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Development of a Job-Task-Exposure Matrix to assess occupational exposure to disinfectants among U.S. nurses

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Abstract

Objectives—Occupational exposure to disinfectants is associated with work-related asthma, especially in healthcare workers. However, little is known about the specific products involved. To evaluate disinfectant exposures, we designed job-exposure (JEM) and job-task-exposure (JTEM) matrices, which are thought to be less prone to differential misclassification bias than self-reported exposure. We then compared the three assessment methods: self-reported exposure, JEM, and JTEM.

Methods—Disinfectant use was assessed by an occupational questionnaire in 9,073 U.S. female registered nurses without asthma, aged 49–68 years, drawn from the Nurses' Health Study II. A JEM was created based on self-reported frequency of use (1–3, 4–7 days/week) of 7 disinfectants and sprays in 8 nursing jobs. We then created a JTEM combining jobs and disinfection tasks to further reduce misclassification. Exposure was evaluated in 3 classes (low, medium, high) using product-specific cut-offs (e.g., <30%, 30–49.9%, ≥50%, respectively, for alcohol); the cut-offs were defined from the distribution of self-reported exposure per job/task.

Results—The most frequently reported disinfectants were alcohol (weekly use: 39%), bleach (22%) and sprays (20%). More nurses were classified as highly exposed by JTEM (alcohol 41%, sprays 41%, bleach 34%) than by JEM (21%, 30%, 26%, respectively). Agreement between JEM and JTEM was fair-to-moderate (kappa: 0.3–0.5) for most disinfectants. JEM and JTEM exposure

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estimates were heterogeneous in most nursing jobs, except in emergency room and education/administration.

Conclusion—The JTEM may provide more accurate estimates than the JEM, especially for nursing jobs with heterogeneous tasks. Use of the JTEM is likely to reduce exposure misclassification.

Keywords

Job-Exposure Matrix; Job-Task-Exposure Matrix; occupational exposure; nurses; disinfectants

INTRODUCTION

Hospital workers, and particularly nurses, are highly exposed to cleaning and disinfecting products both in frequency and intensity.[1,2] To protect patients from healthcare-associated infections, various types of disinfectants are used by healthcare and cleaning workers.[3] The application of infection prevention guidelines has meant that healthcare workers commonly engage in cleaning and disinfection tasks[4] including the use of products in spray form.[3,5] Cleaning and disinfecting products are complex mixtures of many chemicals components, and some of them can cause or exacerbate asthma.[3] Ammonia, bleach, glutaraldehyde, ortho-phthalaldehyde or quaternary ammonium compounds (quats) are common chemicals found in cleaning products or disinfectants.[1,4,6] Several studies have shown associations with onset or symptoms of asthma but little is known about specific agents involved,[2,3,7] which limits the development of disease prevention strategies.[8] Indeed, identifying which specific agents might affect the respiratory health of healthcare workers is challenging,[4,9] partly due to the lack of suitable exposure assessment methods.

Among the methods used in epidemiological studies, self-report is the most common, especially to evaluate exposure to specific agents (e.g., ammonia, bleach). Self-reported exposure may be affected by information biases[10] (memory, misclassification) with potentially differential misclassification between asthmatic and non-asthmatic individuals.[1,10,11] In a study by Donnay et al, the use of cleaning products and disinfectants in hospital workers was significantly underreported when compared to expert assessment.[1] Expert assessment method provides exposure estimates at individual level and thus takes into account variability of exposure between individuals in a same job, but is not practical in the large surveys needed to investigate the asthma risk of specific cleaning and disinfecting agents. Assessment of exposure by a job-exposure matrix (JEM) is less prone to differential misclassification bias than self-report and is a low cost exposure assessment method, but attributes the same exposure to all the workers in a given job,[10,11] and thus doesn't take into account the variability of exposure between workers within the same occupation.[12] Occupational exposure may be heterogeneous for a given occupation according to tasks performed. Several authors underlined the importance of taking into account the tasks to reduce exposure misclassification,[9,13] leading to the emergence of the task-exposure matrix (TEM) and job-task-exposure matrix (JTEM), mainly in cancer epidemiology.[9,12,14,15] To the best of our knowledge, no JEM, TEM or JTEM are available to evaluate exposure to the specific agents or compounds of cleaning products and disinfectants.

Using occupational exposure data collected in 9,073 U.S. registered nurses from the Nurses' Health Study II, we aimed to design nurse-specific JEM and JTEM to evaluate exposure to cleaning products and disinfectants. In addition, we compared exposure assessment based on self-report, JEM and JTEM. Our hypothesis was that important variability in exposure would be observed within jobs according to tasks performed, making the JTEM a likely better method for the assessment of occupational exposure than the JEM.

Methods

Population

The Nurses' Health Study II (NHSII)[16,17] is an ongoing prospective study which began in 1989 when 116,430 registered female nurses aged 25–44 years, from 15 U.S. states, completed a mailed questionnaire on their medical history, lifestyle characteristics and nursing job types. Every two years, follow-up questionnaires were sent to update information on potential risk factors, identify newly diagnosed diseases and nursing jobs. Since 2009, nurses have been asked two questions on the frequency of instrument disinfection and surface cleaning tasks.[6]

In 2014, we initiated a nested case-control study on asthma. In order to evaluate exposure to specific disinfectants among nurses, an occupational questionnaire was sent to nurses with and without asthma. In the current study to design JEMs and JTEMs, to avoid differential misclassification of exposure, we selected at random a sample of 12,280 non-asthmatic nurses (Figure E1) out of those who never reported asthma (from 1989 to 2011; n=94,758) and who were still in a nursing job at the time of the 2011 follow-up questionnaire. Out of 12,280 non-asthmatic nurses, 10,189 were selected among all types of nursing jobs and an additional sample of 2,091 nurses (enriched sample) was selected among operating room, emergency room and intensive care unit nurses in order to enrich the sample of less frequent nursing jobs with expected high exposure levels.

The NHSII study and the current investigation were approved by the Institutional Review Board at the Brigham and Women's Hospital (Boston, Massachusetts, USA).

Current job, disinfecting tasks and use of disinfectants

The 2014 occupational questionnaire was adapted to the U.S. context from a questionnaire used in the European Community Respiratory Health Survey (ECRHS)[18] and the Epidemiological Study on the Genetics and Environment of Asthma, Bronchial Hyper-responsiveness and Atopy (EGEA).[1]

Data on current nursing job was collected in the 2014 occupational questionnaire by the question "Which best describes your current employment status?", with 8 categories provided: nursing in the emergency room (ER), operating room (OR), intensive care unit (ICU), other inpatient nurse, outpatient or community, other hospital nursing, nursing outside hospital and nursing education or administration (see question 1 on figure E2, online supplement). Two questions (4 and 5, Figure E2) regarding the frequency (days/week) of the main disinfecting tasks performed at work were also included: ≪ Thinking about your current job and the use of disinfectants (such as ethylene oxide, hydrogen peroxide, ortho-

phthalaldehyde, formaldehyde, glutaraldehyde and bleach): (a) On how many days per week, on average, do you clean medical instruments with disinfectants? (b) On how many days per week, on average, do you clean surfaces (like floors, tables) at work with disinfectants? (never, <1 day/week, 1–3 days/week, 4–7 days/week) ». These tasks were chosen based on results from the Texas Health Care Workers study,[6] which suggested that they were the most relevant in terms of asthma risk.

Finally, questions were asked about the frequency of use ("On how many days per week do you use the following disinfectants at work?"; see questions 14a to 14p, online supplement, Figure E2) of 14 specific disinfectants (e.g., glutaraldehyde, bleach, quats). Participants could fill in the brand name of the products they use if they did not know the active compound. We searched the safety data sheets of all provided brand names to determine the products' main active compounds. Self-reported exposure to each specific disinfectant was evaluated using crude report and this additional information, and was considered in most analyses as binary variables according to weekly use (1–3 or 4–7 days/week *versus* never or <1 day/week).

Job-Exposure and Job-task exposures Matrices

Current job and use of disinfectant were used to design JEMs and JTEMs by 3 methods based on weekly use of products (yes/no), frequency (days/week) and/or intensity (hours/day) of exposure (Table E1 and figure E2, online supplement). To create JTEMs, the two questions on disinfecting tasks (to clean medical instruments/to clean surfaces) were combined to create a 3-category variable, to define tasks performed weekly: no weekly disinfection tasks; weekly use of disinfectants to clean surfaces only; and weekly use of disinfectants to clean at least medical instruments (regardless the use of disinfectants to clean surfaces). The category "clean instruments only" was not studied separately because of the low number of participants in this category (2.9%); it was thus grouped with the category "clean instruments and surfaces" into the larger category "clean at least instruments".

The first method to generate the JEM and JTEM was based on the percentage of participants reporting exposure to a given disinfectant in a given nursing job (JEM) or for a given nursing job and task category (JTEM).[19,20] The job axis of the JEM included the 8 types of nursing jobs (OR, ER, ICU …). The "job-task" axis of the JTEM included the 24 possible combinations of 8 types of nursing jobs by 3 categories of cleaning tasks (surfaces only, at least instruments, none). For the exposure axis of the JEM and JTEM, the 14 disinfectants and the general use of sprays were considered. However, only 7 disinfectants for which at least 10% of the nurses in at least one nursing job reported weekly exposure (alcohol, hypochlorite bleach, peroxide bleach, glutaraldehyde, quaternary ammonium compounds, enzymatic cleaners, formaldehyde), and sprays, were retained. The other 7 disinfectants (acetic acid, ammonia, chloramine T, ethylene oxide, ortho-phthalaldehyde, peracetic acid, phenolics) were grouped together as "other" (with requirement of exposure to at least one of these agents) since less than 10% of the women reported exposure, regardless of the nursing job.

The second method was based on a score (ranged 0 to 6) combining frequency (0: <1; 1: 1–3; 2: 4–7 days/week) and intensity (1: <1; 2: 1–4; 3: >4 hours/day) of exposure, evaluated by

the following questions “On how many days per week do you use the following disinfectants at work?” for frequency and “On days with disinfectant use, how many hours, on average, do you use disinfectants” for intensity. The score was calculated for each nurse with the assumption that intensity was the same for all disinfectants used. The third method was based on a weighted score according to the frequency of exposure to specific chemicals using the percentage of self-reported exposure weighted by 2 (1–3 days/week) and 5 (4–7 days/week). The second and third methods for both the JEM and JTEM are detailed online (Table E1).

Specific cut-offs were defined to classify exposure in “low”, “medium” and “high” levels for each disinfectant and each method developed (Table E2). Cuts-offs were chosen according to the distribution of the exposure prevalence (e.g., % nurses reporting weekly exposure; Figure 1) over the 24 categories defined by job types and cleaning tasks (i.e., 8 job types by 3 tasks) for each disinfectant. For a given method, the same cut-offs were used for the JEM and the JTEM. The first quartile (Q1) and median were used to define cut-offs for low and high exposure, respectively. For some chemicals, Q1 and the median were very low and minimum cut-offs were defined as follows: for the first method, we choose the maximum value between the median and 10% to define the cut-off for high level exposure; and the maximal value between Q1 and 5% to define the cut-off for low level exposure. Indeed, we considered that classifying a job as “highly” exposed to a specific disinfectant was not realistic if less than 10% of nurses in this job reported being exposed. Similarly, classifying a job as “moderately” exposed to a specific disinfectant was not realistic if less than 5% of nurses in this job reported being exposed.

Statistical analyses

Exposures evaluated by the JEM were compared to those evaluated by the JTEM, and both were compared to self-reported exposure alone. Specificity and sensitivity were computed for each exposure considering the JTEM as the reference, according to our *a priori* hypothesis. Both Cohen’s Kappa (chance-corrected) and Phi (chance-independent) coefficients were calculated to evaluate agreement between JEM and JTEM, as previously suggested.[10] To interpret strength of the agreement, standard cut-offs (poor: <0; slight: 0–0.2; fair: 0.2–0.4; moderate: 0.4–0.6; substantial: 0.6–0.8; and almost perfect: 0.8–1) were used.[21] Differences between JEM and JTEM assessment were tested by the McNemar test.

In addition, sensitivity analyses were performed by stratifying analyses on age (49–54; 55–59; ≥60 years).

All analyses were performed with SAS 9.3 (Cary, NC).

Results

Description of the study population

Out of 12,280 nurses invited, 11,134 (91%) completed the 2014 occupational questionnaire. After excluding 2,061 women (2,057 not in a nursing job in 2014; 4 declined study), the study population included 9,073 non-asthmatic women (figure E1).

The nurses were on average 59 years of age (standard deviation, 4; range, 49 to 68), with slightly younger nurses in the enriched sample (Table 1). In the random sample, 3% of the nurses worked in emergency room, 6% in operating room and 5% in intensive care unit. Most nurses reported working in outpatient or community (23%) and in nursing education or administration (16%). Fifty-four percent of nurses reported that they cleaned surfaces with disinfectants weekly, while 21% cleaned instruments with disinfectants weekly. Fifty-five percent of nurses reported using at least one of the 14 specific disinfectants weekly, 11% used them at least 1 hour per day and 20% performed only administrative tasks (Table 1). Across nursing jobs, the percentage of nurses using disinfectants 4–7 days/week ranged from 5% to 48%, while weekly use ranged from 19% to 88% (Table E3). Nurses in the emergency room, operating room and intensive care unit more often used disinfectants weekly to clean instruments or surfaces (>80%), as compared to other nursing jobs.

The most frequently reported disinfectants were alcohol (weekly use: 39%), hypochlorite bleach (22%) and sprays (20%) (Figure 2). These agents were followed by quats (14%), peroxide bleach (9%), glutaraldehyde (7%), formaldehyde (5%) and enzymatic cleaners (4%).

Definition of cut-offs used to design the JEM and JTEM

The distribution of self-reported occupational exposure varied widely according to disinfectants (Figure 1). Therefore, product-specific cut-offs were defined as described in Methods and table E1. For example, for alcohol, Q1 was 30.0 and median was 49.5; a nursing job in which less than 30% of the nurses reported weekly exposure was thus classified as “low exposure”, between 30% and 49.9% as “medium exposure” and more than 50% as “high exposure” (Table E2). For other disinfectants, exposure levels were similarly assigned based on product-specific Q1 and median. For glutaraldehyde, enzymatic cleaners, peroxide bleach and formaldehyde, values of Q1 and median were very low (less than 5% and 10%, respectively; Figure 1), and minimum cut-offs were used.

JEM and JTEM design

The JEM and JTEM design strategies are presented in Table 2 (examples) and Table E4 (full matrices). Self-reported exposures varied considerably according to nursing jobs and tasks. Among emergency room nurses, 38% reported weekly use of hypochlorite bleach and were classified as highly exposed by the JEM (Table 2). Operating room nurses reported less use of hypochlorite bleach (24%) than emergency room nurses and were classified with medium exposure by the JEM. Exposures within a job also varied according to disinfecting tasks. For example, operating room nurses were assigned a low exposure level to hypochlorite bleach when they performed no cleaning tasks (weekly use reported by 9% of the nurses); those who cleaned only surfaces (weekly use: 24%) were assigned a medium exposure level to hypochlorite bleach; and nurses who cleaned at least instruments (weekly use: 36%) were assigned a high exposure level.

Comparison of self-report, JEM and JTEM exposure assessments

More nurses were classified as exposed overall (i.e., medium or high exposure) by the JEM (alcohol 84%, hypochlorite bleach 84%, sprays 84%) and JTEM (62%, 62%, and 59%,

respectively) than by self-report. In addition, more nurses were classified highly exposed by JTEM (41%, 34%, and 41% for alcohol, hypochlorite bleach and sprays, respectively) than by the JEM (21%, 26%, and 30%, respectively; Figure 2).

JEM and JTEM estimates of exposure were heterogeneous for most nursing jobs and disinfectants, except for nurses working in the emergency room and in education or administration (e.g. 89% and 81% classified similarly by the JEM and the JTEM for hypochlorite bleach, respectively; Table E5). For exposure to formaldehyde, JEM and JTEM estimates were similar.

Comparing high *versus* medium/low exposure, more nurses were classified highly exposed by the JTEM than by the JEM whereas the opposite was observed comparing high/medium *versus* low exposure (Table 3). For alcohol, for example, 21% of the nurses were classified as high exposure with the JEM, versus 41% with the JTEM; however, 84% were classified as high/medium exposure with the JEM and 62% with the JTEM. For most disinfectants, except enzymatic cleaners and formaldehyde, the JTEM classified more nurses in the low and high categories whereas the JEM classified more nurses in the intermediate category (Figure 2). Agreement between the JEM and JTEM was fair-to-moderate (Kappa coefficient: 0.3–0.5) for all disinfectants except for formaldehyde (0.8). Phi values were slightly higher than kappa values for all disinfectants.

Sensitivity analyses

Using methods 2 and 3 to design the JEM and JTEM, exposure assessments were mostly similar to those observed with method 1. We observed discordance between the three methods for peroxide bleach, glutaraldehyde and formaldehyde (2/0/1) for some nursing jobs (Table E6).

Self-report, JEM and JTEM exposure assessment were stratified according to three age categories (49–54/55–59/≥ 60 years). Older nurses were less often classified highly exposed than younger nurses by the JEM and the JTEM, consistently with self-report assessments (Table E7).

Discussion

In a study of 9,073 registered nurses, we found strong heterogeneity in exposure to specific disinfectants, according to both nursing jobs and instrument/surface cleaning tasks. Weekly use of disinfectants to clean surfaces or instruments was commonly reported, especially among nurses working in the emergency room, operating room and intensive care unit. We developed a nurse-specific JTEM to assess occupational exposure to disinfectants, by taking into account the observed variability of exposure in a given job. These results suggest that the JTEM may be the preferred method to assess occupational exposure to disinfectants among nurses, compared to the JEM or self-report. The JTEM is likely to reduce exposure misclassification compared to the JEM, especially for jobs with heterogeneous tasks.

Exposure assessment

Exposure assessment is a crucial step to obtain reliable results when studying associations with the disease.[13] Several methods were developed to assess occupational exposure to cleaning and disinfecting products but none is optimal. The expert method, which is often considered to be the most accurate method for retrospective exposure assessment, takes into account individual occupational information (tasks, specific exposure).[1,22] However, this method is lengthy, expensive, depends on the competency of the expert, and is not practical for large epidemiologic studies; moreover, this method is not reliable for all hazards.[1]

Self-reported exposure is a simple method that allows variations in exposure within job titles[11] and is easily applied in large epidemiologic studies. However, reporting or recall bias might be present and lead to differential misclassification.[11] In the present study, results showed lower prevalence of most self-report exposures compared to JEM and JTEM exposure assessments. Exposure is often under-estimated by healthcare workers in other studies, possibly because some workers do not know the components of the cleaning and disinfecting products they use. In the study by Donnay et al, investigators observed an under-estimation of self-report compared to expert exposure assessment for all hazards.[1]

In respiratory epidemiology, few JEMs have been designed to evaluate occupational risk factors for asthma[23,24] or chronic obstructive pulmonary disease.[19,25] An asthma-specific JEM assessing exposure to asthmagens (known risk factors for occupational asthma), including exposure to non-specific disinfectants[23] has been widely used.[26,27] Two JEMs have been developed in healthcare workers to estimate exposure to a large group of agents[28] and tasks[6] in France and in the U.S., but do not provide specific information regarding the components of cleaning or disinfecting agents.

Quantitative exposure estimates, such as exposure of volatile organic compounds (VOCs), may provide a more accurate characterisation of exposure,[29] but there are also limitations. First, detection limits prevents determination of precise measurements.[30,31] Moreover, for some agents such as quats, atmospheric measurements are difficult due to the low volatility of the agent.[2] Finally, duration of exposure cannot be taken into account, and other sources of VOCs such as building materials can induce errors in measurement.[32] To date only one study with measurement data in U.S. healthcare workers is available.[29] In this study, personal VOC exposures varied among occupations, but different nursing jobs were not distinguished.[29]

Interest of the JTEM

We believe that we are the first to develop a nurse-specific JTEM, to evaluate occupational exposure to specific disinfectants while taking into account the variability of exposure within a given nursing job according to the disinfecting tasks performed.

In previous epidemiologic studies in healthcare workers, registered nurses were considered as a single job.[10,33] The importance to consider tasks in a job has been suggested in the literature.[12,14,15] Taking into account tasks, Droste el al, found significant associations between lung cancer and occupational exposure to carcinogens evaluated through a JTEM, but not with self-report.[15] Our results suggest that the JTEM is more accurate than the

JEM to evaluate exposures for most nursing jobs, except for emergency room and education/administration nursing in which exposure seems more homogeneous within the job.

Using the JTEM rather than a JEM reduces the loss of information due to the grouping of individual data.[34] In the current study, compared to the JTEM, the JEM estimates lacked sensitivity for high exposure level, and lacked specificity for medium exposure level. Both lack of specificity and lack of sensitivity lead to important bias toward the null when evaluating associations with health outcomes.[35] For future work, the JTEM will be applied to study the association between occupational exposure to disinfectants and asthma in the NHSII cohort.

Specific disinfectants and cleaning agents

Cleaning and disinfecting products are complex mixtures of many chemicals components that can cause or exacerbate asthma because of their irritant or sensitizer properties[3] by mechanism still not well understood. In our study, we designed JEM and JTEM to evaluate cleaning products and disinfectant considered as irritants (e.g., bleach, ammonia) and sensitizers (e.g., quats, glutaraldehyde).[36,37] Exposure estimates for each nursing job and task are consistent with the typical use of specific disinfectants in hospitals. For instance, quats are commonly used as non-critical surface (e.g., floors, furniture) disinfectants but also for disinfection of medical equipment that contacts intact skin;[38] glutaraldehyde is used especially for high-level disinfecting of medical equipment such as endoscopes.[38]

In the current study, use of formaldehyde at work was mainly reported by operating room nurses, and all of them were assigned the highest exposure level by the JTEM regardless of the cleaning tasks. A possible explanation is that operating room nurses use formaldehyde for specific tasks like biopsy and not for disinfecting tasks.[38] In addition, given the low proportion of nurses reporting using formaldehyde, we had to use a minimum cut-off value of 10% for “high” exposure and 5% for “medium” exposure. As formaldehyde exposure is likely heterogeneous, this cut-off may poorly discriminate high exposures to formaldehyde. For example, it is unlikely that operating room nurses without disinfecting tasks have high-level exposure (see Table 2). Formaldehyde has been classified as a human carcinogen by the International agency for research on cancer (IARC) and a probable carcinogen by the U.S. Environmental Protection Agency (EPA). Accordingly, its use has probably decreased in hospitals as limited contact with formaldehyde has been recommended.[38]

In a study conducted in 5 U.S. hospitals, cleaning and disinfecting tasks (at least once per shift), were frequent among registered nurses (66%),[9] consistent with our results. Among U.S. hospital workers[6], self-reported exposures to cleaning and disinfecting products during instrument cleaning (42%) and building surface cleaning (78%) were higher than in the present study. In a French study of hospital workers,[1] 15% reported exposure to formaldehyde, 39% to bleach, 64% to alcohol, 14% to quats, 7% to ammonia and 39% to sprays, which is higher than in the current study for all disinfectants, except for quats. However, the study population included cleaners in hospitals, who may have higher exposure levels than nurses. Interestingly, the ranking (most to least frequently used) of the disinfectants was the same as in our study. In another French study, much higher exposure levels were observed (e.g., 98% of registered nurses reported occupational exposure to

quats).[2] However, exposure was defined as reported use of products at least once a month whereas in the present study, weekly exposure was considered. Weekly use of disinfectant or cleaning products has been associated with asthma whereas few studies underline the impact of sporadic exposure (except for a high peak of exposure).

Strengths and limitations

Strengths of our study are its large sample size (n=9,073) and high participation rate (91%). As shown by Delclos et al for cleaning and disinfecting products,[10] it is helpful to construct a JEM blinded to health outcomes to avoid differential misclassification of exposure. Accordingly, we designed the JEM and JTEM using a sample of nurses without asthma to assess occupational exposure independently of the disease. Moreover, we designed literature the JEM and JTEM through a detailed occupational questionnaire providing specific information on cleaning or disinfecting agents, and on instrument and surface cleaning tasks, previously shown to be relevant in terms of asthma risk.[6] We have further collected data on the brand names of the products used by the nurses, and re-evaluated individual exposures to specific chemicals using information from safety data sheets. We used a standardized method to determine product-specific cut-off for high, medium and low exposure levels. In addition, we designed the JTEM using three different methods, based on weekly exposure only or further considering exposure intensity and frequency. The method based on intensity required more assumptions (e.g., that intensity was the same for all disinfectants used), and its accuracy may be further limited by the relatively low proportion of participants reporting to be exposed more than one hour per day. However, for all three methods used to design the JTEM, close exposure assessments were observed for most specific disinfectants (which was less the case for JEMs), supporting the validity of the JTEM estimates. Finally, using the proposed JTEM to evaluate exposure to many disinfectants among nurses is not costly as it is only based on 3 simple questions (type of nursing job and two general cleaning tasks). This tool is thus of particular interest for applications to epidemiological studies of large populations.

The JEM and JTEM we developed also have limitations. First, for some disinfectants (acetic acid, ammonia, chloramine T, ethylene oxide, ortho-phthalaldehyde, peracetic acid, phenolics) the exposure assessment was not available due to the low exposure prevalence (<10%) in all nursing jobs.[39] However, nurses' exposure to these chemicals is likely to be limited or passive. For example, peracetic acid is used in automated machines for instrument sterilization. Ammonia and phenolics, sometimes used to clean environmental surfaces (e.g., bedside tables, bedrails, floors),[3,38] may be used more often by other workers (cleaners, technicians).[9] Furthermore, the JEM and JTEM were developed in a population of U.S. registered nurses, and the reproducibility of these methods in other populations requires further study. Finally, we could not formally validate the JEM and JTEM estimates because of a lack of gold standard, which is a classical limitation of JEMs.[40]

In conclusion, cleaning and disinfecting tasks, which involved the use of various potentially asthmagenic products, are frequent among registered nurses. Occupational exposure among nurses varied widely according to both type of nursing job and tasks. We designed a nurse-specific Job-Task Exposure Matrix that allows investigators to take into account the

variability of exposure within a given job. Creating reliable tools to evaluate occupational exposure to specific agents is crucial to quantify their adverse health effects and further develop optimal strategies to prevent occupational asthma. Going forward, we plan to apply the JEM and JTEM to study the association between occupational exposure to disinfectants and asthma in the whole NHSII cohort.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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What this paper adds

- Assessment of occupational exposure to specific disinfectants is an essential step to evaluate their role in respiratory health. Development of accurate methods of assessment is needed.
- In a study of 9,073 registered nurses, use of disinfectants varied widely according to nursing jobs and related cleaning tasks.
- We developed a nurse-specific job-task-exposure matrix (JTEM) to assess occupational exposure to disinfectants, by taking into account variability of exposure in a given job.
- JTEM is likely to reduce exposure misclassification compared to a job-exposure matrix (JEM), especially for jobs with heterogeneous tasks.

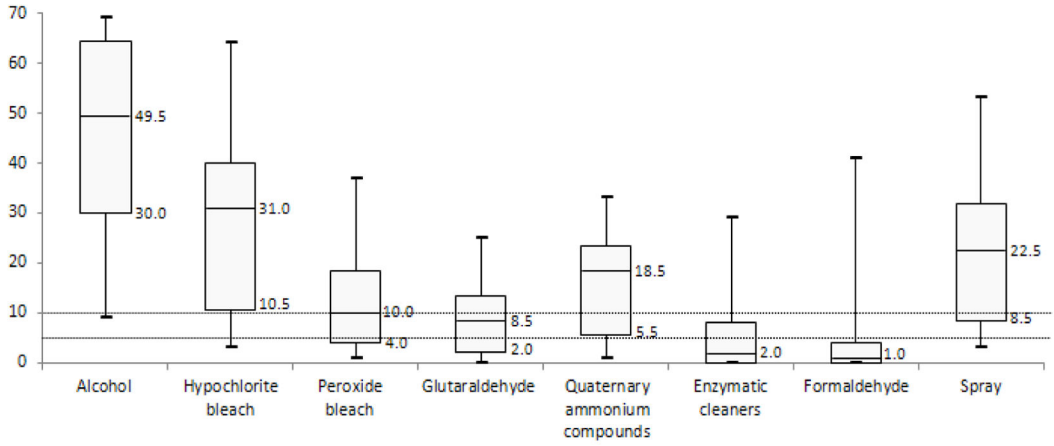

Figure 1. Box-plot of the percentage of participants reporting weekly exposure over the 24 categories defined by job types/cleaning tasks groups (8 job types * 3 tasks) for each disinfectant

The distribution (minimum, quartile 1, median, quartile 3 and maximum) of the 24 values is presented for each disinfectant, and was used to define product-specific cut-offs to create the Job-Exposure Matrix and the Job-Task-Exposure Matrix.

The first quartile (Q1) and the median were used to define cut-offs for each disinfectant. For some chemicals, Q1 or median were very low, we defined minimum cut-offs as the maximal value between Q1 and 5% (minimum cut-off for low exposure category) and the maximal value between median and 10% (minimum cut-off for high exposure category).

Numbers on the right of each boxplot are Q1 and median.

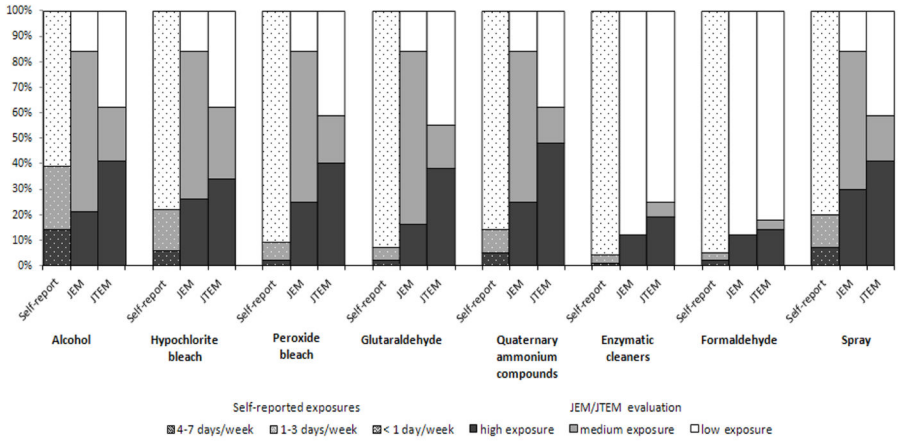

Figure 2. Reported use of disinfectants and evaluation of exposure by the Job-Exposure Matrix (JEM) and by the Job-Task-Exposure Matrix (JTEM)

Reported frequency of use of disinfectants (alcohol (n=8,719), hypochlorite bleach (n=8,628), peroxide bleach (n=8,589), glutaraldehyde (n=8,512), quaternary ammonium compounds (n=8,734), enzymatic cleaners (n=8,549), formaldehyde (n=8,676) and spray (n=8,995) and evaluation of exposure by the job-exposure matrix (JEM) (n=9,073) and by the job-task-exposure matrix (JTEM) (n=8,926).

For the 7 disinfectants and spray, reported frequency of use was missing for 0.9 to 6.6% of the participants.

Table 1

Description of 9,073 female registered nurses without asthma, drawn from the NHS II cohort

	All	Method of selection among NHS II participants	
		Random sample*	Enriched sample*
n	9,073	7,441	1,632
Age, %			
49–54 years	22	22	25
55–59 years	39	38	40
60–68 years	39	40	35
Current job, n (%)			
Emergency room	433 (5)	194 (3)	239 (15)
Operating room	1,074 (12)	482 (6)	592 (36)
Intensive care unit	763 (8)	344 (5)	419 (26)
Other inpatient nurse	1,158 (13)	1,058 (14)	100 (6)
Outpatient or community	2,086 (23)	2,000 (27)	86 (5)
Other hospital nursing	904 (10)	818 (11)	86 (5)
Nursing outside hospital	1,233 (13)	1,195 (16)	38 (3)
Nursing in education or administration	1,422 (16)	1,350 (18)	72 (4)
Self-reported weekly use of disinfectants, %			
To clean surfaces	54	50	74
To clean instruments	21	19	29
Multiple exposures, self-reported, %			
0 product	45	48	29
1 product	24	24	27
2 products	18	17	23
≥3 products	13	11	21
Intensity of exposure, self-reported, %			
< 1 hour/day	89	90	84
1–4 hours/day	9	8	13
> 4 hours/day	2	2	3
Only administrative tasks, %	20	23	6

*Random sample: selected at random among all women in a nursing job in 2011; Enriched sample: selected at random among nurses in ER, OR and ICU (more exposed to disinfectants) in 2011. NHS: Nurses' Health Study.

Table 2

Examples of level of exposure evaluated through Job- and Job-Task -Exposure Matrices using percentage of self-reported weekly use of disinfectants

Jobs		Tasks		Hypochlorite bleach		Glutaraldehyde		Quaternary ammonium compounds		Formaldehyde	
			n	%	Exposure level	%	Exposure level	%	Exposure level	%	Exposure level
Emergency Room	JEM		433	*38*	2	*11*	2	*21*	2	*0*	0
	JTEM	Clean only surfaces	287	*39*	2	*11*	2	*22*	2	*0*	0
		Clean at least instruments *	91	*56*	2	*18*	2	*33*	2	*1*	0
		No disinfecting tasks	49	*4*	0	*0*	0	*2*	0	*0*	0
Operating Room	JEM		1,074	*24*	1	*11*	2	*20*	2	*30*	2
	JTEM	Clean only surfaces	574	*24*	1	*10*	2	*24*	2	*32*	2
		Clean at least instruments *	279	*36*	2	*19*	2	*23*	2	*41*	2
		No disinfecting tasks	204	*9*	0	*3*	0	*4.6*	0	*11*	2
Outpatient or community	JEM		2,086	*18*	1	*8*	1	*14*	1	*2*	0
	JTEM	Clean only surfaces	709	*27*	1	*10*	2	*22*	2	*2*	0
		Clean at least instruments *	387	*37*	2	*22*	2	*24*	2	*9*	1
		No disinfecting tasks	957	*4*	0	*1*	0	*3*	0	*0*	0
Nursing in education or administration	JEM		1,422	*10*	0	*1*	0	*4*	0	*0*	0
	JTEM	Clean only surfaces	226	*34*	2	*4*	0	*14*	1	*0*	0
		Clean at least instruments *	45	*64*	2	*7*	1	*14*	1	*0*	0
		No disinfecting tasks	1,128	*3*	0	*0*	0	*2*	0	*0*	0

Data are presented as n, % of self-reported weekly use and corresponding JEM/JTEM exposure level estimate.

Exposure was evaluated in 3 classes (0: low; 1: medium; 2: high) using product-specific cut-offs defined from the distribution of the percentage of self-reported exposure per job and tasks (see Figure 1 and Table E3 (online supplement)).

* Most nurses in this category reported cleaning instrument and surfaces.

Results are presented as n and rounded percentages (to the nearest whole number, or to the first decimal if the value was close to the JEM/JTEM cut-off)

Table 3

Comparison of JEM and JTEM exposure assessments

n=9,073	JEM exposure evaluation, %	JTEM exposure evaluation, %	Kappa coefficient	Phi coefficient	Sensitivity*	Specificity*
Exposure: high versus medium and low						
Alcohol	21	41	0.33	0.36	39	91
Hypochlorite Bleach	26	34	0.31	0.31	45	84
Peroxide Bleach	25	40	0.32	0.34	43	87
Glutaraldehyde	17	38	0.36	0.42	37	95
Quaternary ammonium compounds	25	48	0.36	0.40	43	92
Enzymatic cleaners	12	19	0.55	0.58	50	97
Formaldehyde	12	14	0.92	0.92	86	100
Spray	30	41	0.32	0.33	48	83
Exposure: high and medium versus low						
Alcohol	84	62	0.32	0.38	95	34
Hypochlorite Bleach	84	62	0.32	0.38	95	34
Peroxide Bleach	84	59	0.29	0.35	95	31
Glutaraldehyde	84	55	0.34	0.45	99	33
Quaternary ammonium compounds	84	62	0.32	0.38	95	34
Enzymatic cleaners	12	25	0.57	0.63	47	100
Formaldehyde	12	18	0.76	0.78	66	100
Spray	84	59	0.29	0.35	95	31

*considering JTEM as reference

McNemar tests: P-value <0.0001 for all disinfectant and exposure