Characterization of exposures to cleaning products used for common cleaning tasks in hospitals –a pilot study

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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. Currently, there is a clear need for systematic evaluation of cleaning products ingredients and exposures associated with product applications. The main 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 developed a systematic approach to identify and prioritize hazardous ingredients in cleaning products commonly used in hospitals. This included: interviews with facility managers and housekeeping staff; reviews of product's Materials Safety Data Sheets and the scientific literature on cleaning ingredients physicochemical properties and related health effects; and industrial hygiene observational analyses. Qualitative assessment of airborne exposures and semi-quantitative assessment of dermal exposures applying the Dermal Exposure Assessment Method (DREAM) were conducted to assess the potential for airborne and dermal exposures during product applications.

Results: Cleaning products even in the simplest formulation are mixtures of organic and inorganic chemicals, including respiratory and dermal irritants and sensitizers such as quaternary ammonium compounds, 2-butoxyethanol, and ethanolamines. Common cleaning activities involve short term tasks, frequently repeated during the workday. Airborne exposures to volatile ingredients and aerosol particles can be generated from cleaning tasks. They can reach the peak during product spraying and when several tasks are conducted one after the other, in small volume areas such as bathrooms. There is potential for dermal exposures from cleaning tasks, with hands being at higher risk of exposures.

Conclusions: Hazardous exposures from cleaning activities are a function not only of product formulations but also of the way that tasks are performed. That is why a combination of both a precautionary approach toward finding safer, healthier alternatives and an evaluation of workplace exposures is best for protecting workers and the general public to cleaning hazards.

INTRODUCTION

Cleaning products have become an indispensable part of our modern lives. They are used on a daily basis in nearly all workplaces and homes. Health hazards associated with cleaning are often not obvious, and in many cases are not even attributed to cleaning agents. There are several reasons for this including: cleanliness is equated with good, rather than poor health; cleaning is a support function, not a main production activity; and the workers who perform cleaning are often lower wage, immigrants or those with fewer socio-economic advantages.

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. Several research groups have been focused on adverse health outcomes due to exposure to cleaning products [1-9]. Results from these studies have supported the hypothesis that exposure to cleaning agents are related to the development and/or exacerbation of respiratory symptoms, including asthma. Due to the lack of exposure data and systematic occupational hygiene analyses, it is not clear which cleaning–related exposures induce or aggravate asthma and other health effects. Currently, there is a clear need for a systematic evaluation of cleaning products, their potential hazards and related adverse effects.

The main objectives of this work were to: 1) identify a set of cleaning products used for common cleaning tasks; 2) evaluate the products' hazardous ingredients in relation to respiratory and skin irritation and sensitization; and 3) assess the potential for inhalation and skin exposures during common cleaning tasks.

This paper provides data on the ingredients of products used everyday for common cleaning tasks in hospitals and methods that can be easily employed for qualitatively assessing the potential exposures in the workplace. The results of this work can be useful for both epidemiologic studies exposure surveys and workplace hazards control.

Health effects of concern

Recent epidemiologic studies, mostly from Europe, indicate a possible association of respiratory irritation and asthma with exposure to cleaning agents. A cross sectional study in Spain investigated the risk of asthma among cleaning workers employed in different industries in Spain and concluded that working as a "cleaner" increases the risk of developing asthma[5]. A cohort study compared asthma risk among cleaning workers in Finland and also found an elevated risk among them [2]. Zock et al. (2002) compared asthma symptoms among cleaning workers versus workers in other occupations. The study concluded that asthma in cleaning workers had many similarities with that in occupations known to be at risk of occupational asthma. Cleaning and disinfecting workers employed in the food industry in France were found to be at risk of developing acute irritant symptoms due to exposures to chloramines and aldehydes [10].

Only a few studies have focused on identifying agents responsible for asthma among cleaning workers. A case control study of women employed in domestic cleaning in Spain found bleach as one of the responsible agents for asthma and chronic bronchitis [7]. The study also concluded that other irritants present in the cleaning products could contribute to respiratory symptoms. In another study from the same author, short term exposures to certain irritant agents were found to aggravate lower respiratory tract symptoms of female cleaners with asthma. Such agents included diluted bleach, degreasing sprays/atomizers and air fresheners [8].

Surveillance systems of work related asthma, carried out in several states in the US, including California, Massachusetts, Michigan and New Jersey, found that 12% of the overall cases of work-related asthma were associated with exposures to cleaning agents[1][11]. Furthermore, published case reports indicate aggravation or development of asthma with exposures to several cleaning agents [12, 13]. For example aggravations of asthma symptoms have been reported in a case study where a 44 years old pharmacist experienced severe asthma symptoms. The cause was found to be a cleaning agent, lauryl dimethyl benzyl ammonium chloride, used in floor cleaners. Substituting to a different floor cleaner led to a substantial improvement in asthma symptoms [14]. Systemic hypersensitivity was reported in one case study from exposures to a toilet bowl cleaner that contained benzalkonium chloride. Pulmonary and epicutaneous challenge tests showed positive responses with exposure to benzalkonium chloride. Removal from the work environment resulted in an improvement of symptoms [15].

Skin contact with cleaning ingredients may cause skin irritation, development of rash or drying resulting in dermatitis [4] [1, 11]. Recent literature suggests that some chemical ingredients like isocyanates may be able to penetrate the skin and cause systemic respiratory effects. The extent to which most cleaning chemicals may permeate the skin and cause systemic effects is unknown [16-18].

Dermal exposures to cleaning agents and related health impacts have been investigated by only a few studies. Vincent at al 1993 investigated the importance of the dermal exposure route for the body uptake of 2-buthoxyethanol (2-BE), an ingredient used frequently in cleaning products. Airborne exposure measurements and biological monitoring of 2-BE were conducted among window cleaning workers. Concentrations of 2-BE in the air and concentrations of the 2-BE metabolite in urine, 2-butoxyacetic acid, were measured. The study showed no correlations of airborne exposures with levels of the metabolite in urine concluding that dermal uptake is an important route for 2-BE to enter the body. Few case reports of skin conditions related to exposures to cleaning agents in the workplace have been published. Hand dermatitis is frequently reported among hospital cleaning workers [19]. Contact dermatitis is reported among hospital workers in Italy at a rate of 21%, mostly among women such as nurses and cleaners [20]. Several known cleaning agents such as anionic and cationic surfactants have been reported in the literature as skin irritants due to their ability to solubilize fats and oils [21].

Exposure to cleaning agents is seen as a particular concern in hospitals because, driven by the need to protect workers from transmission of bloodborne pathogens, hospitals are increasingly cleaning and disinfecting more. The apparent level of cleanliness in hospitals is very important for patient confidence and usually the lack of cleanliness is perceived as lack of care [28]. Janitors, custodians, aids or other environmental services staffs are responsible for these activities in hospitals. However, many other healthcare workers, such as nurses and medical technicians, may be involved in routine cleaning activities.

Common cleaning products

The focus of the study is on the routine cleaning activities such as floor, window and bathroom cleaning. These activities are performed not only in hospitals, but almost in every workplace. Cleaning products used for this purposes can be classified in two groups based on their function. The first group includes “cleaners” that are designed to mechanically remove the surface contaminants such as soil particles, grease and microorganisms. The second group includes “disinfectants” that are designed to destroy microorganisms [4]. However, in practice the use of products that are comprised of both cleaners and disinfectants is common. Workplace and home cleaning products are often similar, although they may vary in the concentration of active ingredients.

The most common ingredients in cleaning products include surfactants, solvents, acids or bases, fragrances, dyes and pigments, preservatives. Surfactants include detergents, classified as anionic (e.g. polyethylene glycol ethers) and cationic (e.g. alkyl ethoxylates). The function of surfactants is to improve cleaning by lowering the surface tension of water. Solvents are used to dissolve oily substances. Examples of solvents are alcohols (ethanol, iso-propanol) and glycol ethers (e.g. 2-butoxyethanol). Acids have dissolving effects on calcium, while bases have dissolving effects on oily substances. Some of the acids used in cleaners are hydrochloric, phosphoric, acetic and oxalic. Examples of alkaline compounds include sodium hydroxide and calcium carbonate. Fragrances, although common, are not essential for cleaning. They are added to cleaning products to give them a pleasant odor or to mask the unpleasant odor. Preservatives, such as formaldehyde, are used to prevent microbial growth and increase the shelf life of the product [4].

Disinfectants, including chlorine, phenols, ammonia, and quaternary ammonium compounds, are of particular health concern because of their known toxic properties [4, 22]. While disinfecting have essential benefits for human health, their usefulness for routine cleaning activities has been questioned [23] [24] . One hospital study evaluated the necessity of daily disinfection of surfaces not contaminated by biological fluids and concluded that routine disinfection of environmental surfaces does not necessarily make it safer for patients or health care workers in hospitals [25]. There are also questions regarding the risk of microbial resistance to some specific disinfectants, although the evidence to date is minimal [26, 27].

METHODS

Evaluation of product lines and identification of chemical ingredients comprising cleaning mixtures

Information on major products lines and brand names of cleaning products was obtained by interviewing environmental services representatives of six hospitals in

Eastern Massachusetts. All hospitals offered a full range of in-patient and outpatient services and were located in several different cities. They were 3 large sized urban teaching hospitals, one medium sized urban hospital and two medium sized suburban hospitals. Worker 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 manufacturer's 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.

Due to equipment compatibility, cost, and purchasing contracts, institutions including hospitals buy a line of cleaning and disinfecting products from a single manufacturer (e.g. general purpose, window, bathroom and floor cleaners all by the same manufacturer). Our preliminary survey indicated that a limited number of cleaning product lines are used among different hospitals in Massachusetts. Further, our evaluation of the components of the individual products indicated that there was more variability of the ingredients within the product lines (e.g. between bathroom and general purpose cleaners produced by the same manufacturer) than between the same product produced by different manufactures (e.g. bathroom cleaner made by two different manufacturers). We thus concluded that the products investigated in this study are representative of the major products /ingredients used in Massachusetts hospitals.

Determination of the most hazardous ingredients

A list of chemical ingredients identified from MSDSs review was created. Because cleaners are mixtures of many ingredients, a set of criteria was developed to identify and prioritize ingredients with respect to health effects with respiratory and dermal focus. An ingredient was considered to be more hazardous if it: 1) is a sensitizer or irritant, either to the skin or respiratory system; 2) occurred in high concentrations in the product; 3) occurred frequently in multiple cleaning products; 4) was a volatile compound.

Respiratory and skin irritation and sensitization have been associated with exposures to cleaning agents from epidemiological studies and several case reports. Although other adverse health effects could be associated with these exposures our study was focused mostly on the agents that cause respiratory and skin irritation and sensitization. Health effects and physical-chemical properties of the ingredients were researched using several tools such as online Hazardous Substances Data Bank (HSDB), the ACGIH 2006 TLVs and BEIs booklet [29] , the NIOSH pocket guide to chemical hazards [30]. In addition, literature searches were conducted to provide data on the health effects of exposures to these chemicals. The most hazardous ingredients were then selected for further qualitative/semi quantitative assessment of airborne and dermal exposures.

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.

A "task" was defined as a cleaning activity that requires application of one single product type. Common cleaning tasks performed on a daily basis included patient room cleaning, bathroom cleaning and floor cleaning. Patient room cleaning and bathroom cleaning involved several tasks such as mirror cleaning, toilet bowl cleaning, counter cleaning and floor cleaning.

Cleaning tasks were performed very similarly among different hospitals. Each task involved a series of process steps such as mixing, spraying or wiping. Flow charts were developed for each of the cleaning tasks observed. They showed similar process steps for similar tasks among different workplaces. An example of the process flow diagram is given in the results section.

Qualitative assessment of inhalation exposures

The potential for inhalation exposures to hazardous chemical ingredients was evaluated qualitatively by investigating three important determinants of inhalation exposure:

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

Intensity of exposure to a chemical ingredient was considered directly proportional to the volatility of the chemical, its concentration in the product, and the volume of the product consumed during the task. Ingredients' volatility data were collected through literature searches; concentration data were obtained from MSDSs review and product consumption data were obtained by workers interviews. Task frequency and duration and the cleaning product application method (spraying, wiping, mopping) were assessed via workplace observations, videotaping and worker's interviews.

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[31],[32],[33]. The DREAM method is based on the conceptual model developed by Schneider [34]. This model accounts for three major mechanisms by which the contaminant could contact the skin: emission, deposition and transfer. Emission is the transport of substances from primary sources to the skin in the form of vapors or particles. Emissions could be also due to splashing, spilling etc. Deposition is the transport from air to the skin and it is dependent on the deposition velocity, concentration in air outside the layer and area of the skin contact. Transfer is the transport of substances by direct contact with skin for example from contaminated working tools[31].

The potential skin exposure per task (Skin-P_{TASK}) was estimated for a set of common cleaning tasks. Estimations were performed based on a series of equations as described in DREAM method [31]. The main elements of these equations include probability and intensity of exposure from emission, deposition and transfer. Potential dermal exposure for the body is presented as the sum potential exposure for 9 body parts: head, hands, upper arms, lower arms, torso front, torso back, lower body part, lower legs, and feet. Cleaning tasks were classified in different exposure categories including “no exposure”; “very low exposure”; “moderate exposure”; and “extremely high exposure”., based on value of the Skin-P_{TASK}. Categories assigned by the DREAM were used for this categorization. Additionally, body parts with the highest potential for dermal exposures during these tasks 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. The main manufacturers of the identified products were Butchers and 3M. 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 were identified by applying the criteria as explained in the methods section. A summary of their health effects and their chemical properties is given in Table 3. The following section describes the chemical and physical properties, health effects of exposures, and the purpose of the application of these ingredients in cleaning products.

Quaternary ammonium compounds (or quats) are used as disinfectants and surfactants in cleaning products. One of the most widely used quats in the cleaning products is benzalkonium chloride or N-Alkyl dimethyl benzyl ammonium chloride. Individually, quats are low-level disinfectants. Commonly, several quats are added in cleaning products in order to achieve both disinfection and detergent properties. In the present investigation, quats were found mostly in the washroom, floor and general purpose cleaners.

Occupational exposures to quats can cause eye, nose and throat irritation. Inhalation exposures to quats could happen from product aerosolization [35]. Occupational asthma has been reported in several case reports after exposure to benzalkonium chloride [15], [12]. Occupational asthma has also been linked to exposure to lauryl dimethyl benzyl ammonium chloride in a case report by Burge 1994 [14]. Repeated occupational exposure to quats solutions can cause skin sensitization and dermatitis. Although, absorption though the skin contact is limited for these polar compounds, they could be absorbed into the body through damaged skin. Bernstein has described a case of combined respiratory and cutaneous hypersensitivity syndrome induced by exposures to quats [15].

. *Ammonia* gas has a strong irritating odor. In its aqua solutions (in cleaning products) equilibrium is established between dissolved ammonia gas and ammonium ions, creating a potential for exposure to ammonia vapors during the application of the products.

$$NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$$

Exposure to its vapors can irritate the nose, throat and lungs causing wheezing and shortness of breath. Prolonged exposure can cause bronchitis. Chronic exposures to ammonia can produce a combined restrictive /obstructive respiratory effect [36]. Skin contact to its solutions can cause dryness, itching and redness. Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) for ammonia exposure is 50 pm 8-hour time weighted average (TWA) and NIOSH REL is 25 ppm over 10 hours of exposure. ACGIH short term exposure limit is 35 ppm. Ammonia hydroxide was found in several products investigated.

Glycol ethers are used as solvents in cleaning products to achieve a homogeneous solution. *2-Butoxyethanol (2-BE)* is one of the most commonly used glycol ethers in cleaning products including glass/window cleaners, carpet cleaners and other surface cleaners. 2-BE is a water miscible colorless liquid, which also dissolves in most organic solvents. 2-BE can volatilize from the solutions, but has a low volatility (boiling point 168.4 ^{0}C). Exposures to its vapors are irritating to the eyes nose, mouth, throat and skin. OSHA permissible exposure limit is 50 ppm (8 h TWA), ACGIH threshold limit value is 20 ppm (8 h TWA) and NOISH recommended exposures limit is 5ppm (10 hour exposure). There is a skin designation for 2- BE from both OSHA and NIOSH. There are not sufficient data on human carcinogenicity, but it is designated as IARC class A3 (confirmed animal carcinogen). Its major metabolite is butoxyacetic acid (BAA) , measured in urine and blood of the human voluntaries exposed through air and skin [37]. No evidence of sensitization to 2-BE exposure was found from the literature review.

*Phenol*s are used as disinfectants in cleaning products. Ortho-benzyl-para-chlorophenol (OBPC) and othro-phenyl phenol (OPP) were commonly used in hospital products. Both have low vapor pressures (respectively BP= 162^{0} C and BP=286^{0}C). Dermal exposure may be their major human exposure route due to their low volatility. They are severely irritant to eyes and corrosive to skin at high concentrations. Mild skin irritation can occur from exposure to diluted solutions. Animal studies suggest that OBPC is potential skin sensitizer [38].

Ethanolamines are used as surfactants in cleaning products. Mono-ethanolamine has low volatility (BP of 171 ^{0}C) and dissolves very well in water. It 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. Prolonged exposure can cause occupational asthma[13]. Ethanolamines are absorbed though the skin and they are known to cause local skin irritation with exposure to high concentrations solutions. Ethylenediamine, diethylenetriamine, and thriethylenetetramine are well known contact sensitizers

Isopropyl alcohol (IP) is a colorless liquid with disinfectant properties. It is a volatile compound with a boiling point 85 ^{O}C. IP can enter the body via inhalation and skin exposure and can irritate the eyes, mucous membranes, and respiratory tract. Repeated skin exposure can cause itching, redness, rash, drying and cracking. *Benzyl alcohol,* with a boiling point of 205^{o}C, has a very low vapor pressure and volatilizes slowly from aqueous solutions. Exposure to benzyl alcohol may occur through inhalation and dermal contact. Vapors are irritating to eyes, nose and throat. It is slightly irritating to skin. *Secondary alcohol ethoxylates* are nonionic surfactants and have become very popular in the last decade because they are more biodegradable than alkyl phenol ethoxylates used for the same purpose. They are eye, respiratory and skin irritants.

Tetrasodium ethylenediamine tetra acetate (or sodium EDTA) is an alkaline solution. It is used in cleaning products to reduce Ca and Mg hardness in water. The most probable routes of exposure would be dermal contact. Due to its alkaline properties exposure to its solutions can cause eye injury and edema.

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 buffing, waxing and stripping.

Preparation of cleaning solutions: Cleaning solutions were prepared at the beginning of the workday. In all cases, solutions were prepared using a dispensing system. No manual mixing was observed. An example of the dispensing system used was the 3M

Twist'n Fill^{TM} Cleaning Chemical Management System. In this case, cleaning products came in the concentrated form in 2 liter bottles labeled with icons to indicate the dispense rate that should be used for preparations. Bottles of the products were placed on the top of the dispenser and mixed with running water. The dilution rate differed from one product to another for example a floor cleaner was diluted with a rate of 3 gal/min and a glass cleaner 1 gal/min.

Floor cleaning tasks: Two methods of floor cleaning were observed: a) wet mop cleaning and b) microfiber mop cleaning. The first is a traditional method that involves dipping the mop into a bucket filled with cleaning solutions. This was observed in most of the cases. In the second (observed in one hospital), microfiber cloths were soaked in cleaning solution and a new one was attached to a mop and used for each patient room. Cleaning solutions were prepared in the preparation room and then placed on a cart for transport to each floor. The duration of the floor cleaning depended on the surface area of the floors cleaned, for example floor cleaning of the patient's rooms required about 5-10 minutes and hallway floor cleaning lasted several hours.

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

Bathroom cleaning tasks: Bathroom cleaning involved several cleaning tasks such as: sink cleaning, mirror cleaning, toilet bow cleaning, and floor cleaning. Products used for these tasks included: a heavy duty glass cleaner (for mirror cleaning), a toilet bowl cleaner/disinfectant (for sink cleaning) and a disinfectant (for floor cleaning). 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. Air deodorant spraying was observed in one case. Its consumption rate was twice higher compared to the glass product usage in the same number of bathrooms.

Floor care tasks (stripping, waxing buffing): Floor stripping was usually performed twice a year or more often in cases where floors were worn or scratched. The stripper was applied to the floor for about 10-20 minutes. A special machine was used to remove the stripper. Floor waxing was performed after stripping by putting a protective coat onto the floor, which was buffed as needed. After waxing the floor was left to dry for about 20-40 minutes depending on the indoor air temperature and humidity. Fans were usually used to speed up the drying process. Floor buffing was done on a daily basis by spraying the buffing solution in a localized area. A buffing machine was used to polish the floors. Sometimes these activities were performed in the presence of the patients in the rooms by removing them to the side.

Patients' room cleaning: Cleaning personnel were responsible for cleaning of the patients' rooms at least one time /shift and in addition every time the patient was discharged from the hospital. A combination of several cleaning tasks, such as floor, counters and bathroom cleaning tasks, were performed during patient room cleaning. The duration of each individual task ranged from 5-10 minutes. Several products were applied including general purpose cleaners and bathroom cleaners. These are very frequent short duration tasks. In one hospital the worker was responsible for cleaning 22 rooms per shift. An example of a patient room cleaning flow chart is given in Figure 1.

Inhalation exposures from cleaning tasks

The results of qualitative assessments of inhalation exposures are summarized for several tasks, grouped on their potential for generating airborne exposures.

The first group, floor cleaning, can generate relatively less airborne exposures compared to other tasks. Floor cleaning generates less airborne exposures because: a*)* floor cleaning products investigated contained mainly nonvolatile compounds (such as quats) as the major active ingredient; and b) floor cleaning solutions were considerably more diluted, resulting in fewer emissions in the air. Despite the longer duration of these tasks (example hallway floor cleaning), they produce lower concentrations of VOC in the air, therefore create smaller potential for inhalation exposures. Airborne exposures to these tasks could be characterized as low concentration exposures to VOCs.

The second group of tasks includes: *window/mirror cleaning; sink cleaning; counter cleaning; toilet bowl cleaning.* The potential for inhalation exposures during these tasks can be higher compared to floor cleaning tasks because: a) products used contained many highly volatile compounds at high concentrations (for example concentrations of 2-BE –a main ingredient in these products ranging from 15-40 % by weight); and b) these tasks involved product spraying that creates risk to inhalation exposures of aerosols particles. Product spraying facilitates inhalation exposures to non-volatile ingredients, which could not be possible otherwise. For example, inhalation exposures to quats which are not volatile compounds can happen when general purpose cleaners are sprayed during counter cleaning. Airborne exposures from these tasks can be characterized as very frequent and high concentrations when the product is aerosolized. The highest exposures are expected to happen when the tasks are performed in small volume and unventilated areas.

The third group is the "combination tasks" for example bathroom and patient room cleaning. Because these tasks are performed consecutively after each other, concentration generated from each task can contribute to the overall increase of airborne concentrations compared to when the tasks are performed separately. Individual tasks performed during the patient room cleaning are presented in Figure 1. The shadowed boxes indicate tasks that potentially generate higher airborne exposures. Overall, the potential for inhalation exposures is high for both workers and patients, when cleaning tasks are performed after each other in these small environments.

The fourth group includes floor care tasks, such as stripping, waxing and buffing. Cleaning product evaluation showed that products used for these tasks contain many volatile ingredients including several types of alcohols, and glycol ethers. Furthermore, volatile ingredient product concentrations were among the highest compared to products used for other cleaning tasks. Airborne exposures are expected to be higher when fans are used to speed up surface drying process. The use of the stripping and buffing machines increases the airborne exposures to chemical particles distributed in the air. The frequency of stripping and waxing is very low because these are activities performed only 2-3 times /year. Although less frequent, we concluded that floor care cleaning tasks generate the highest airborne concentrations of VOC in the air, creating very high potential for *acute* inhalation exposures to workers performing these tasks.

Dermal exposures from cleaning tasks

DREAM estimations were performed for five cleaning tasks that include: toilet bowl cleaning, sink cleaning, mirror cleaning, floor cleaning with traditional method and floor cleaning with microfiber mops. 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 each contribution of three exposure routes emission, deposition and transfer for each task. The individual body part contribution to the potential total body dermal exposure / task is presented in Figure 3. As indicated in these figures, floor cleaning tasks were associated with the lowest potential for dermal exposures. Overall, hands had the highest potential for dermal exposures compared to other body parts.

DISCUSSION

This study characterized exposures associated with the use of cleaning products by both identifying products' hazardous ingredients and investigating application methods that facilitate generation of these exposures. A considerable number of respiratory and skin irritants and sensitizers were identified from a pool of cleaning products used for common cleaning tasks in hospitals. Application of these products generates vapors, aerosol liquid particles and gases potentially being inhaled by cleaning workers, nurses, doctors or patents. Dermal exposure is probably the most important route of exposure because these ingredients are semi-volatile and application of the products involves skin exposures (such as emersion of hands into cleaning solutions). Overall, the study suggests that workers performing cleaning tasks and other building occupations are at risk of both inhalation and dermal exposures to these hazardous ingredients.

This work shows that:

1. *Cleaning products are complex mixtures of many chemicals.* When investigating ingredients using products MSDSs, it is important to evaluate the concentrated form of a product as well as the RTU form, because ingredients at concentrations less than 1% are not required to be listed. Because sensitization may occur even at trace concentrations, identifying the presence of these compounds in RTU form is important.

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

2-Butoxyethanol, a respiratory and skin irritant, was widely used in general purpose cleaners and glass cleaners. The presence of 2-BE in cleaning products is reported from several studies [39] [40]. Because 2-BE is not a highly volatile compound (boiling point of 168.4 deg C) air concentrations of its vapors are expected to be at low ppm ranges. Quantitative measurements are necessary to assess these exposures and compare them with the existing occupational standards for 2-BE. Dermal exposures to 2-BE is an important exposure route because 1) 2-BE has both lipophilic and hydrophilic properties it can be absorbed through the skin 2) there is a potential for skin contact during cleaning activities.

Quaternary ammonium compounds, known sensitizers, were widely used as disinfectants in many of the products especially in bathroom cleaners. Because quats are salts and not volatile compounds there is a small potential for inhalation exposures to their vapors. However, inhalation exposures to its aerosol liquid particles can happen during product spraying. Dermal exposures are possible during product application or by contacting cleaned surfaces. Several cases of asthma aggravation and other respiratory conditions were reported in hospitals of our study among nurses in the operating rooms.

Reports from these nurses showed that nurses are involved in cleaning activities, therefore both inhalation and skin exposure to quats is possible among this group of workers.

Fragrances were used commonly; however, their chemical name/composition were not reported in MSDSs. Concentrations of fragrances during cleaning activities can be above their odor threshold, because qualitatively they could be smelled during product application. Few studies argue that even at low concentrations, slightly above their odor thresholds, (that are orders of magnitude lower than irritation thresholds), exposures to fragrances can cause respiratory irritation[41]. The presence of the odor was obvious during our visit in the workplace. In many exposure scenarios the odor was unbearable. Bathroom deodorants are also a topic of special interest and worthy of detailed investigation. Even at low concentrations, these chemicals (example terpenes) could react with ozone producing additional species that are airway irritants [42].

Surprisingly, bleach was not used in any of these products compared to findings from other studies, that found that bleach can be responsible for asthma symptoms specifically among domestic cleaners [43, 44].

3. Common cleaning tasks generate airborne exposures.

Cleaning tasks usually produce short term airborne exposures. Exposures to VOCs reach a peak within minutes, but later may decay to background concentrations, depending on room ventilation. This means that beside the workers performing cleaning nurses, doctors, or patients who enter the room after cleaning, are also exposed.

Volatile compounds identified in cleaning products covered a wide range of volatilities and chemical classes. Most of the compounds of our interest were semi volatile, suggesting that expected airborne concentrations are at low ppm range. Air concentrations can to reach the peak when workers perform specific activities, such as spraying and wiping. The concern for inhalation exposures increases for some processes like bathroom cleaning, because they are performed in small and probably poorly ventilated spaces. A quantitative characterization of airborne exposures during activities is necessary to measure peak exposures and exposure profile during and after the tasks

Hazardous exposures related to cleaning agents 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, some compounds such as glycol ethers, are released slowly from the surfaces into air creating potential for inhalation exposures to occupants in the building hours after the cleaning activities are performed [39, 40]. Although the presence of these chemicals could be judged qualitatively from the odor presence, a quantitative assessment is necessary to accurately assess airborne exposures after cleaning tasks are stopped.

4. Common cleaning tasks create potential for dermal exposures.

There is evidence from the scientific literature that many of the ingredients of cleaning products have the ability to permeate skin or enter the damaged skin. Dermal exposures may cause the local skin adverse effects or the systemic effects such as respiratory sensitization. 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. This could 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. 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 & lower legs were at higher risk during floor cleaning. This conclusion is important for developing a strategy for quantitative dermal exposure assessment.

Application of the DREAM method in five cleaning tasks was found useful on separating different applications such as mopping vs. spraying in different exposure categories (see results for floor cleaning vs. sink cleaning). The method did not find a big difference between tasks that involve both spraying and wiping (such as mirror cleaning vs. sink cleaning). However, these results are useful for workplace interventions with the purpose reduction of dermal exposures on body parts and activities that are at higher risk.

5. *Identification of hazardous ingredients is important so that safer alternative(s) can be used or developed.* To avoid potential harm from cleaners, the strategy that is currently employed in workplaces is precautionary in nature, such as by purchasing green cleaning products. Green cleaners may be safer alternative, although a green (environmentally safer) product should also be safer for human health. There are a number of government

agencies that provide information on the green cleaning products. Green Seal is a nonprofit organization that promotes environmentally sound products. A preliminary evaluation of several products, certified by the Green Seal (even the honorable mentions products) revealed the presence of several hazardous ingredients, as defined by this study. Hazardous ingredients identified in these “green “products included quats, 2-BE and other glycol ethers, and mono ethanolamine. The presence of sensitizers and irritants in these products raises the signals that although safer for the environment, these products might not be safe for human health. Because disinfectants are designed to destroy microorganisms, selection of products that perform technically and are safe for humans & environment is challenging. However, exposures to hazardous ingredients can be reduced by improving work practices and careful selection of the areas that disinfection is needed.

6. *Identification of the aspects of task* that generate airborne and dermal exposure is important for development of effective interventions such as worksite policies , job/task redesign , use of safer products and application methods, and improved personal protective equipment.

Limitations:

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.

The results of this work are based on a small number of products. While we think that the products evaluated are representative of those used in Massachusetts hospitals, it is possible that other products with additional ingredients are used elsewhere.

CONCLUSIONS

Common cleaning tasks generate exposures to hazardous ingredients, including respiratory and dermal irritants and sensitizers, which can impact workers involved in cleaning. Both inhalation and dermal exposures are important to consider in exposure assessment strategies for epidemiologic studies and workplace exposure control. This study concludes that exposures are a function of product formulations and product applications. That is why a combination of both a precautionary approach toward finding safer, healthier alternatives and an evaluation of workplace exposures is best for protecting workers and the general public to cleaning hazards. This study suggests that exposure assessment is necessary to investigate the health impact of the currently used products and new alternatives to cleaning products for which health hazard data do not exist or are limited.

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; helped with paper revisions.

Donald Milton: Contributed on DREAM adaptation to cleaning tasks; helped on paper revisions.

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Figures legend:

Figure 1: Process flow chart diagram of a patients' 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: List of chemical ingredients as reported from products' MSDSs

1	*1-Methoxy 2- propanol*	*30*	*Hydroxyacetic acid*
2	*1-Methyl 1-4 (1- Methylethenanal) Cyclohexen Emulsion*	*31*	***Hydroxyalkyl amine oxides***
3	*1-octyl -2-pyrolidinone*	*32*	*Isobutane*
4	***2-Buthoxyethanol***	*33*	***Isopropyl alcohol***
5	*2-Ethyl –hexyloxyethanol*	*34*	*Linear primary alcohol ethoxylate*
6	*2-methoxy-1-propanol*	*35*	*Malic acid*
7	*Alcohol ethoxylates*	*36*	*Monoisopropanolamine*
8	*Aliphatic petroleum distillates*	*37*	***N-Alkyl dimethyl benzyl ammonium chloride***
9	*Alkyl dimethyl benzyl ammonium chloride*	*38*	*N-Alkyl dimethyl ethyl benzyl ammonium chloride*
10	***Ammonia***	*39*	*Nonionic surfactant*
11	***Ammonium hydroxide***	*40*	***Nonyl phenol ethoxylate***
12	*Amphoteric surfactant*	*41*	*Nonylphenoxypoly ethanol*
13	*Benzenesulfonic acid derivative*	*42*	*Octyl decyldimethyl ammonium chloride*
14	***Benzyl alcohol***	*43*	***Octyl dimethyl amine oxide***
15	*Butane*	*44*	***Ortho-benzyl-para chlorophenol***
16	*Calcium carbonate*	*45*	***Ortho-Phenylphenol***
17	*Citic acid*	*46*	*Para-tertiary-amyl phenol*
18	***Didecyl dimethyl ammonium chloride***	*47*	*Polyethylene emulsion*
19	***Di-ethylene glycol mono methyl ether***	*48*	*Propylene glycol methyl ether*
20	*Dioctyl dimethyl ammonium chloride*	*49*	*Quaternary ammonium chlorides*
21	*Dipropylene glycol butoxy ether*	*50*	***Secondary alcohol ethoxylate***
22	*Dipropylene glycol monomethyl ether*	*51*	*Silica, quartz*
23	*Dodecyl benzene sulfonic acid*	*52*	*Sodium hydroxide*
24	*Dye*	*53*	*Sodium metasilicate*
25	***Ethanol***	*54*	***Sodium xylene sulphonate***
26	***Ethanolamine***	*55*	*Telomere B monoether with polyethylene glycol*
27	*Ethyl alcohol*	*56*	***Tetrasodium ethylenediamine tetraacetate***
28	*Ethylenediamine tetra acetic acid*	*57*	*Trebutoxy ethyl phosphate*
29	***Fragrance***		

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

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

Body part	**Emission**	**Deposition**	**Transfer**	**Intrinsic emission (E)**	**Potential Skin Exp.**
	$E_{BP} = P_{E.BP} * I_{E.BP} * ER_E * E$	$D_{BP} = P_{D.BP} * I_{D.BP} * ER_D * E$	$T_{BP} = P_{T.BP} * I_{T.BP} * ER_T * E$	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**
Total body	**12.15**	**3.51**	**15.21**		**30.87**

** Main hazardous ingredient of cleaning product: quaternary ammonium compounds*
**Main activities : dipping the mop into the cleaning solution and mopping*

Table 5. Potential and actual dermal exposure for mirror cleaning*.

Body part	Emission	Deposition	Transfer	Intrinsic emission (E)	Potential Skin Exp.
	$E_{BP}= P_{E.BP} * I_{E.BP} * ER_E * E$	$D_{BP}= P_{D.BP} * I_{D.BP} * ER_D*E$	$T_{BP}= P_{T.BP} * I_{T.BP} * ER_T*E$	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**
Total	**51.3**	**40.8**	**33.3**		**125.4**

** Main ingredient: 2-Buthoxyethanol*
** Main cleaning activities: spray and wipe*

Figure 1: Process flow chart diagram of a patient's room cleaning.

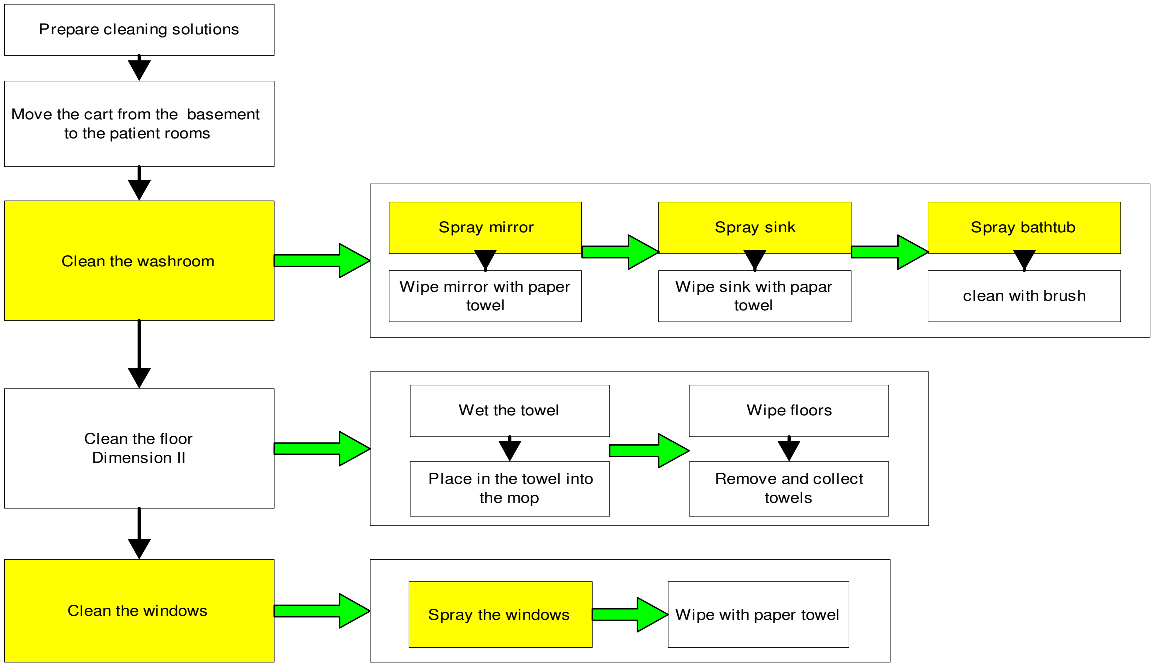

Figure 2: Potential dermal exposure for five cleaning tasks.

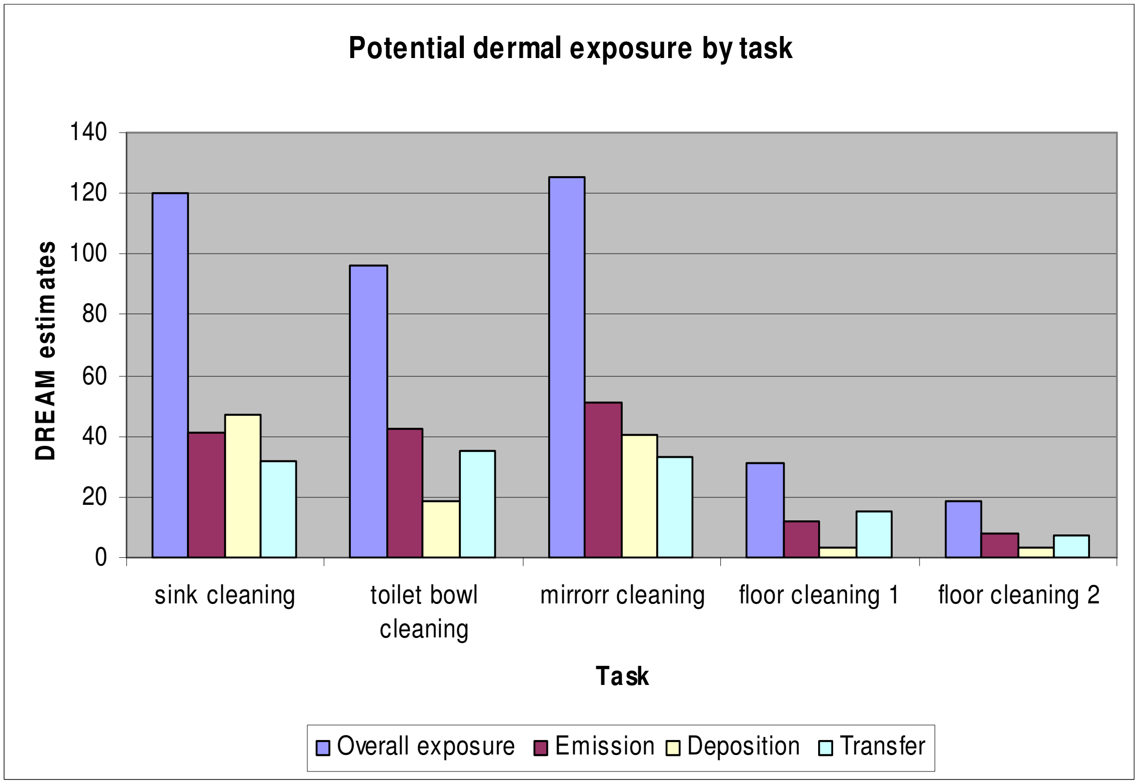

Figure 2

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

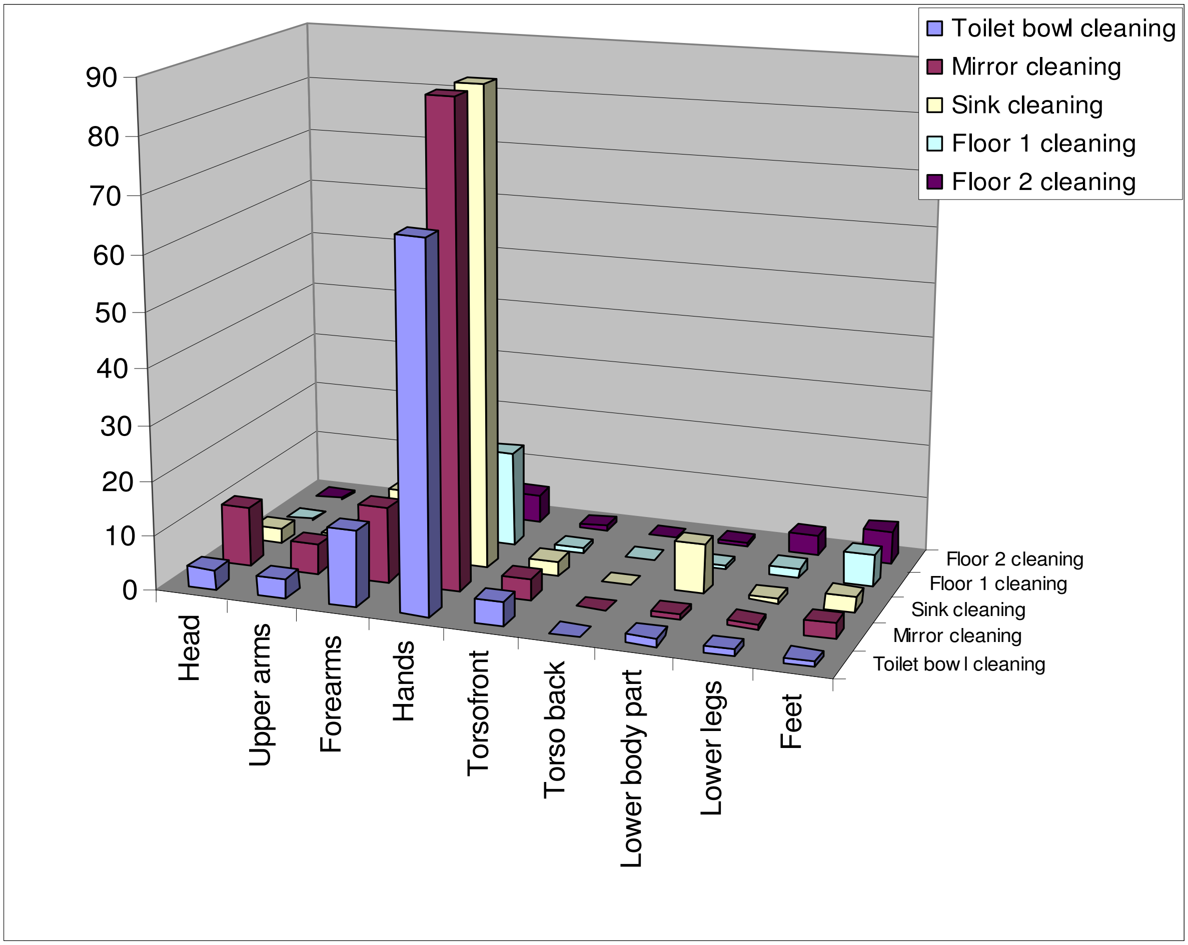

Figure 3

Additional files provided with this submission:

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