contaminated with cleaning solution.

Overall, floor cleaning tasks were associated with the lowest potential for dermal exposures. Hands were identified as having the highest potential for dermal exposure for most of the tasks. Forearms were at higher risk of exposure during sink, toilet bowl & mirror cleaning while feet and lower legs were at higher risk during floor cleaning.

DISCUSSION

This study investigated exposures generated from common cleaning tasks in hospitals by considering both the product formulations and the inhalation and dermal exposures potential to hazardous ingredients during product applications. This work shows that:

1. Cleaning products are complex mixtures of many chemicals.

The chemical ingredients identified in the products included disinfectants, surfactants, solvents, and fragrances. These ingredients are representative of different chemical classes such as ethers, alcohols, amines, acids and have a very wide range of volatilities and other chemical properties. The same chemical ingredients we have identified here have been previously reported by several studies [1, 26, 27].

When investigating ingredients using products MSDSs, health and safety professionals should review not only MSDSs of concentrated product forms, but also the ready to use forms (RTU). We found that many ingredients reported in the concentrated form were missing in the RTU form, because MSDSs are required to list only ingredients at concentrations less than 1% in the product. This is important for identifying ingredients that are sensitizers in the workplace; given the fact that sensitization may occur even at trace concentrations.

One important finding is related to the high frequency of use of disinfectants among different product groups. Disinfectants are added to the cleaning products with the main goal to destroy the microbial life. On the other hand, cleaning is done with the goal to mechanically remove the surface contaminates. An important question that can be raised is: Can disinfectants achieve their goal if they are applied in combination cleaner-disinfectant product? In order for disinfection to be effective , it should follow surface cleaning and the disinfectant should reside on the surface for about 10-15 minutes after application[28]. In the case of combination product (cleaner –disinfectant) application these procedures can not be followed. The effectiveness of disinfectants use for common cleaning activities has been questioned in the literature [29] [30] [31]. Although the evidence to date is minimal, repeated application of disinfectants may increase the risk of microbial resistance, which will require the use of stronger disinfectants in order to be destroyed [32, 33]. Given : 1) the uncertainty of disinfectant effectiveness on cleaning public areas; 2) the risk of inducing bacteria resistance; and 3) the health concerns related to the use of disinfectants, it is critical to further evaluate disinfectants' effectiveness for common cleaning activities and to develop workplace strategies for preventing workers from exposures to disinfectants. Such strategies may include purchasing of green cleaning products, identification of the areas where disinfection is needed, and following the necessary disinfection procedures in the cases when disinfection is necessary.

2. There is evidence of exposures to respiratory and dermal irritants and sensitizers from cleaning products.

2-Butoxyethanol (2-BE) a glycol ether, was commonly used in cleaning products including glass/window cleaners, carpet cleaners and other surface cleaners. It is a volatile compound with boiling point (BP) of 168.4 ^{0}C. Exposures to its vapors are irritating to the eyes nose, mouth, throat and skin. OSHA permissible exposure limit

(PEL) is 50 ppm for 8 h time weighed average (TWA), ACGIH threshold limit value (TLV) is 20 ppm (8 h TWA) and NOISH recommended exposures limit (REL) is 5ppm (10 hour exposure). There is a skin designation for 2- BE from both OSHA and NIOSH. The presence of 2-BE in cleaning products has been reported by several studies [34] [35]. Concentrations of 2-BE in the air generated during window cleaning reported by Vincent 1993 ranges from 0.1-7.33 ppm, lower then existing occupational standards. The study suggested that dermal exposure may be the most important exposure route in the workplace[36]. Because 2-BE was one of the most frequent solvents in our products and had the highest concentrations in the bulk products, it is an important to further assess its workplace exposures. Quantitative workplace investigations are necessary measure the degree of exposure intensity and relationship with irritation symptoms reported among cleaning workers.

Quaternary ammonium compounds or quats were widely used in many of the products investigated. Quats have been identified as one of indoor agents that promote development of airway allergy by Nielsen 2007 [27]. In his review he summarizes the evidence from animal and humans studies that relates quats exposures with allergy – promoting effects. He concludes that the mechanism of asthma from quats remains unknown.

One important consideration on understanding mechanism of asthma from quats is the understanding of its exposure routes in the workplace. Several studies and case reports have reported the relationship of human exposures to quats with asthma [2, 5, 6]. From these case reports it is hard to identify how the exposure has happened. In the second case report of a study by Puhorit 2000, the nurse developed symptoms after entering the room that was cleaned with a surface cleaning product that contained benzalkonium chloride[5]. Because the nurse was not involved in cleaning activities the most probable exposure route would be inhalation. Inhalation to quats may happen in two ways: 1) by inhaling aerosolized liquid particles generated during product application; or 2) by inhaling quats absorbed into the dust particles that are re-suspended in the air. A study by Vincent 2006 showed non-detectable levels of aerosolized quats in the hospital environments [37]. Further quantitative workplace investigations of inhalation and dermal exposures will provide important evidence on understanding actual exposure routes and mechanism of asthma from quats.

Mono-ethanolamine, used as surfactant, was found in most of the products types investigated with exception of the floor cleaners. It has a boiling point of 171 ^{0}C and dissolves very well in water. Exposures to its vapors can irritate the nose, throat, and lungs causing coughing, wheezing and shortness of breath. OSHA PEL for mono-ethanolamine is 3 ppm and ACGIH 15 min short term exposure limit (STEL) is 6ppm. Exposure to mono-ethanol amines from cleaning agents have been related to occupational asthma [4]. Because the evidence to date is limited, to understand asthma mechanism it is necessary to investigate exposure patterns in the workplace for example short term peak or chronic low exposures. Dermal exposure assessment should be considered in further workplace exposure assessment strategies, given the concern that mono-ethanolamine can be absorbed though the skin[19].

Fragrances were used commonly in bathroom cleaners. However, their chemical name or composition were not reported in MSDSs. Exposure to fragrances is a topic of special interest given the recent concerns related to the secondary emissions as result of the reactions of the primary exposures (e.g. terpenes) with oxidizers present in indoor air (e.g ozone)[38]. Reaction of ozone with d-limonene , a commonly used air freshener, may generate submicron particles that can contribute in indoor air quality [39]. Even at low concentrations, the presence of compounds with low odor threshold may cause perceived respiratory irritation because of odor annoyance[40]. However, to understand that irritation is due to the odor perception or due to the secondary reactions with oxidizers that produce sensory irritants in indoor environment needs further investigation. Furthermore, this is a topic of special interest given the sensitization effects reported from exposure to fragrances [41].

Surprisingly, bleach was not used in any of these products compared to findings from other studies, which found that bleach can be responsible for asthma symptoms among domestic cleaners [14, 42].

3. Cleaning tasks generate airborne exposures.

Volatile compounds identified in cleaning products covered a wide range of volatilities, from highly volatile ingredients such as ammonia (BP= -33^0C) and isopropyl alcohol (BP= 82^0C) and relatively less volatile ingredients such as 2-butoxyethanol (BP= 168^0C) and mono-ethanolamine (BP= 171^0C). The highest intensity of VOC exposures in the workplace is expected during the use of floor strippers and general purpose cleaners because they contain highest concentrations of VOC in the bulk. Inhalation exposure to aerosol particles of volatile and non-volatile ingredients can be facilitated during product spraying. The worst exposure scenarios can happen when several cleaning tasks are performed in small and poorly ventilated spaces, such as bathrooms.

Hazardous exposures related to cleaning products are an important public health concern, because these exposures impact not only cleaning workers, but also other occupants in the building. Data from laboratory studies indicate a two phase decay of the air concentrations in the room. The first phase decay happens very fast (in the first 10 minutes) and the second phase decay happens slowly (about 1-2 hours for the air concentrations to reach the background level). Furthermore, experimental studies have shown that some compounds such as glycol ethers are released slowly from the surfaces. This creates potential for exposure of other occupants in the building, hours after the cleaning activities are performed [34, 35]. The intensity of exposures after cleaning has stopped is not investigated by filed studies. In a follow up study we will conduct quantitative assessment airborne exposures during cleaning and will provide evidence on the exposure levels after cleaning.

4. Cleaning tasks create potential for dermal exposures.

Application of the DREAM method for five cleaning tasks was successful because it allowed their categorization in different exposure categories. In addition to the chemical composition of the products, spraying was an important factor impacting dermal exposures for each task. However, the DREAM method did not find a big difference between all tasks that involve spraying (such as mirror cleaning vs. sink cleaning). Furthermore, no difference was found between two different floor cleaning methods. Further application of DREAM for other cleaning tasks in the workplace is necessary beyond this pilot study. One important finding was that hands were at higher potential for dermal exposure compared to other body parts, indicating that the prevention focus should be mostly on hands and the activities that involve product spraying.

Our evaluation indicated that dermal exposure to cleaning hazards is an important route for chemicals to enter the body. Recent literature suggests that some chemical ingredients, such as isocyanates, may be able to penetrate the skin and cause systemic respiratory effects [43]. Further evaluation of the cleaning chemicals that may permeate the skin and cause systemic effects is essential for understanding asthma and other respiratory symptoms from cleaning hazards.

5. *This work showed that cleaning exposure is function not only of the product formulations. but also the way that tasks are performed.* To avoid potential harm from cleaners, the strategy that is currently employed in workplaces is substitution of cleaning products with green cleaners. Although purchasing of green cleaning products is important for risk reduction, it does not guarantee workers and other consumers that there are no risks. For example, it is possible that application of a green product (with low content of volatile ingredients) via aerosolization creates potential for inhalation exposures non-volatile compounds that are respiratory irritants that might not become airborne if they were applied in another manner. Therefore, combination of both a precautionary approach toward finding safer, healthier alternatives and an evaluation of workplace exposures is best for protecting workers and general public to cleaning hazards.

Limitations:

The results of this work are based on a small number of products. While we selected only few representative hospitals, it is possible that other products with additional ingredients are used elsewhere.

This study does not address the lack of quantitative data in the literature regarding the concentrations of cleaning compounds in workplace air. Quantitative characterization of exposures would better identify activities that produce the highest exposure, important for control measures. This work was preparation for a detailed quantitative assessment of airborne exposures from cleaning tasks.

CONCLUSIONS

This study found that cleaning products are mixtures of many hazardous chemical ingredients that may impact workers health through air and dermal exposures. Because cleaning exposures are a function of both product formulations and product application procedures, combination of product evaluation with workplace exposure data is necessary to develop strategies for protecting workers from cleaning hazards. The task based assessment conduced here, allowed classification of cleaning tasks in different exposure categories, a strategy that can be employed by epidemiological investigations of the impact of cleaning on health. The methods presented here can also be used by occupational and environmental health practitioners to identify workplace interventions to improve health.

Authors' contributions

Anila Bello: Led the design of the research, drafted the paper; carried out the workplace interviews and observations; performed exposure assessment analyses.

Margaret Quinn: Co-led the design of the research and guided paper writing; facilitated workplace connections and conducted paper revisions.

Melissa Perry: Provided critical input on criteria for product selection and representative data collection in the workplace; contributed to paper revisions.

Donald Milton: Contributed to adapting the DREAM Method for cleaning tasks; contributed to paper revisions.

Acknowledgments

The authors wish to acknowledge environmental services representatives and workers involved in the study, for providing very important information on cleaning products used in their facilities. We also thank Catherine Galligan at Sustainable Hospitals Program at University of Massachusetts Lowell, for her contribution on establishing hospital contacts and workplace data collection. This investigation was funded by two grants from National Institute for Occupational Safety and Health (NIOSH) a) grant R01 0H03744 as part of the National Occupational research Agenda (NORA) ; and b) grant No. T42/CCT122961-02, via Harvard School of Public Health, Education Research Center Pilot Project Award. Its contents are exclusively the responsibility of the authors and do not necessarily represent the official views of the NIOSH.

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Figures legend:

Figure 1: Process flow diagram of the tasks performed for patient room cleaning. *Legend: the shaded boxes indicate cleaning tasks/ steps with higher potential for inhalation exposure.*

Figure 2: Potential dermal exposure for five cleaning tasks. *Legend: Contribution of emission deposition and transfer to the overall potential body exposure is shown in addition to the overall potential for the total body dermal exposure.*

Figure 3: Potential skin exposure for different body parts during different cleaning tasks. *Legend: Floor cleaning 1 represents floor cleaning with microfiber mops and floor cleaning 2 represents floor cleaning with the traditional mop & bucket method.*

Table 2: Chemical ingredients reported in the cleaning product material safety data sheets (MSDSs)

1	*1-Methyl 1-4 (1- Methylethenanal) Cyclohexen Emulsion*	*30*	Ethylene glycol
2	*1-Octyl -2-pyrolidinone*	*31*	*Hydroxyacetic acid*
3	***2-Buthoxyethanol***	*32*	***Hydroxyalkyl amine oxides***
4	*2-Ethyl –hexyloxyethanol*	*33*	*Isobutane*
5	*2-Methoxy-1-propanol*	*34*	***Isopropyl alcohol***
6	***Alcohol ethoxylates***	*35*	*Laureth 6 carboxylic acid*
7	*Aliphatic petroleum distillates*	*36*	*Linear primary alcohol ethoxylate*
8	***Alkyl dimethyl benzyl ammonium chloride***	*37*	*Malic acid*
9	***Ammonia***	*38*	*Mono isopropanol amine*
10	***Ammonium hydroxide***	*39*	*N-Alkyl dimethyl ethyl benzyl ammonium chloride*
11	*Amphoteric surfactant*	*40*	*Nonionic surfactant*
12	*Benzenesulfonic acid derivative*	*41*	*Nonyl phenol ethoxylate*
13	***Benzyl alcohol***	*42*	*Nonyl phenoxypoly ethanol*
14	*Butane*	*43*	*Octyl decyl dimethyl ammonium chloride*
15	*Carboxy imidazolinium salt*	*44*	*Octyl dimethyl amine oxide*
16	*Calcium carbonate*	*45*	***Ortho-benzyl-para chloro-phenol***
17	*Citric acid*	*46*	***Ortho-phenyl-phenol***
18	***Didecyl dimethyl ammonium chloride***	*47*	*Para-tertiary-amyl phenol*
19	*Diethyl phthalate*	*48*	*Polyethylene emulsion*
20	*Di-ethylene glycol mono methyl ether or 2-(2-ethoxyethoxy) ethanol*	*49*	***Propylene glycol methyl ether (or*** *1-methoxy 2- propanol)*
21	*Dioctyl dimethyl ammonium chloride*	*50*	*Quaternary ammonium chlorides*
22	*Dipropylene glycol butoxy ether*	*51*	*Secondary alcohol ethoxylate*
23	***Dipropylene glycol methyl ether***	*52*	*Silica, quartz*
24	*Dodecyl benzene sulfonic acid*	*53*	*Sodium hydroxide*
25	*Dye*	*54*	*Sodium metasilicate*
26	***Ethyl alcohol***	*56*	*Sodium xylene sulphonate*
27	***Ethanolamine or (*** *2-Aminoethanol)*	*57*	***Tetrasodium ethylene di amine tetraacetate***
28	*Ethylene diamine tetra acetic acid*	*58*	*Tre butoxy ethyl phosphate*
29	***Fragrance***		

**Ingredients with an appearing in 3 or more products are highlighted in bold.*

Table 4: Potential dermal exposure estimates for floor cleaning (using microfiber mops)*.

Body part	Emission	Deposition	Transfer	Intrinsic emission (E)	*Skin-P$_{BP}$*
	$E_{BP} = P_{E.BP} * I_{E.BP} * ER_E * E$	$D_{BP} = P_{D.BP} * I_{D.BP} * ER_D * E$	$T_{BP} = P_{T.BP} * I_{T.BP} * ER_T * E$	PS*C*EV*V	
Head	E_{HE}= 0	D_{HE}=3*1*1*0.09= 0.27	T_{HE}=0	E=1*0.3*0.3*1	0.27
Upper arms	E_{UA}= 0	D_{UA}=3*1*1*0.09= 0.27	T_{UA}=0	0.09	0.27
Lower arms	E_{FA} =1*1*3 *0.09 =0.27	D_{FA} =3*1*1*0.09= 0.27	T_{FA} =3*10*1 *0.09=2.7	0.09	3.24
Hands	E_{HA}= 3*10*3* 0.09=8.1	D_{HA} = 3*1*1*0.09= 0.27	T_{HA} = 10*10*1*0.09= 9	0.09	**17.37**
Torso front	E_{TF} = 1*1*3*0.09=0.27	D_{TF} = 3*1*1*0.09= 0.27	T_{TF} = 1*3*1*0.09=0.27	0.09	0.81
Torso back	E_{TB} = 0	D_{TB} = 3*1*1*0.09= 0.27	T_{TB} = 0	0.09	0.27
Lower body part	E_{LB} = 1*1*3*0.09=0.27	D_{LB} =3*1*1*0.09= 0.27	T_{LB} = 1*3*1*0.09=0.27	0.09	0.81
Lower legs	E_{LL} =3*1*3*0.09=0.81	D_{LL} = 3*3*1*0.09=0.81	T_{LL} = 1*3*1*0.09=0.27	0.09	1.89
Feet	E_{FE} = 3*3*3*0.09=2.43	D_{FE} = 3*3*1*0.09=0.81	T_{FE} = 3*10*1*0.09= 2.7	0.09	5.94
Skin-P$_{task}$ *for total body*	12.15	3.51	**15.21**		**30.87**

** The main hazardous ingredients of floor cleaning products are quaternary ammonium compounds*

**Main activities involved dipping the mop into the cleaning solution and mopping*

Table 5: Potential dermal exposure for mirror cleaning*.

Body part	**Emission**	**Deposition**	**Transfer**	**Intrinsic emission (E)**	***Skin-P$_{BP}$***
	$E_{BP}= P_{E.BP} * I_{E.BP} * ER_E * E$	**$D_{BP}= P_{D.BP} * I_{D.BP} * ER_D*E$**	**$T_{BP}= P_{T.BP} * I_{T.BP} * ER_T*E$**	**PS*C*EV*V**	
Head	E_{HE}=3*3*3*0.3= 8.1	D_{HE}=3*3*1*0.3= 2.7	T_{HE}=0	E=1*0.3*1*1=0.3	10.8
Upper arms	E_{UA}=1*3*3*0.3=2.7	D_{UA}=3*3*1*0.3=2.7	T_{UA}=0	0.3	5.4
Lower arms	E_{FA} =3*3*3 *0.3=8.1	D_{FA} =3*3*1*0.3=2.7	T_{FA} =1*10*1 *0.3=3	0.3	13.8
Hands	E_{HA} = 3*10*3 *0.3=27	D_{HA} = 10*10*1*0.3=30	T_{HA} = 10*10*1*0.3=30	0.3	**87**
Torso front	E_{TF} = 1*1*3*E=0.9	D_{TF} = 3*3*1*0.3=2.7	T_{TF} = 1*1*1*0.3=0.3	0.3	3.9
Torso back	E_{TB} = 0	D_{TB} = 0	T_{TB} = 0	0.3	0
Lower body part	E_{LB} = 1*1*3*E=0.9	D_{LB} = 0	T_{LB} = 0	0.3	0.9
Lower legs	E_{LL} =1*1*3*E=0.9	D_{LL} = 0	T_{LL} = 0	0.3	0.9
Feet	E_{FE} = 1*3*3*E=2.7	D_{FE} = 0	T_{FE} = 0	0.3	2.7
Skin-P$_{task}$ *for total body*	**51.3**	40.8	33.3		**125.4**

** The main hazardous ingredient in glass cleaning products is 2-buthoxyethanol and main cleaning activities involve spraying and wiping*

Figure 1: Process flow diagram of the tasks performed for patient room cleaning.

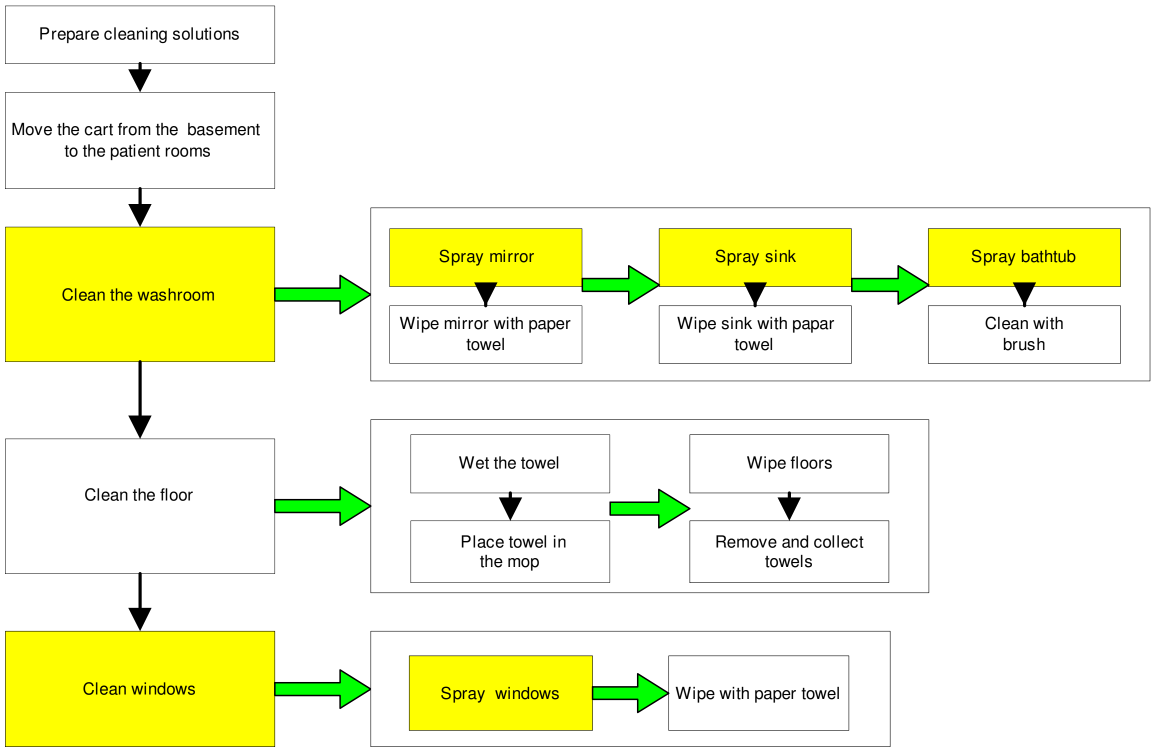

Figure 1

Figure 2: Potential dermal exposure for five cleaning tasks.

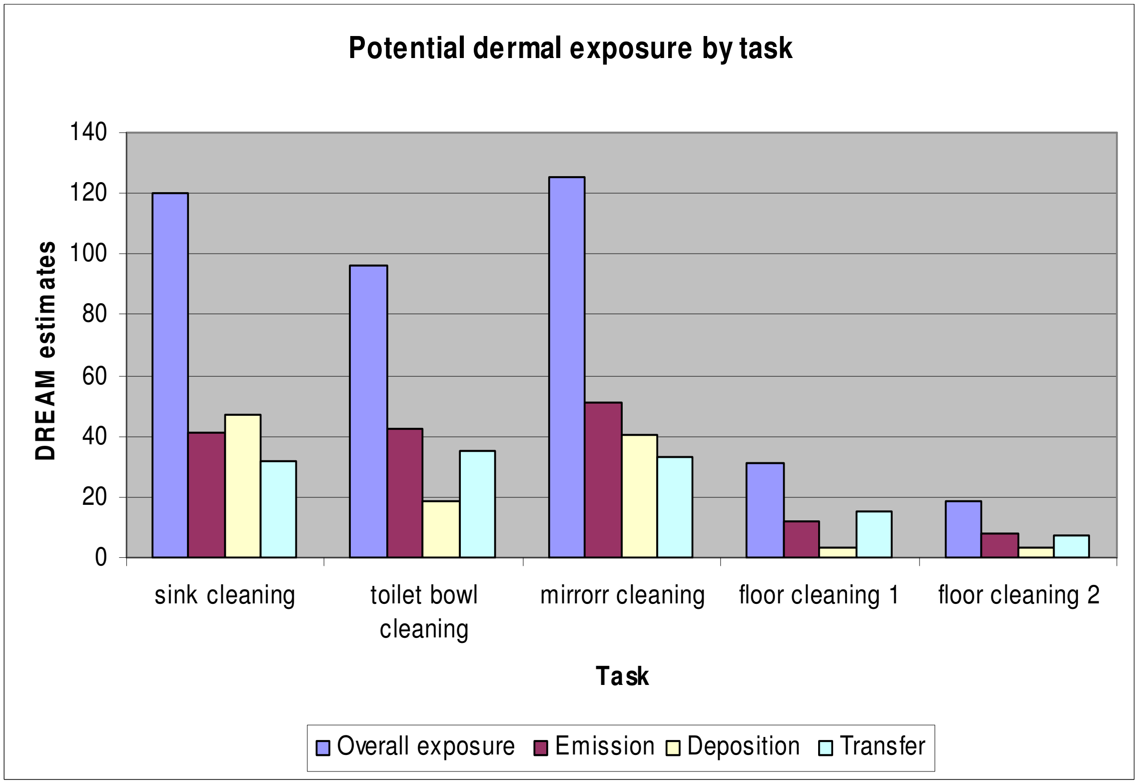

Figure 2

Figure 3: Potential skin exposure for different body parts during different cleaning tasks.

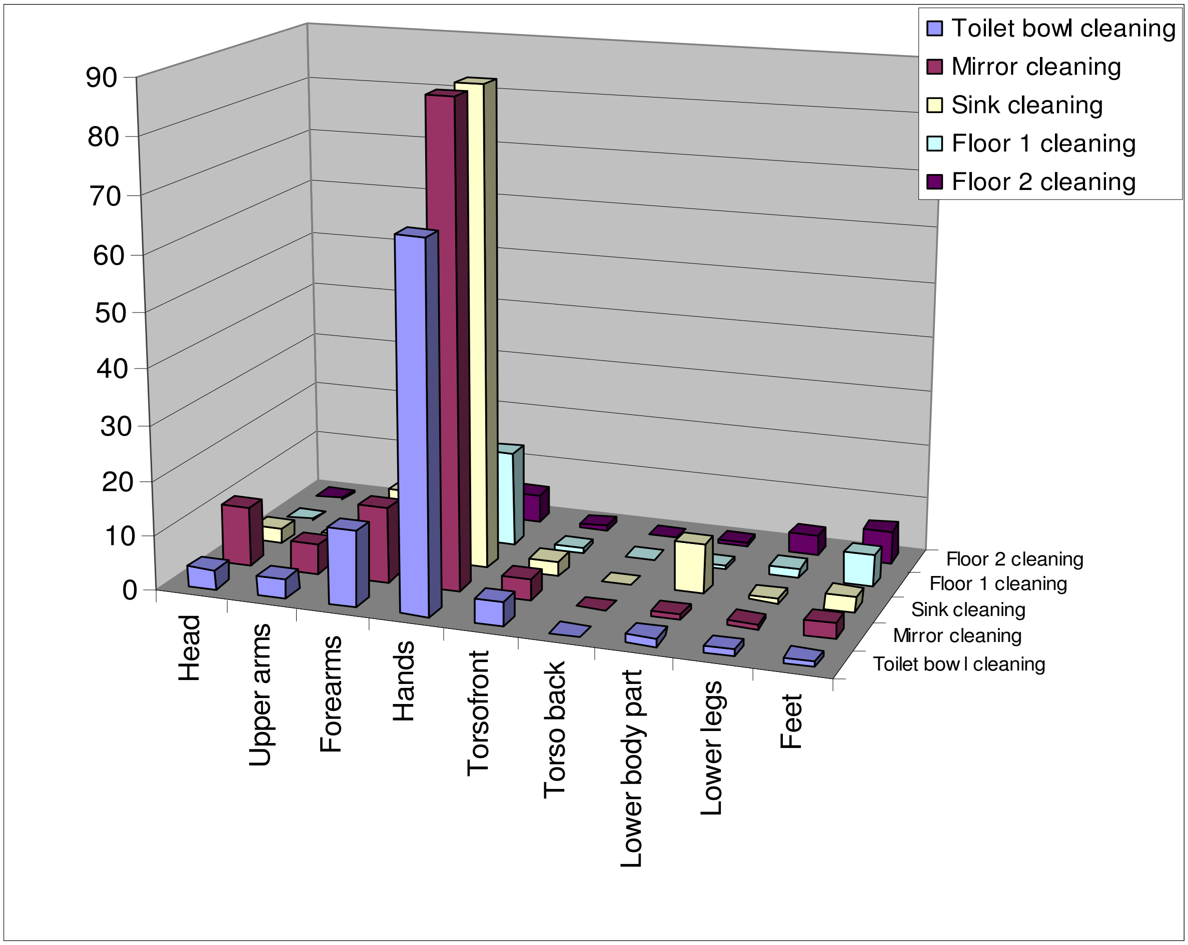

Figure 3

Additional files provided with this submission:

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