

Asthma among workers in healthcare settings: role of disinfection with quaternary ammonium compounds

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Summary

Introduction An increased incidence of asthma has been reported among healthcare workers. The role of quaternary ammonium compounds (QACs), commonly used in cleaning/disinfection products, has not been clearly defined. The aim of this study was to analyse associations between asthma and occupational exposure to disinfectants, especially QACs. **Methods** The study was performed on a stratified random sample of the various healthcare departments of 7 healthcare settings. The study included: questionnaire, physical examination and specific IgE assays. Occupational exposure assessment was performed by means of a work questionnaire, workplace studies and a review of products ingredients. Data were analysed by logistic regression.

Results Response rate was 77%; 543 workers (89% female) participated; 37.1% were registered nurses (RNs), 16.4% auxiliary nurses (ANs), 17.3% cleaners; 32.8% were atopic. 335 participants were exposed to QACs. Nursing professionals reported a significantly higher risk of reported physician-diagnosed asthma and, for RNs, of nasal symptoms at work than administrative staff working in healthcare sector. This risk was particularly marked during disinfection tasks and when exposure to QACs. Exposure to QACs increased significantly the risk of reported physician-diagnosed asthma and nasal symptoms at work (adjusted OR = 7.5 and 3.2, respectively). No significant association was found with other exposures such as latex glove use, chlorinated products/bleach or glutaraldehyde.

Conclusion RNs and ANs presented a higher risk of reported asthma than administrative staff. The highest risk was associated with tasks involving dilution of disinfection products by manual mixing, suggesting possible exposure to repeated peaks of concentrated products known to be strong respiratory irritants. Workplace interventions should be conducted to more clearly determine QAC exposure and improve disinfection procedures.

Keywords cleaners, disinfection, healthcare workers, nurses, occupational exposure, quaternary ammonium compounds, work-related asthma

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Introduction

Occupational exposures account for a substantial proportion of adult-onset asthma incidence. In recent years, there has been a growing recognition of work-related asthma and rhinitis as a public health concern

because of their high prevalence and societal burden [1–3]. An analysis of general population-based studies published up until 2007 indicated that 17.6% of all adult-onset asthma is attributable to workplace exposures [4]. The Sentinel Event Notification Systems for Occupational Risks Program indicated that healthcare

workers and cleaners emerged as the first or second most frequently reported jobs among all cases of work-related asthma (WRA) reported from 1993 to 1997, as healthcare workers accounted for 16% of the overall confirmed WRA cases [5]. These results are consistent with those of other similar programmes in Europe, such as Surveillance of work-related and occupational respiratory disease in the UK or Observatoire National des Asthmes Professionnels in France [6–9]. In the ECRHS II cohort [10], hospital technicians and other healthcare workers had a more than fourfold increased risk of new-onset asthma compared with the referent group. Concerning nurses, Delclos et al. [11] reported a prevalence of 7.3% for asthma with onset after entry into the profession in a cross-sectional survey of licensed nurses in the United States. At the same time, studies have strengthened the evidence for asthma and other adverse respiratory effects in cleaning workers, but few specific occupational risk factors have been identified [12, 13]. Exposure to cleaning sprays, chlorine bleach and other disinfectants is the factor most commonly mentioned [14]. Healthcare workers (HCWs) are exposed to a large variety of cleaning products containing both irritants and sensitizers. The main sensitizers contained in cleaning products are disinfectants such as quaternary ammonium compounds (e.g. benzalkonium chloride), amine compounds and aldehydes (e.g. formaldehyde or glutaraldehyde). Cleaning products also contain strong irritants such as bleach, hypochlorite and alkaline agents (e.g. ammonia). HCWs present higher exposure levels compared with other groups of cleaners because hospitals use a wide range of disinfectants, and the frequency of cleaning activities has considerably increased to comply with existing regulations and guidelines for the protection of patients from infectious diseases [15]. However, work-related asthma among HCWs has not been well documented with the exception of asthma associated with latex or glutaraldehyde allergies [11, 15, 16]. Quaternary ammonium compounds, usually called 'QACs or quats', are commonly used as disinfectants for surfaces but are also increasingly used for medical instrument or equipment disinfection-related tasks in hospitals and clinics. They frequently replace aldehydes. A recent study on trends of WRA in France for the period 2001–2009 documents a significant increase for cases associated with QAC exposure mainly in health and social sector [17]. Occupational asthma to several QACs has been documented [18–21]. However, the mechanism of QAC-related asthma remains controversial [20, 21]. Few population-based studies on cleaning tasks and use of disinfectants among healthcare workers have characterized in detail the agents responsible for asthma or other reported respiratory symptoms [10, 11, 22–25]. This lack of data

is related to the difficulties of occupational exposure assessment in this sector, the number and variety of products used, the lack of workplace exposure data, particularly concerning product formulations, description of the specific tasks and application procedures.

The purpose of this study was to analyse associations between occupational exposures, cleaning/disinfecting tasks performed and nasals symptoms at work or asthma outcomes among all workers, particularly registered nurses, auxiliary nurses and cleaners compared with administrative staff, of a representative sample of 7 healthcare settings including private and public hospitals and clinics. Exposures and tasks were assessed by questionnaire and expert panel evaluating the workplace setting, particularly for detailed review of QAC exposure.

Methods

Study population and health data

A multi-centre cross-sectional study was conducted between May 2006 and October 2007 in 7 French healthcare settings. Stratified random sampling of the various healthcare departments was performed according to activity (surgery/medicine) and sector (public university hospital/private hospitals or clinics) to obtain an equal number of subjects in each stratum (total of 700 subjects; Fig. 1).

All staff members aged 18–65 years, working for at least 6 months in the sampled departments (physicians, registered nurses (RNs), auxiliary nurses (ANs), charge nurses, cleaners, radiological technicians, physiotherapists, administrative personnel), were eligible for inclusion. An information meeting about study aims and methods was conducted in each sampled department. Informed consent was obtained from all participants, and the study was approved by an independent ethics committee (Advisory Committee on Protection of Persons in Biomedical Research of the University Hospitals of Strasbourg).

For each participant, the study included: a detailed self-administered questionnaire, physical examination and a blood sample with specific IgE assays including Phadiatop®, specific IgE for recombinant rHev b5 and rHev b6.02 latex allergens (ImmunoCAP®, PHADIA Sweden Diagnostics SAS) and specific IgE to quaternary ammoniums performed according to the Guilloux method [26]. IgE values were used in a dichotomous way (increased or normal). Phadiatop is an assay for the determination of atopy. The test comprises a balanced mixture of relevant inhalant allergens that react with specific IgE antibodies in the patient serum. All laboratory assays were performed in the same laboratory (Institut Merieux, Lyon, France).

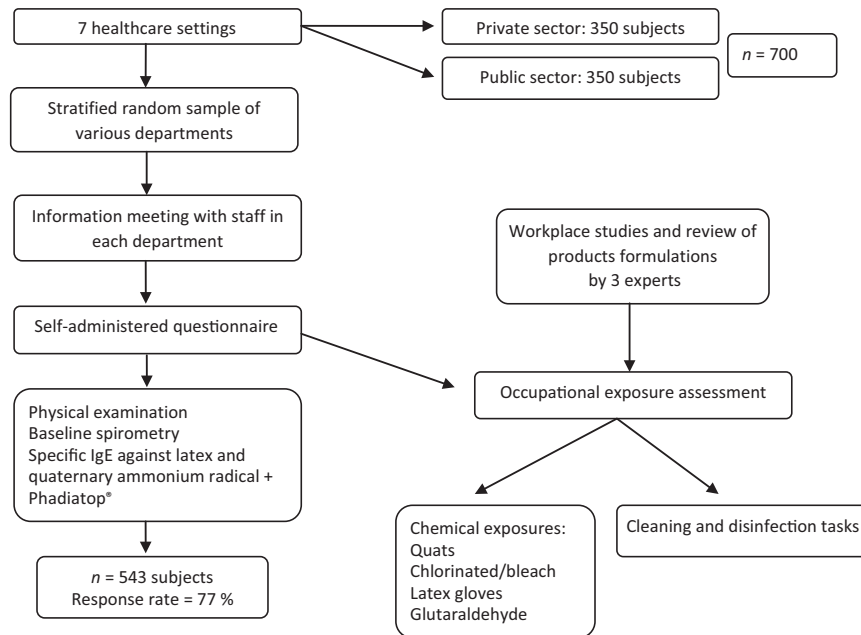


Fig. 1. Study flow chart.

Questionnaire

The self-administered questionnaire was designed and proposed to participants by a multi-disciplinary team (occupational physician, epidemiologist, chest physician and asthma specialist). The questionnaire included questions about ear, nose, throat (ENT) and respiratory symptoms, medical history, especially allergy, asthma medication taken, detailed occupational and exposure data, especially occupational history, current job, various disinfection and cleaning tasks performed, cleaning and disinfection products used (type or brand name, frequency of use), latex glove use, course of symptoms in relation to work/rest periods or according to the products used at work. Symptoms and questions related to asthma were selected from validated questionnaires, such as those of the European Community Respiratory Health Survey (ECRHS) [27], the International Study of Asthma and Allergies in Childhood (ISAAC) [28] and the Epidemiological Study of Genetics and Environment in Asthma (EGEA) [29].

Dependent variables

Three dichotomous outcome variables were defined, based on questionnaire responses:

- Physician-diagnosed asthma: this variable was defined as positive responses to both 'have you ever had asthma?' and 'was it confirmed by a doctor?'.
- New-onset asthma: this variable was defined as physician-diagnosed asthma but reporting onset after entry in the healthcare sector.

- Nasal symptoms at work: this variable was defined as having runny nose or sneezing or blocked nose during last 12 months outside having a cold and having these symptoms during work or when products used at work.

Covariates from the questionnaire were age, gender, number of years as a healthcare worker (seniority), current occupation title, smoking status, body mass index (BMI; kg/m²) classified as normal (< 25.0) or overweight/obese (≥ 25.0) and atopy defined as a positive Phadiatop® test.

Occupational exposure assessment

The main exposures of interest were defined for the current job and in two different ways:

- Cleaning/disinfection-related chemicals of products used.
- Cleaning/disinfection tasks performed.

Disinfection/cleaning product exposure assessment was determined from both the answers to the questionnaire and workplace observations. All Material Safety Data Sheets (MSDS) of the products reported by participants or identified by workplace observations were reviewed by 3 experts (MCK, CD, MG) to determine the main ingredients of concern (QACs, chlorinated products/bleach, glutaraldehyde).

The various types of cleaning and disinfection tasks performed were based on questionnaire responses.

- General disinfection tasks concerned disinfection of patient rooms, furniture surfaces, equipment or

instruments, preparation of soaking solutions for instruments disinfection, preparation and dilution of products.

- General cleaning tasks concerned floors, windows and furniture surfaces, sinks, bathrooms, toilets, preparation and dilution of cleaning products.
- High-risk procedures with exposure to higher concentration of products were also identified: product dilution process by manual mixing, use of sprays, placing lids back or not on soaking containers, etc.

Subjects exposed to QACs were defined as those who reported direct use of a QAC containing compound at the workplace at the frequency of at least once a month. Subjects presenting passive exposure to these products without using them directly were included in the non-exposed group. When product ingredients could not be identified, especially for QACs, data were considered as missing values.

Statistical analysis

Simple descriptive statistics were performed by stratifying by current occupation. Pearson's chi-square (χ^2) test or, when appropriate, other non-parametric tests, depending on the sample size (Fisher's exact test), were used to compare independent variables between the various occupation groups. Associations between outcome variables (reported diagnosed asthma, new-onset asthma and nasal symptoms at work), explanatory variables (QACs exposure, latex gloves, chlorinated product exposure, glutaraldehyde exposure, various tasks, use of sprays) and confounding factors (age, gender, smoking status, atopy, BMI, seniority) were examined using unconditional logistic regression analysis. Odds Ratios (OR) and their corresponding 95% confidence intervals (95% CIs) were calculated. All variables with a *P*-value $\leq 10\%$ in univariate analyses were included in the models. All models were adjusted for potential confounding effects. A *P*-value $< 5\%$ was deemed statistically significant.

All analyses were performed with SAS (SAS Institute Inc., Cary NC, release 9.0) or SPSS (SPSS Inc., Chicago III, Statistics 17.0) software.

Results

The overall response rate to the survey was 77%. The study included finally 543 subjects (Fig. 1).

General characteristics

The average age of the study population was 39.9 years (SD = 10.5), and the majority was female (88.9%); 54.8% of subjects had never smoked and 32.8% were atopic (Table 1). Nurses (in France all nurses are

registered nurses, RNs) and auxiliary nurses (or nurse's aides, ANs) represented 53.4% of participants, cleaners 17.3% and administrative personnel working in health-care departments 10.9%. Other occupations were grouped in the 'others' group and mainly comprised physicians (7.4%), charge nurses (4.1%), physiotherapists (3.1%) and midwives (1.1%). Charge nurses were included in the group 'Others' because they performed very rarely cleaning or disinfection tasks. Table 1 presents the general characteristics of study participants according to the current job. Healthcare seniority (total years in healthcare) of nurses and cleaners was lower than that of other professionals; nurses and cleaners were also younger. Current smokers were more frequent among RNs, ANs and cleaners than among other occupations. No significant difference of atopy or BMI was observed according to occupation.

Occupational exposures

Concerning QAC exposure, 75.4% of included participants without missing data, mainly nursing professionals and cleaners, were exposed, while 109 participants were not exposed or only passively (8 subjects). QAC exposure could not be determined for 99 subjects due to lack of information concerning the products used (99/543). The characteristics of occupational exposures according to occupation are described in Table 1. Three hundred and seventeen participants (60.8%) regularly used latex gloves, among these 229 used powdered latex gloves. Almost 75% of RNs wore latex gloves while latex gloves were used less frequently by ANs and cleaners. More than 50% of participants were exposed to chlorinated products or bleach, mainly cleaners and less frequently nurses. Glutaraldehyde exposure was reported by 19.4% of participants. Description of the various tasks performed according to occupation (Table 1) highlighted the very large number of subjects who were regularly exposed to cleaning and disinfection tasks. Preparation of soaking solutions for medical equipment disinfection was mainly performed by ANs and RNs, but less frequently by cleaners. Dilution of disinfection products was mainly performed by RNs and ANs, while dilution of cleaning products was mainly realized by cleaners.

Atopy was more frequent among subjects exposed to QACs (36.4%) than unexposed (27.7%), but the difference was not significant (OR = 1.49, 95% CI [0.90–2.45]).

Description of outcomes

The prevalence of asthma was 11.2% for physician-diagnosed asthma and 4.4% for new-onset asthma (Table 1). RNs and ANs reported a significantly higher

Table 1. General characteristics, outcomes, occupational exposures and tasks of study participants according to occupation and overall

	Total N = 543 N (%)	Nurses N = 201 (37.0) N (%)	Auxiliary nurses N = 89 (16.4) N (%)	Cleaners N = 94 (17.3) N (%)	Others [†] N = 100 (18.4) N (%)	Administrative N = 59 (10.9) N (%)	P-value *
General characteristics							
Gender (missing data = 10)							
Male	59 (11.1)	10 (5.1)	9 (10.5)	0 (0.0)	36 (36.4)	4 (6.8)	< 10 ^{−3}
Female	474 (88.9)	187 (94.9)	77 (89.5)	92 (100.0)	63 (63.6)	55 (93.2)	
Age (years) (missing data = 4)							
0–29	112 (20.8)	65 (32.3)	13 (15.1)	23 (24.7)	4 (4.0)	7 (11.9)	< 10 ^{−3}
30–39	145 (26.9)	67 (33.4)	20 (23.3)	22 (23.7)	24 (24.0)	12 (20.3)	
40–49	160 (29.7)	41 (20.4)	37 (43.0)	29 (31.2)	31 (31.0)	22 (37.3)	
50 +	122 (22.6)	28 (13.9)	16 (18.6)	19 (20.4)	41 (41.0)	18 (30.5)	
Tobacco status (missing data = 8)							
Never smokers	293 (54.8)	107 (53.8)	48 (55.2)	50 (54.4)	55 (55.5)	33 (56.9)	0.041
Former smokers	105 (19.6)	33 (16.6)	17 (19.5)	12 (13.0)	28 (28.3)	15 (25.9)	
Current smokers	137 (25.6)	59 (29.6)	22 (25.3)	30 (32.6)	16 (16.2)	10 (17.2)	
Atopy (missing data = 49)							
No	332 (67.2)	111 (61.3)	52 (64.2)	61 (73.5)	67 (71.3)	41 (74.6)	0.152
Yes	162 (32.8)	70 (38.7)	29 (35.8)	22 (26.5)	27 (28.7)	14 (25.4)	
Body Mass Index (missing data = 83)							
< 25	285 (62.0)	113 (66.9)	42 (53.9)	47 (62.7)	58 (65.2)	25 (51.0)	0.147
≥ 25	175 (38.0)	56 (33.1)	36 (46.1)	28 (37.3)	31 (34.8)	24 (49.0)	
Healthcare sector seniority (years) (missing data = 12)							
0–9	197 (37.1)	97 (48.5)	28 (31.8)	46 (53.4)	11 (11.0)	15 (26.3)	< 10 ^{−3}
10–19	133 (25.0)	45 (22.5)	26 (29.6)	20 (23.3)	31 (31.0)	11 (19.3)	
20 +	201 (37.9)	58 (29.0)	34 (38.6)	20 (23.3)	58 (58.0)	31 (54.4)	
Outcomes variables							
Physician-diagnosed asthma (missing data = 18)							
No	466 (88.8)	161 (83.9)	70 (83.3)	84 (92.3)	94 (94.9)	57 (96.6)	0.003
Yes	59 (11.2)	31 (16.1)	14 (16.7)	7 (7.7)	5 (5.1)	2 (3.4)	
New-onset asthma (missing data = 23)							
No	497 (95.6)	180 (94.2)	78 (94.0)	85 (95.5)	96 (97.0)	58 (100.0)	0.319
Yes	23 (4.4)	11 (5.8)	5 (6.0)	4 (4.5)	3 (3.0)	0 (0.0)	
Nasal symptoms at work (missing data = 0)							
No	253 (46.6)	86 (42.8)	40 (44.9)	43 (45.7)	49 (49.0)	35 (59.3)	0.251
Yes	290 (53.4)	115 (57.2)	149 (55.1)	51 (54.3)	51 (51.0)	24 (40.7)	
Occupational exposures							
Quaternary ammonium compounds (missing data = 99)							
Not exposed	109 (24.6)	4 (2.3)	2 (2.7)	3 (4.5)	50 (61.7)	50 (100.0)	< 10 ^{−3}
Exposed	335 (75.4)	167 (97.7)	73 (97.3)	64 (95.5)	31 (38.3)	0 (0.0)	
Chlorine/bleach (missing data = 19)							
Not exposed	266 (50.8)	95 (47.7)	35 (43.2)	9 (9.8)	78 (78.0)	49 (94.2)	< 10 ^{−3}
Exposed	258 (49.2)	104 (52.3)	46 (56.8)	83 (90.2)	22 (22.0)	3 (5.8)	
Latex gloves (missing data = 22)							
Not exposed	204 (39.2)	50 (25.4)	35 (40.2)	35 (40.7)	29 (31.2)	55 (94.8)	< 10 ^{−3}
Exposed	317 (60.8)	147 (74.6)	52 (59.8)	51 (59.3)	64 (68.8)	3 (5.2)	
Glutaraldehyde (missing data = 239)							
Not exposed	245 (80.6)	68 (69.4)	32 (80.0)	32 (68.1)	63 (91.3)	50 (100.0)	< 10 ^{−3}
Exposed	59 (19.4)	30 (30.6)	8 (20.0)	15 (31.9)	6 (8.7)	0 (0.0)	
Tasks							
Spray use at work (missing data = 17)							
Not exposed	331 (62.9)	101 (50.5)	63 (75.0)	41 (46.1)	73 (73.7)	53 (98.2)	< 10 ^{−3}
Exposed	195 (37.1)	99 (49.5)	21 (25.0)	48 (53.9)	26 (26.3)	1 (1.8)	
General disinfection tasks (missing data = 1)							
No	161 (29.7)	6 (3.0)	3 (3.4)	37 (39.4)	57 (57.6)	58 (98.3)	< 10 ^{−3}
Yes	381 (70.3)	195 (97.0)	86 (96.6)	57 (60.6)	42 (42.4)	1 (1.7)	

(continued)

Table 1 (continued)

	Total N = 543 N (%)	Nurses N = 201 (37.0) N (%)	Auxiliary nurses N = 89 (16.4) N (%)	Cleaners N = 94 (17.3) N (%)	Others [†] N = 100 (18.4) N (%)	Administrative N = 59 (10.9) N (%)	P-value *
Dilution of disinfectants (missing data = 153)							
No	164 (42.1)	6 (4.8)	4 (6.0)	39 (54.9)	57 (81.4)	58 (100.0)	< 10 ⁻³
Yes	226 (57.9)	118 (95.2)	63 (94.0)	32 (45.1)	13 (18.6)	0 (0.0)	
General cleaning tasks (missing data = 9)							
No	167 (31.3)	31 (15.7)	4 (4.7)	3 (3.2)	72 (73.5)	57 (96.6)	< 10 ⁻³
Yes	367 (68.7)	167 (84.3)	82 (95.3)	90 (96.8)	26 (26.5)	2 (3.4)	
Dilution of cleaning products (missing data = 46)							
No	270 (54.3)	107 (55.4)	21 (29.6)	6 (7.0)	83 (89.3)	53 (98.2)	< 10 ⁻³
Yes	227 (45.7)	86 (44.6)	50 (70.4)	80 (93.0)	10 (10.7)	1 (1.8)	
Soaking solution preparation (missing data = 31)							
No	239 (46.7)	51 (26.2)	7 (8.4)	49 (57.0)	74 (83.1)	58 (98.3)	< 10 ⁻³
Yes	273 (53.3)	144 (73.8)	76 (91.6)	37 (43.0)	15 (16.9)	1 (1.7)	

*P-value from Pearson's chi-square test or Fisher's exact test.

[†]Others: other healthcare professionals (physicians, midwives, charge nurses, physiotherapists).

Table 2. Outcomes according to specific IgE assays

	Total N = 494 (%)	Physician-diagnosed asthma* N = number (%)	P-value	New-onset asthma [†] N = number (%)	P-value	Nasal symptoms at work [‡] N = number (%)	P-value
Specific IgE to QACs							
No	462 (93.5)	51 (11.4)	0.515	20 (4.5)	0.197	250 (56.0)	0.588
Yes	32 (6.5)	4 (12.5)		3 (9.3)		19 (59.3)	
Latex-specific IgE recombinant (rHev b5, rHev b6.02)							
No	480 (97.1)	50 (10.4)	0.010	20 (4.3)	0.026	259 (53.9)	0.277
Yes	14 (2.9)	5 (35.7)		3 (21.4)		10 (71.4)	

Missing data: *16; [†]20; [‡]0.

P-value from Pearson's chi-square test or Fisher's exact test.

QACs, quaternary ammonium compounds.

prevalence of asthma than other study participants, especially for physician-diagnosed asthma (16.1% among RNs and 16.7% among ANs, 7.7% among cleaners, 5% among other workers and 2% among administrative staff, $P = 0.003$). A similar tendency was observed for new-onset asthma, but differences between occupation groups were not significant (6% among ANs, 5.8% among RNs, 4.5% among cleaners, 3% among other workers and 0 among administrative, $P = 0.319$). More than 53% of subjects reported nasal symptoms at work during last 12 months (Table 1).

Specific IgE assays

Specific IgE assays were performed in 494 study participants (91% of population), revealing recombinant latex-specific IgE (rHev b5, rHev b6.02) in 14 subjects (2.9%) and specific IgE for QACs in 32 subjects (6.5%). No statistically significant association was found between IgE results for QACs and exposure, asthma or nasal symptoms at work (Table 2).

Risk factors associated with asthma

Unadjusted analysis Unadjusted analysis of *physician-diagnosed asthma* highlighted a significant association with occupation, mainly for RNs and ANs, QACs exposure and some cleaning/disinfection tasks performed. Dilution of disinfection products by manual mixing was the task associated with the highest risk, OR = 4.58, 95% CI [1.87–11.21]. No significant association was found with other exposures such as latex glove use (powdered or not), chlorinated products/bleach or glutaraldehyde.

Reported asthma was also significantly associated with atopy and BMI ≥ 25 kg/m² but not with the other general characteristics of participants (Table 3).

Unadjusted analysis found that QAC exposure was associated with *reported new-onset asthma* but not significantly, and confidence interval was wide (OR = 6.35, 95% CI [0.83–48.19], $P = 0.07$; Table 3). Chlorinated product/bleach exposure was also associated with reported new-onset asthma, but less marked

Table 3. Reported diagnosed asthma and new-onset asthma according to occupational exposures, tasks and general characteristics of study participants (unadjusted analysis)

	Total N = 543 N	Physician- diagnosed asthma N (%)	Crude OR [95% CI]	P-value*	New-onset asthma N (%)	Crude OR [95% CI]	P-value*
Occupational exposures							
Quaternary ammonium compounds (total missing data = 111)							
Not exposed	108	3 (2.8)	1	0.003	1 (0.9)	1	0.070
Exposed	324	47 (14.5)	5.94 [1.81–19.49]		18 (5.6)	6.35 [0.83–48.19]	
Chlorine/bleach (total missing data = 37)							
Not exposed	260	26 (10.0)	1	0.356	8 (3.1)	1	0.100
Exposed	246	31 (12.6)	1.30 [0.75–2.26]		15 (6.2)	2.08 [0.86–5.00]	
Latex gloves (total missing data = 39)							
Not exposed	197	21 (10.7)	1	0.712	8 (4.1)	1	0.650
Exposed	307	36 (11.7)	1.11 [0.63–1.97]		15 (5.0)	1.22 [0.50–2.94]	
Powdered latex gloves (total missing data = 22)							
Not exposed	302	29 (9.6)	1	0.145	12 (4.0)	1	0.553
Exposed	219	30 (13.7)	1.49 [0.86–2.57]		11 (5.1)	1.28 [0.55–2.97]	
Glutaraldehyde (total missing data = 248)							
Not exposed	236	22 (9.3)	1	0.558	7 (3.0)	1	0.060
Exposed	59	7 (11.9)	1.31 [0.53–3.23]		5 (8.5)	3.01 [0.92–9.86]	
Tasks							
Spray use at work (total missing data = 33)							
Not exposed	321	33 (10.3)	1	0.510	13 (4.1)	1	0.535
Exposed	189	23 (12.2)	1.21 [0.69–2.13]		10 (5.3)	1.30 [0.56–3.04]	
General disinfection tasks (total missing data = 19)							
No	157	6 (3.8)	1	0.001	2 (1.3)	1	0.030
Yes	367	53 (14.4)	4.25 [1.79–10.10]		21 (5.8)	4.68 [1.08–20.22]	
Dilution of disinfectants (total missing data = 165)							
No	160	6 (3.8)	1	< 10 ⁻³	2 (1.3)	1	0.049
Yes	218	33 (15.1)	4.58 [1.87–11.21]		12 (5.5)	4.56 [1.00–20.29]	
General cleaning tasks (total missing data = 27)							
No	164	9 (5.5)	1	0.005	3 (1.8)	1	0.060
Yes	352	50 (14.2)	2.85 [1.37–5.95]		20 (5.7)	3.25 [0.95–11.10]	
Dilution of cleaning products (total missing data = 64)							
No	262	29 (11.1)	1	0.876	10 (3.8)	1	0.498
Yes	217	25 (11.5)	1.05 [0.59–1.85]		11 (5.1)	1.35 [0.56–3.25]	
Soaking solution preparation (total missing data = 49)							
No	231	18 (7.8)	1	0.022	9 (3.9)	1	0.583
Yes	263	38 (14.5)	2.00 [1.11–3.61]		13 (5.0)	1.27 [0.53–3.04]	
Disinfection tasks frequency (total missing data = 32)							
Never or sometimes by month	198	12 (6.1)	1	0.003	4 (2.0)	1	0.031
Sometimes by week or every day	313	46 (14.7)	2.67 [1.37–5.17]		19 (6.1)	3.13 [1.05–9.35]	
General characteristics							
Gender (total missing data = 28)							
Male	57	5 (8.8)	1	0.530	3 (5.3)	1	0.769
Female	458	53 (11.6)	1.36 [0.52–3.56]		20 (4.4)	0.83 [0.24–2.88]	
Age (years) (total missing data = 22)							
0–29	108	14 (13.0)	1.78 [0.74–4.31]	0.597	1 (0.9)	0.15 [0.18–1.20]	0.202
30–39	142	17 (12.0)	1.63 [0.69–3.81]		5 (3.5)	0.57 [0.17–1.85]	
40–49	154	18 (11.7)	1.58 [0.68–3.67]		10 (6.6)	1.09 [0.40–2.97]	
50 +	117	9 (7.7)	1		7 (6.0)	1	

(continued)

Table 3 (continued)

	Total N = 543 N	Physician- diagnosed asthma N (%)	Crude OR [95% CI]	P-value*	New-onset asthma N (%)	Crude OR [95% CI]	P-value*
Tobacco status (total missing data = 26)							
Never smokers	280	28 (10.0)	1	0.463	8 (2.9)	1	0.044
Former smokers	104	15 (14.4)	1.52 [0.78–2.97]		9 (8.7)	1.07 [0.31–3.62]	
Current smokers	133	14 (10.5)	1.06 [0.54–2.09]		4 (3.1)	3.14 [1.19–8.52]	
Atopy (total missing data = 65)							
No	320	15 (4.7)	1	< 10 ⁻³	8 (2.5)	1	0.003
Yes	158	40 (25.3)	6.89 [3.67–12.95]		15 (9.5)	4.03 [1.67–9.74]	
Body Mass Index (total missing data = 97)							
< 25	277	21 (7.6)	1	< 10 ⁻³	7 (2.0)	1	0.001
≥ 25	169	31 (18.3)	2.74 [1.52–4.95]		16 (9.1)	4.46 [1.59–8.84]	
Occupation (total missing data = 18)							
Nurses	192	31 (16.1)	5.49 [1.27–23.7]	0.008	11 (5.8)	2.99 [0.83–10.73]	0.369
Auxiliary nurses	84	14 (16.7)	5.70 [1.24–26.12]		5 (6.0)	3.13 [0.74–13.10]	
Cleaners	91	7 (7.7)	2.38 [0.48–11.85]		4 (4.5)	2.33 [0.52–10.44]	
Administrative	59	2 (3.4)	1		0		
Others	99	5 (5.1)	1.52 [0.29–8.07]		3 (1.9)	1	
Healthcare sector seniority (years) (total missing data = 30)							
0–9	191	21 (11.0)	1	0.467	1 (0.5)	1	0.035
10–19	127	18 (14.2)	1.34 [0.68–2.62]		8 (6.4)	0.07 [0.01–0.52]	
20 +	195	19 (9.7)	0.87 [0.45–1.68]		14 (7.2)	0.88 [0.35–2.16]	

*P-value from Pearson's chi-square test or Fisher's exact test.

OR, Odds Ratio; CI, confidence interval.

than that observed for QACs and not significantly, a similar tendency was observed for glutaraldehyde exposure. No relationship was found with latex gloves (powdered or not).

The risks of reported new-onset asthma according to the tasks performed were not significant except for general disinfection tasks and dilution of disinfection products by manual mixing but with wide confidence intervals. Interestingly, a significant relationship was also found with job seniority in healthcare sector with a decreasing risk for seniority above 20 years when compared to the more recent seniority period (0–9 years) taken as reference. As for physician-diagnosed asthma, a significant association was found with atopy, and BMI ≥ 25 (Table 3).

Unadjusted analysis of reported *nasal symptoms at work* highlighted a significant association with occupation but only for RNs compared with administrative staff (OR = 1.95, 95% CI [1.08–3.51]). Concerning chemical exposures, only QAC exposure was significantly associated with these symptoms (OR = 2.52, 95% CI [1.61–3.94]). Disinfection tasks (general, dilution of products, soaking solution preparation) and spray use were at significantly higher risk for nasal symptoms, nevertheless lower than for asthma. Concerning general characteristics, atopy, gender and age were significantly associated with this outcome (Table 4).

A possible dose–response relationship was investigated by association analysis between frequency of

disinfection tasks and outcomes (Tables 3 and 4). Results showed a significantly increased risk for asthma as well as nasal symptoms according to frequency of disinfection tasks.

Multi-variate analysis Multi-variate analysis concerning reported physician diagnosis asthma confirmed the unadjusted results for QAC exposure after adjustment for age, BMI, gender, smoking status and atopy. Other occupational co-exposures (latex gloves, chlorinated products/bleach) were also considered in the model (Table 5). Perform disinfection tasks remained associated with a higher risk of reported diagnosed asthma, contrary to cleaning tasks or soaking solution preparation that became non-significant. Concerning nasal symptoms at work, multi-variate analysis also confirmed the unadjusted results for QAC exposure (Table 6) for disinfection and general cleaning tasks after adjustment for age, BMI, gender and atopy. Spray use and soaking solution preparation became non-significant.

Among disinfection tasks, manual dilution of disinfectant products remained the task with the highest risk for both diagnosed asthma and nasal symptoms at work (OR = 4.01; 95% CI [1.34–12.00] and 1.90; 95% CI [1.13–3.18], respectively; Tables 5 and 6). QAC exposure was the only occupational chemical exposure that remained statistically significant after adjustment. Concerning reported new-onset asthma, the multi-variate analysis did not seem relevant given the small number

Table 4. Nasal symptoms at work according to occupational exposures, tasks and general characteristics of study participants (unadjusted analysis)

	Total N = 543 N	Nasal symptoms at work N (%)	Crude OR [95% CI]	P-value*
Occupational exposures				
Quaternary ammonium compounds (total missing data = 99)				
Not exposed	109	40 (36.7)	1	< 10 ^{−3}
Exposed	335	199 (59.4)	2.52 [1.61–3.94]	
Chlorine/bleach (total missing data = 19)				
Not exposed	266	136 (51.1)	1	0.283
Exposed	258	144 (55.8)	0.82 [0.58–1.16]	
Latex gloves (total missing data = 22)				
Not exposed	204	117 (57.4)	1	0.630
Exposed	317	162 (51.1)	0.77 [0.54–1.10]	
Glutaraldehyde (total missing data = 239)				
Not exposed	245	123 (50.2)	1	0.430
Exposed	59	33 (55.9)	1.25 [0.71–2.23]	
Tasks				
Spray use at work (total missing data = 17)				
Not exposed	331	163 (49.2)	1	0.01
Exposed	195	117 (60.0)	1.54 [1.08–2.21]	
General disinfection tasks (total missing data = 1)				
No	161	71 (44.1)	1	0.005
Yes	381	218 (57.2)	1.69 [1.16–2.45]	
Dilution of disinfectants (total missing data = 153)				
No	164	72 (43.4)	1	0.004
Yes	226	133 (58.8)	1.82 [1.21–2.74]	
General cleaning tasks (total missing data = 9)				
No	167	76 (45.5)	1	0.017
Yes	367	208 (56.7)	1.56 [1.08–2.26]	
Dilution of cleaning products (total missing data = 46)				
No	270	134 (49.6)	1	0.110
Yes	227	129 (56.8)	1.33 [0.93–1.90]	
Soaking solution preparation (total missing data = 31)				
No	239	115 (48.1)	1	0.034
Yes	273	157 (57.5)	1.45 [1.02–2.06]	
Disinfection tasks frequency (total missing data = 14)				
Never or sometimes by month	202	93 (46.0)	1	0.008
Sometimes by week or every day	327	189 (57.8)	1.60 [1.12–2.28]	
Gender (total missing data = 10)				
Male	59	23 (39.0)	1	0.023
Female	474	260 (54.9)	1.90 [1.09–3.30]	
Age (years) (total missing data = 4)				
0–29	112	70 (62.5)	1	0.042
30–39	145	74 (51.0)	0.62 [0.37–1.03]	
40–49	160	88 (55.0)	0.73 [0.44–1.20]	
50 +	122	54 (44.3)	0.47 [0.28–0.80]	
Tobacco status (total missing data = 8)				
Never smokers	137	153 (52.2)	1	0.217
Former smokers	105	64 (61.0)	0.92 [0.61–1.39]	
Current smokers	293	69 (50.4)	1.42 [0.90–2.24]	
Atopy (total missing data = 49)				
No	166	166 (50.0)	1	0.005
Yes	103	103 (63.6)	1.74 [1.18–2.56]	
Body Mass Index (total missing data = 0)				
< 25	359	189 (52.6)	1	0.620
≥ 25	184	101 (54.9)	1.09 [0.76–1.56]	

(continued)

Table 4 (continued)

	Total N = 543 N	Nasal symptoms at work N (%)	Crude OR [95% CI]	P-value*
Occupation (total missing data = 1)				
Nurses	201	115 (57.2)	1.95 [1.08–3.51]	0.250
Auxiliary nurses	89	49 (55.1)	1.78 [0.91–3.47]	
Cleaners	94	51 (54.3)	1.73 [0.89–3.34]	
Administrative	59	24 (40.7)	1	
Others	99	50 (50.5)	1.48 [0.77–2.85]	
Healthcare sector seniority (years) (total missing data = 12)				
0–9	197	112 (56.9)	1	0.463
10–19	133	70 (52.6)	0.84 [0.54–1.31]	
20 +	201	102 (50.7)	0.78 [0.52–1.16]	

*P-value from Pearson's chi-square test or Fisher's exact test.

OR, Odds Ratio; CI, confidence interval.

of cases and the wide confidence intervals found in unadjusted analysis.

Given the high number of missing values in the study, the characteristics of observations with at least one missing data were compared with the others (without missing data). Only occupation was statistically different between the 2 groups. Observations with at least one missing value were more frequent among cleaners and less frequent among nurses (Table 7).

Discussion

The results of this study show that healthcare workers, particularly nursing professionals, presented an increased risk of reported physician-diagnosed asthma and nasal symptoms at work compared with administrative staff working in healthcare sector. Among the various tasks performed, disinfection was associated with a higher risk than simple cleaning, and this study highlighted the relation between reported physician asthma or nasal symptoms at work and the presence of QACs in the products used.

The results concerning asthma prevalence among nursing professionals especially for new-onset asthma (5.8% for RNs, 6% for ANs) are quite similar with those reported in other recent studies conducted according to different designs, as the prevalence of new-onset asthma among healthcare professionals ranged from 6% to 9.8% depending on the study and the job [10, 11, 22, 27, 30].

One of the strengths of this study is a careful identification of QAC exposure by means of a combined approach taking into account self-reported data based on questionnaire and data concerning the products used in the workplace. QACs are widely used in many of the disinfectants and cleaning products used in healthcare settings, especially benzalkonium and didecyl dimethyl

ammonium chlorides. The presence of these substances was confirmed for most subjects (75.4%) based on analysis of the MSDS for the various products performed by 3 experts independently of the medical status of the participants combined with occupational self-reported data. A task-based approach was preferred to simple analysis of job titles, as cleaning/disinfection tasks can vary considerably according to the ward or the healthcare settings, and a similar job title may correspond to different tasks or exposures. This approach also has the advantage of allowing more generalized and more relevant conclusions.

To the best of our knowledge, a detailed population-based assessment of individual QAC exposure and asthma in healthcare facilities has not been published to date. Published data comprising detailed QAC exposure assessment are mainly derived from case reports [18, 19, 21, 31, 32]. This assessment remains complex because of the diversity of the disinfection/cleaning products used in the healthcare settings. Most exposed workers do not know the exact composition of the products that they use and especially whether or not they contain QACs, as confirmed by the results of a recent study conducted among hospital workers comparing self-reported occupational exposure to expert assessment [25]. Investigations based exclusively on self-reported data or job titles cannot determine the participants' real exposure.

Atmospheric measurements are difficult to obtain due to the low volatility of QACs [15, 33]. To our knowledge, 2 job-exposure matrices (JEM) have been developed in healthcare workers [11, 34] but they did not provide any specific information concerning the ingredients of disinfectant products, especially QACs. In particular, one of these JEMs [11, 22] was based on 3 main disinfection/cleaning task groups (related to patients, related to medical instruments, related to building

Table 5. Reported physician-diagnosed asthma according to occupational data after adjustment (multi-variate analysis, logistic regression)

Total N = 543	Adjusted OR [95% CI]	P-value
Occupational exposures*		
Quaternary ammonium compounds (total missing data = 210)		
Not exposed	1	0.005
Exposed	7.56 [1.84–31.05]	
Chlorine/bleach (total missing data = 210)		
Not exposed	1	0.987
Exposed	1.01 [0.47–2.18]	
Latex gloves (total missing data = 210)		
Not exposed	1	0.355
Exposed	0.69 [0.32–1.51]	
Tasks†		
Spray use at work (total missing data = 140)		
No	1	0.622
Yes	0.84 [0.42–1.69]	
General disinfection tasks (total missing data = 131)		
No	1	0.023
Yes	3.16 [1.17–8.52]	
Dilution of disinfectants (total missing data = 244)		
No	1	0.013
Yes	4.01 [1.34–12.00]	
General cleaning tasks (total missing data = 137)		
No	1	0.064
Yes	2.26 [0.95–5.35]	
Dilution of cleaning products (total missing data = 167)		
No	1	0.352
Yes	0.81 [0.39–1.65]	
Soaking solution preparation (total missing data = 155)		
No	1	0.216
Yes	1.56 [0.77–3.18]	

*Variables in the model for occupational exposures: gender, age, tobacco consumption status, atopy, BMI, quaternary ammonium compounds, latex gloves and chlorinated/bleach.

†Variables in the models for tasks: gender, age, tobacco consumption, atopy, BMI, latex gloves and task.

OR, Odds Ratio; CI, confidence interval.

surfaces). The present study described 5 different cleaning/disinfection task groups but based on the real work performed by each participant in their current job.

The correlation between occupational factors and reported physician-diagnosed asthma was demonstrated consistently, as the results were analysed:

- According to *occupation* (OR = 5.49, 95% CI [1.27–23.7] for RNs, 5.70, 95% CI [1.24–26.12] for ANs, 2.38, 95% CI [0.48–11.85] for cleaners).
- By *task* (OR = 4.25, 95% CI [1.79–10.10] for disinfection, 2.85, 95% CI [1.37–5.95] for cleaning).
- By *QAC exposure* (OR = 5.94, 95% CI [1.81–19.49]).

Moreover, a significant increased risk of reported asthma and nasal symptoms was also found according to frequency of disinfection tasks performed.

Table 6. Nasal symptoms at work according to occupational data after adjustment (multi-variate analysis, logistic regression)

Total N = 543	Adjusted OR [95% CI]	P-value
Occupational exposures*		
Quaternary ammonium compounds (total missing data = 210)		
Not exposed	1	0.005
Exposed	3.21 [1.42–7.22]	
Chlorine/bleach (total missing data = 210)		
Not exposed	1	0.945
Exposed	0.98 [0.51–1.86]	
Latex gloves (total missing data = 210)		
Not exposed	1	0.217
Exposed	0.67 [0.36–1.26]	
Tasks†		
Spray use at work (total missing data = 140)		
No	1	0.381
Yes	1.19 [0.80–1.78]	
General disinfection tasks (total missing data = 131)		
No	1	0.011
Yes	1.83 [1.15–2.91]	
Dilution of disinfectants (total missing data = 244)		
No	1	0.014
Yes	1.90 [1.13–3.18]	
General cleaning tasks (total missing data = 137)		
No	1	0.049
Yes	1.55 [1.00–2.39]	
Dilution of cleaning products (total missing data = 167)		
No	1	0.253
Yes	1.26 [0.84–1.90]	
Soaking solution preparation (total missing data = 155)		
No	1	0.139
Yes	1.36 [0.90–2.05]	

*Variables in the model for occupational exposures: gender, age, atopy, BMI, quaternary ammonium compounds, latex gloves and chlorinated/bleach.

†Variables in the models for tasks: gender, age, atopy, BMI, latex gloves and task.

OR, Odds Ratio; CI, confidence interval.

The consistency of these results seemed to support the hypothesis of a risk factor associated with QAC exposure and was confirmed by multi-variate analysis, especially because among tasks, only disinfection remained significant. Differences between nursing professionals and cleaners rates could be explained by the tasks performed (Table 1) and not by a different likelihood of being diagnosed as in France each worker had the same access to care.

Workplace investigations also demonstrated that some tasks, such as dilution by manual mixing could produce higher concentrations of disinfectants. Concentrated products were diluted to the ready to use form at a certain dilution rate. These rates often differed from one product to another or according to task to do. Dilution errors resulting from the use of non-standard procedures, unsuitable containers or dosing errors can

Table 7. Characteristics of the observations with at least one missing data compared with the others, in the multi-variate model for occupational exposures

	Observations with no missing data <i>N</i> = 543	Observations with at least one missing data <i>N</i> = 210	<i>P</i> -value *
Physician-diagnosed asthma (missing data = 18)			
No	293 (88.0)	173 (90.1)	0.460
Yes	40 (12.0)	19 (9.9)	
Gender (missing data = 10)			
Male	39 (11.7)	20 (10.0)	0.542
Female	294 (88.3)	180 (90.0)	
Age (years) (missing data = 4)			
0–29	80 (24.0)	32 (15.5)	0.097
30–39	90 (27.0)	55 (26.7)	
40–49	92 (27.7)	68 (33.0)	
50 +	71 (21.3)	51 (24.8)	
Tobacco status (missing data = 8)			
Never smokers	86 (25.8)	51 (25.3)	0.660
Former smokers	69 (20.7)	36 (17.8)	
Current smokers	178 (53.5)	115 (56.9)	
Atopy (missing data = 49)			
No	219 (65.8)	113 (70.2)	0.327
Yes	114 (34.2)	48 (29.8)	
Body Mass Index (missing data = 83)			
< 25	212 (63.7)	73 (57.5)	0.222
≥ 25	121 (36.3)	54 (42.5)	
Occupation (total missing data = 0)			
Nurses	133 (40.0)	68 (32.4)	0.047
Auxiliary nurses	51 (15.3)	38 (18.1)	
Cleaners	46 (13.8)	48 (22.8)	
Administrative	37 (11.1)	22 (10.5)	
Others	66 (19.8)	34 (16.2)	
Healthcare sector seniority (years) (missing data = 12)			
0–9	130 (39.7)	67 (32.8)	0.233
10–19	81 (24.8)	52 (25.5)	
20 +	116 (35.5)	85 (41.7)	

**P*-value from Pearson's chi-square test.

induce exposure peaks to products known to be strong respiratory irritants. These exposure peaks could explain our results showing a highest risk for asthma associated with disinfection product dilution tasks. Cleaners used more frequently than nurses automated dispensing systems.

Ten participants in our study had very high levels of *QAC-specific IgE*, but no relationship was demonstrated between exposures and asthma. The exact mechanisms involved in the pathogenesis of asthma caused by QAC exposure have not been elucidated [14, 20, 21]. QACs, like other chemical substances, could induce asthma by either non-immunological or immunological mechanisms. Several case reports were in favour of IgE-

mediated hypersensitivity; however, QAC-specific IgE were not detected [19, 21, 31]. In our study, QACs do not appear as strong specific IgE inducers. Our results seem to underline the irritative effect of QACs in the onset of respiratory symptoms. Other authors highlighted the strong irritative properties of QACs and the possibility of developing asthma as a result of low-to-moderate chronic exposure with airway inflammatory changes [14, 35].

Preller et al. [36] suggested that disinfectant use in another sector than health care, among pig farmers in agriculture, may induce immunoglobulin E sensitization to common aeroallergens and was associated with an increase in atopy. Exposure to non-allergic air pollutants was also found in some studies as possible cofactors in atopic sensitization; in particular, diesel exhaust particles could enhance allergic inflammation and induce the development of allergic immune responses [37–39]. Our results do not clearly find an increased risk of atopic sensitization among healthcare workers using disinfectants containing QACs. Although, atopy was a slightly more prevalent among nurses and cleaners than among other personnel, the difference was not significant (Table 1). Concerning association with QAC exposure, atopy was, indeed, more frequent among exposed subjects (36.4%) than unexposed (27.7%), but the difference was not significant (OR = 1.49 [0.90–2.45]).

This study also confirms the frequent use of *chlorinated product/bleach* in healthcare settings. In the literature, exposure to bleach has been linked to asthma and asthma-like symptoms both in the workplace and at home [14, 22, 40, 41]. No statistically significant association was demonstrated between chlorinated product/bleach exposure and asthma in this study, but a twofold higher risk of new-onset asthma was observed (Table 3), which is similar to recently published results [10, 23].

Changes in the occupational asthma prevalence related to *natural rubber latex gloves* have been reported in the recent literature with a reduction in asthma prevalence as a result of preventive measures in healthcare settings [1, 17, 22]. The results of the present study are consistent with these data, as no significant relationship was demonstrated between the use of latex gloves and reported asthma.

A similar trend was observed for *glutaraldehyde*, a disinfectant and chemical sterilant, often used in hospitals especially for disinfecting endoscopes or medical instruments and linked with asthma in previous studies [18]. Glutaraldehyde is now increasingly replaced by other agents. Exposure to glutaraldehyde was associated especially with new-onset asthma but not significantly (Table 3).

This study presents certain limitations:

- The report of asthma is based entirely on answers to a questionnaire, but this questionnaire comprised

carefully selected validated questions generally considered in the literature to be the most specific in epidemiological studies: 'Have you ever had asthma?', and 'If yes, has your asthma been confirmed by a doctor?' [27–29, 42]. It would have been useful to perform a complementary research of non-specific bronchial hyperresponsiveness but it was not possible given the number of participants.

- The excess in frequency of nasal symptoms found in our study could be related to the vagueness of the question with a probably overestimation of this symptom.
- The cross-sectional design of the study cannot establish the temporal relationship between the exposure and outcomes and therefore incident cases of asthma. Workers who had previously experienced severe asthma may have changed jobs prior to the study, resulting in a lower prevalence of reported asthma, possibly reflecting the healthy worker survivor effect with selection bias that is difficult to correct in cross-sectional studies. Moreover, rehabilitation opportunities or job adaptations after developing work-related asthma are usually more limited for cleaners than for nurses and this fact could also explain a selection bias with a lower frequency of asthma among cleaners.
- The occupational exposure results included many missing data, especially for QACs due to the lack of knowledge of products brand names by participants, or the lack of identification of the ingredients of the products used. However, statistical analysis performed on observations with at least one missing value compared with observations without missing data showed that characteristics were similar except for occupation (Table 7). This could have underestimated the frequency of exposure especially among cleaners and, in part, explained the lower risk of asthma in comparison with nursing professionals.
- Finally, although ORs were statistically significant for the associations between physician asthma and QAC exposure, the wide 95% CIs found were in favour of lacked power.

Conclusion

This study shows that healthcare workers, particularly registered nurses and auxiliary nurses, present a higher risk of reported physician-diagnosed asthma than administrative staff working in healthcare sector. This risk is particularly marked during disinfection tasks and in case of exposure to QACs. The major strength of this study concerns the detailed description of cleaning/disinfection tasks and QAC exposure, derived from both self-reported data and workplace studies with an expert review of the ingredients of the products of concern. The highest risks of asthma are associated with disinfection product dilution tasks by manual mixing, suggesting the possibility of dilution errors and exposure to repeated peaks of concentrated products known to be strong respiratory irritants. In future studies, exposure assessments should consider individual behaviours and disinfection procedures. Take into account the presence of QAC in cleaning/disinfecting products is essential. Workplace interventions and training programmes should be conducted to warn workers about the risks, to ensure better protection against QAC exposure and to improve disinfection procedures, especially for nurses.

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Conflict of interest

The authors declare no conflict of interest.

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