Short Communication

Respiratory and Other Hazard Characteristics of Substances in Cleaning Products Used in Healthcare Centres in England and Wales

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ABSTRACT

Occupational use of cleaning products can cause asthma in healthcare workers but the cleaning agents responsible are not yet known. This study aimed to identify respiratory and other hazards in cleaning products on the National Health Service (NHS) supply chain online catalogue and used in the NHS. Information on cleaning products, their composition, and H-statements that identified hazard characteristics of chemical substances in them was obtained from chemical safety data sheets (SDSs). Furthermore, a quantitative structure-activity relationship model and a published asthmagen list were used to identify potential additional respiratory hazards. 473 cleaning products and 229 substances were identified. SDSs reported only 4 respiratory sensitizers but an additional 51 were suggested by the other 2 methods. In contrast, 25 respiratory irritants were identified using SDSs and only one from the asthmagen list. This comprehensive overview of cleaning agents' hazards has potential use in future risk assessment and epidemiological studies.

1. Introduction

Cleaning products present occupational risks of respiratory or skin disorders such as asthma or dermatitis in cleaning [1,2] and healthcare workers [3]. These professionals use cleaning products routinely for their tasks. A higher risk of asthma has been reported in healthcare workers who use cleaning and disinfection agents for their work more frequently than the healthcare workers who less frequently use them [4]. Additionally, healthcare workers were recommended by the World Health Organization to use cleaning and disinfection products more regularly to eliminate SARS-CoV-2 in healthcare environments during the COVID-19 pandemic [5].

Despite the importance of identifying substances and their hazards, there are no databases with comprehensive information on cleaning agents used in hospitals across the UK, their chemical constituents, and their potential to cause health effects. Outside the UK, a number of databases of non-professional cleaning products and other consumer products have been established [6–9]. For professional cleaning products, a list of cleaning product

substances used by healthcare workers in France has been described but it does not include the hazard characteristics of the substances [10]. Only one comprehensive database was identified in the peer-reviewed literature, which contained data on chemical constituents and hazard information for cleaning agents used by professional cleaners in Switzerland [11].

A database of cleaning products for a workforce, which includes the hazard information of the products' constituent substances, is likely to be of value, particularly in relation to skin and respiratory hazards. A product's chemical safety data sheet (SDS) is a useful tool with which to assess the health hazards of constituent substances as identified by H-statements. Under the UK Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) regulation, whose primary principles are similar to the EU REACH directive, manufacturers or suppliers of the constituents of raw substances have a mandatory requirement to provide downstream users with SDSs [12]. SDSs include general information relating to substances' constituents and composition as well as their human and environmental hazard characteristics according to the Globally

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Harmonized System (GHS) and Regulation (EC) No 1272/2008 on the classification, labeling and packaging of substances and mixtures (CLP) [13]. H-Statements on SDSs are the standardized statements that indicate specific hazards of a product or substance, depending on the type and degree of the hazard [14]. Each individual H-statement, which is assigned a specific number, indicates a different health hazard characteristic that substances and mixtures might have. H-statements on SDSs have been used for identifying hazard characteristics of substances in cleaning products in other studies [11,15].

The manufacturer and supplier of a cleaning product are responsible for providing an SDS with any cleaning products that contain hazardous agents, based on the evidence provided by the suppliers of the chemical components. However, previous studies have shown that the SDSs of cleaning products may not contain information on all the potential respiratory hazardous substances in cleaning products [16].

The aim of this study was to develop a database on cleaning products used in the National Health Service (NHS) in England and Wales, with comprehensive information on the respiratory hazardous substances and general hazards in these products.

2. Methods

2.1. The database of cleaning products

The NHS supply chain manages the order, delivery, and supply of necessary items for operating NHS trusts and healthcare organizations across England and Wales. The NHS supply chain online catalogue provides users with information on all available products [17]. Products in the "Cleaning, hygiene, and infection control" category in the NHS supply chain catalogue were selected. The following products were excluded from the database: 1) solid accessories not containing chemicals (such as bedding and disposable bags); 2) products without SDSs which are potential non-substance-based cleaning products (such as bottles, pods, buckets, and patient wipes); and 3) products with SDSs but which did not list any substances.

All the available SDSs of included cleaning products were downloaded from the NHS supply chain catalogue's website. These cleaning products were collected from the online database initially in April 2019, and subsequently to include any additions in 2021. For each product, the following information was entered into the database: product name, product code, barcode, product physical form, and link to the SDS on the NHS supply chain catalogue website. Moreover, for each substance, the following information was included in the database: substance name, Chemical Abstract Service Registry Number (CAS RN), H-statements, concentration of each substance from the SDSs (% w/w), and functional-use category (FC). The database was developed using Microsoft Excel.

The Functional-use Category (FC) such as surfactant or solvent indicates the role of the substance in products. The Organisation for Economic Co-operation and Development (OECD) has published a list of harmonized FCs [18]. FCs of each substance were reviewed using other resources, mainly in the recent study related to cleaning products from the USA [9], the SaferChoice website [19], etc., and CPCat [20].

2.2. Identification of hazardous substances in cleaning products

2.2.1. Review of H-statements of each substance on SDSs
All H-statements of each component in the same product listed on the product's SDS were reviewed and used as a means of identifying hazardous substances. For each H-statement (e.g. H334: Respiratory sensitization, H335: Respiratory irritation)., the

numbers of hazardous substances and cleaning products containing them were analyzed by FC and physical form.

2.2.2. Identification of potential respiratory hazardous substances
In addition to the information provided on the SDS, two further methods were employed to identify potential respiratory hazards. Respiratory sensitization characteristics of all the individual substances were assessed by a QSAR model [21], which computes a hazard index (HI, value between zero and one) for lower-molecular-weight organic compounds (<1000 Da). For the purpose of this study, a substance with a HI higher than 0.5 was regarded as a potential respiratory sensitizer. In addition, the list of respiratory sensitizers and irritants that cause asthma, developed by the Association of Occupational and Environmental Clinics (AOEC) [22], was used.

3. Results

3.1. Description of cleaning products

Of 524 cleaning products, not solid accessories, identified on the NHS suppliers list. 28 were excluded because they do not contain chemicals and we were not able to find available SDSs on the catalogue and a further 23 products were excluded due to the absence of constituent substance information on the SDSs. In total, therefore, 473 substance-based cleaning and disinfection products, from 38 companies, were included in the database. Their physical forms were predominantly liquid (58.8%), followed by powder (14.8%). Barcodes of 233 products (49.3%) were found. In total, 229 unique chemical agents defined by CAS RN were identified in these products through the SDS. The mean number of constituents in an individual product was 3.0.

Among 229 substances in the cleaning products, the most frequently found constituent substances were sodium carbonate, which was found in 65 products, isopropanol in 52 products, and quaternary ammonium compounds (QACs), benzyl-C12-16-alkyldimethyl, chlorides in 45 products (Table 1). A list of all the constituent substances found is provided in the supplementary information (S1). The amount of a substance included in a cleaning product can vary widely, for example, sodium carbonate accounted for over 60% of one destainer (bleach) product but only 1−3% of one degreaser. Information on the FCs was not found for 66 substances. Surfactant was the most common FC (*n* = 57) among cleaning product substances.

3.2. Respiratory and other hazardous substances in cleaning products

3.2.1. Respiratory hazardous substances identified by SDS, QSAR, and AOEC list
The number of respiratory hazardous substances labeled with H335 (Respiratory irritation, *n* = 25) was greater than the number labeled with H334 (Respiratory sensitization, *n* = 4). Also, 179 (37.8%) cleaning products contained at least one respiratory irritant, compared to 13 products (2.7%) containing a respiratory sensitizer.

Based on the QSAR model and the AOEC asthmagen list, 51 additional potential respiratory sensitizers were identified, increasing the number of cleaning products containing a potential respiratory sensitizer from 13 to 234 (Table 2). 3 respiratory sensitizers; glutaraldehyde (in 7 products), α-amylase (in 4 products), and subtilisin (in 2 products) were identified by two or more methods. Ammonium hydroxide (in 4 products) and hydrochloric acid (in 2 products) were found as respiratory irritants based on both SDSs and the AOEC list (Table 3). Only one

Table 1
List of substances present in at least twenty cleaning products by descending order of frequency

No. products containing the given substance (%)	CAS RN	Name	Formula
65 (13.7)	497-19-8	Sodium carbonate	Na_2CO_3
52 (11)	67-63-0	Isopropyl alcohol	$(CH3)_2CHOH$
45 (9.5)	68424-85-1	Quaternary ammonium compounds, benzyl-C12-16-alkyldimethyl, chlorides	Unspecified (multi-carbon compounds)
41 (8.7)	1310-73-2	Sodium hydroxide	NaOH
35 (7.4)	2634-33-5	1,2-Benzisothiazol-3(2H)-one	C_7H_5NOS
33 (7)	141-43-5	Ethanolamine	$H_2NCH_2CH_2OH$
32 (6.8)	15630-89-4	Sodium percarbonate	Unspecified (mixture)
32 (6.8)	69011-36-5	Isotridecanol, ethoxylated	Unspecified (multi-carbon compounds)
29 (6.1)	2893-78-9	Sodium dichloroisocyanurate	$C_3Cl_2N_3NaO_3$
29 (6.1)	64-17-5	Ethanol	CH_3CH_2OH
28 (5.9)	124-04-9	Adipic acid	$HOOC(CH_2)_4COOH$
28 (5.9)	77-92-9	Citric acid	$C_6H_8O_7$
26 (5.5)	7173-51-5	Didecyldimethylammonium chloride	$C_{22}H_{48}ClN$
23 (4.9)	68439-46-3	Alcohols, C9-11, ethoxylated	Unspecified (multi-carbon compounds)
23 (4.9)	68891-38-3	Alcohols, C12-14, ethoxylated, sulphates, sodium salts	Unspecified (multi-carbon compounds)

further respiratory irritant was found by the AOEC list. The list of respiratory hazardous chemicals identified is provided in Supplementary S2.

3.2.2. Non-respiratory hazardous substances identified by SDSs

When considering non-respiratory hazard statements, the most frequent was substances that cause serious eye damage (H318), with which 92 substances were labeled. 369 (78.0%) products contained one or more hazardous substances labeled H318. There were 89 substances labeled as causing skin irritation (H315), and 88 substances labeled "harmful if swallowed" (H302) (Table 2). The numbers of other hazardous substances not described are provided in Supplementary S3.

4. Discussion

The database of cleaning products used in healthcare in England and Wales presented in this paper demonstrates the frequent presence of a variety of hazardous substances with a potential risk to exposed cleaners and healthcare workers of occupational disorders, such as asthma or dermatitis. Based on SDSs, respiratory irritants were found more frequently than sensitizers in cleaning products, and were present in approximately 40% of cleaning products. However, when the QSAR model and the AOEC asthmagen list were also used, nearly half of cleaning products contained one or more potential respiratory allergens/irritants. Substances hazardous to eyes, skin and those with oral hazards were the most common hazardous substances in this database of healthcare cleaning products, and such substances were contained in over half of the products.

Whilst H-statements on SDSs provide a useful method for screening the hazard characteristics of products and are commonly used in hazard identification studies [11,15], there are some disadvantages to them. Firstly, H-statements are based on self-classification, mainly by manufacturers, and hence the presence of H-statements for the same substance on SDSs from different companies might vary [23]. To try to overcome this problem, ECHA provided a list in Annex VI to the CLP regulation that comprises substances and their harmonized hazards as assessed by the Committee for Risk Assessment [24]. Nevertheless, our study found that the hazard characteristics of the same substances were labeled inconsistently across SDSs. Also, hazardous substances making up less than certain percentages of a product (0.1% or 1% depending on the hazard) can be omitted

Table 2
Hazardous substances by H-statement in cleaning products[*]

Hazard	H-statement or other methods	Description	Number (%) of hazardous substances	Number (%) of products with hazardous substances
Respiratory hazards	H334	Respiratory sensitiser (Rs)	4 (1.7)	13 (2.7)
	H334 or [†]QSAR or [‡]AOEC		55 (24.0)	234 (49.5)
	H335	Respiratory irritant (Rr)	25 (10.9)	179 (37.8)
	H335 or AOEC		26 (11.4)	179 (37.8)
Other hazards	H302	Acute toxicity − oral (Ato)	88 (38.4)	353 (74.6)
	H314	Skin corrosion (Sc)	42 (18.3)	222 (46.9)
	H315	Skin irritation (Sr)	89 (38.9)	290 (61.3)
	H318	Eye damage (Ed)	92 (40.2)	369 (78.0)
	H319	Eye irritation (Er)	77 (33.6)	323 (68.3)

[*] respiratory hazard and other groups identified in over fifteen substances are listed in this table.
[†] QSAR: Quantitative Structure-Activity Relationship (QSAR) needs citation.
[‡] AOEC: List of asthmagen published by Association of Occupational and Environmental Clinics needs citation.

Table 3
Respiratory hazardous substances identified by two or more methods

Respiratory hazard	Methods	No. products containing the given substance (%)	CAS RN	Name
Respiratory sensitiser	H334+QSAR + AOEC	7 (1.5)	111-30-8	Glutaraldehyde
	H334+AOEC	4 (0.8)	9000-90-2	α-Amylase
		2 (0.4)	9014-01-01	Subtilisin
Respiratory irritant	H335+AOEC	4 (0.8)	1336-21-6	Ammonium hydroxide
		2 (0.4)	7647-01-0	Hydrochloric Acid

from the SDS. These cut-points are likely to explain, at least in part, why 23 SDSs were found in our study not to contain any chemicals or hazard information. Due to these disadvantages, using SDSs may not be a sufficient way to identify hazard information relating to all of the individual substances within products.

A number of databases of consumer products including cleaning products [6—8] have been developed, and a list of non-professional cleaning products has been established [9]. However, these databases do not contain health hazard information. In the non-professional cleaning products list in the USA [9], 588 individual substances were identified in 1,093 products. Although there are published lists of professional cleaning agents, one of them did not include hazard information [10] and the other described cleaning agents used by cleaners, not healthcare workers [11].

Consistent with the findings of related studies [9,10], in this study, the most common physical form of cleaning products was liquid. In a previous study [11], the average number of constituent substances was 3.5 ± 2.8 (SD) per professional cleaning product, which was similar to the numbers found in this study. Glycol ethers and 2-butoxyethanol were frequently found previously [11] and in this study. Cleaning product lists can provide information on substances to fill a research gap for further exposure studies and to enable hazard screening for consumers or professionals.

FC relates to the role of a substance in a product, and understanding the FC can suggest a useful way to replace hazardous substances with non/less hazardous substances whilst maintaining the original purpose for which the original substance was included [25]. Also, FC may show useful information for exposure-based prioritization by machine learning techniques [26].

For the respiratory irritants and sensitizers, which might potentially cause or exacerbate asthma in healthcare workers, 55 potential respiratory sensitizers or irritant asthmagens (24.0% of total substances) were identified by their H-statements, the QSAR model or the AOEC asthmagen list. Specifically, the number of potential respiratory sensitizers identified by three methods increased compared to using solely SDSs. Glutaraldehyde, the only respiratory sensitizer identified by all three methods, has been responsible for a number of cases of occupational asthma (OA) in healthcare workers involved in endoscope sterilization [27], and is still used in seven healthcare cleaning products included in this study, albeit at much lower concentrations (0.01—0.1%), than those that were used for high-level disinfection (2—4%) [27]. Ethanolamine, didecyldimethylammonium chloride, and benzyldimethyl(tridecyl)ammonium chloride (Alkyldimethylbenzylammonium chloride) were found as respiratory sensitizers by both the QSAR and the AOEC list simultaneously but not by SDSs. Ethanolamine is a common surfactant and was present in the majority of cleaning products used by hospital cleaners [15]. It is notable that OA cases have been attributed to monoethanolamine and other ethanolamines such as diethanolamine or triethanolamine [28]. Didecyldimethylammonium chloride and alkyldimethylbenzylammonium chloride are QACs which have been frequently reported as respiratory sensitizers [29]. However, they were not identified as sensitizers by SDSs in this study.

Twenty-six irritants (11.4%) were identified by SDS and the AOEC list and the only respiratory irritant identified by the AOEC list but not SDSs was acetic acid. Ethanolamine and sodium metasilicate pentahydrate were observed as hazardous substances with the label H335 (Respiratory irritant) in cleaning products used by cleaners in the Swiss study [11]. Interestingly, ethanolamine featured on SDSs as an irritant but was identified as a sensitizer by the AOEC list and the QSAR model. Sodium dichloroisocyanurate, irritants on SDSs but sensitizer identified by the QSAR model, has been used as a hospital cleaning agent due to its antibacterial properties [30].

Two methods used in this study and the previous study [16], a QSAR model and the AOEC list had limitations to identify potential respiratory sensitizers or irritants. The QSAR model is not able to identify the respiratory sensitization potential of high-molecular-weight compounds and inorganic chemicals [21]. It is also likely to overestimate the number of respiratory sensitizers due to its lower positive predictive value in a screening context [31] even though its negative predictive value in a screening context is high. We have therefore used the phrase "potential respiratory sensitizer" for substances with HI > 0.5 to acknowledge that a high QSAR alone is not proof of this hazard. The applicability of this QSAR model to cationic organic groups, such as in QACs, is also debatable, even though the publicly available version of the model [32] does generate hazard indices. Nevertheless, the clinical evidence that many QACs are respiratory sensitizers, and account for a large proportion of OA in cleaners, is growing [29]. Our finding that the specific QAC, didecyldimethylammonium chloride, to which OA in a cohort of 55 cleaners was most frequently attributed [29], was found in 26 of the 473 (5%) cleaning products in our database. This provides some exposure context to the clinical data. Although the AOEC list has been established based on clinical evidence of asthma causation [22], the list may not identify irritants in work-exacerbated asthma or OA that may be caused by chronic low-dose exposure.

Despite the limitations of the QSAR model and the AOEC list, 51 additional potential sensitizers were found. When solely SDSs were used, no aerosol product contained respiratory sensitizers. However, more than 30% of spray/aerosol products and 40% of liquid products contained potential sensitizers as identified by the QSAR model and AOEC list. Healthcare workers can be exposed to hazardous chemicals by inhalation directly during the use of these products and importantly the use of spray/aerosol products has been associated with OA [33].

A vital step in the risk assessment process is to identify the hazard and risk associated with the hazards appropriately [34]. Then, healthcare workers and their managers could eliminate or substitute the identified hazards. However, if the hazardous substance plays a critical role in cleaning products, managers can set strategies to reduce exposure to the hazard such as ventilation and personal protective equipment. This is especially important for respiratory sensitizers and irritants, as mitigation strategies should be applied regardless of whether the substances are sensitizers or irritants since they frequently co-exist in cleaning products [35]. However, the mechanisms of sensitizer-induced asthma and irritants-induced asthma are different [35]. Hence, medical

treatments for two different types of asthma may vary depending on major exposure.

5. Conclusion

Cleaning agents can be a significant source of exposure to respiratory irritants and sensitizers for healthcare workers. Relying only on the SDSs may underestimate the range of potential exposures to respiratory hazards. The development of this database based upon SDSs, the QSAR, and the AOEC list provides a comprehensive overview of potential respiratory and other hazards and can be used for risk assessment and epidemiology studies.

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CRediT authorship contribution statement

Sewon Lee: Data curation, Funding acquisition, Investigation, Methodology, Validation, Writing — original draft, Writing — review & editing. **Andrew Povey:** Funding acquisition, Investigation, Methodology, Supervision, Writing — review & editing. **Martin Seed:** Conceptualization, Resources, Supervision. **Martie Van Tongeren:** Conceptualization, Data curation, Funding acquisition, Methodology, Resources, Supervision, Validation, Writing — review & editing.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.shaw.2024.04.007.

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