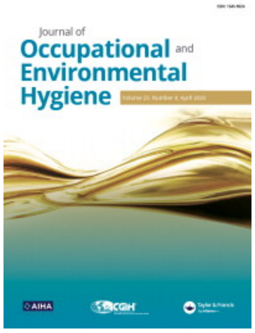

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Occupational toxic inhalation injury to cleaning chemicals during the COVID-19 pandemic, including a case series for disinfectants aerosolized through spray and fog application

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ABSTRACT

The occupational burden of injury caused by exposure to cleaning chemicals during the pandemic is not well described. The objective of this study was to determine whether the COVID-19 pandemic was associated with a change in the rate of toxic inhalation (TI) injuries following occupational exposure to cleaning chemicals. This retrospective study spanned from July 1, 2017, to June 30, 2022, with January 1, 2020, designated as the pandemic start. TI cases were identified among workers' compensation claims filed in Washington State, USA using keyword text search and diagnostic and insurance codes. Qualitative claim data were reviewed to determine the frequency of cases with exposure to aerosolized disinfectants following spray or fog application. Rates of TI claims per full-time equivalent (FTE) workers were compared in the pre- and pandemic periods. Out of the 440 TI claims identified, 30% involved exposure to disinfectants and 13% had a diagnosis of work-related asthma. There was a decline in the overall rate of TI claims in the pre- *vs*. pandemic period (8.9/100,000 FTE *vs*. 7.4/100,000 FTE, respectively). However, the proportion of exposures to disinfectants increased during the pandemic period. Four industries, particularly "Transportation and Warehousing," experienced an increase in TI injury rate. Fog or spray application of disinfectants was involved in 20 cases (including 14 in bus transportation) during the pandemic, compared to zero cases in the pre-pandemic period. In Washington State, the COVID-19 pandemic was associated with industry-specific increased TI injury rates due to cleaning chemicals, but not an overall increased rate. A case series emphasizes that aerosolized disinfectants are a toxic inhalation risk for workers. Studies to further characterize this practice and these injuries are warranted. Prevention efforts should utilize the hierarchy of controls as well as address hazard awareness, product over-application, and the need to estimate and uphold a safe re-occupation time after fog or spray application of disinfectants.

KEYWORDS

Electrostatic spray; hydrogen peroxide; occupational asthma; quaternary ammonia compound; surveillance; transportation industry

Introduction

During the COVID-19 pandemic, public health agencies and the media highlighted the importance of cleaning and disinfecting high-touch surfaces to reduce the transmission of SARS-CoV-2. As a result, many industries rapidly adopted or increased the use of cleaners and disinfectants. In particular, the use of quaternary ammonia compounds (QACs) expanded as they were the active ingredient in the majority of disinfectants approved for use against SARS-CoV-2 (Moran et al. 2024; EPA n.d.-a). Many employers may have had no prior experience with the safe use of these chemicals or with large-area disinfection application techniques such as fogging and spraying.

Globally, occupational exposure to cleaning agents is an established cause of respiratory disease, such as work-related asthma, rhinitis, and chronic obstructive pulmonary disease (COPD) (Mwanga et al. 2024). In a meta-analysis, Archangelidi et al. (2020) concluded that occupational cleaners have an increased risk for

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reversible and irreversible obstructive airway disease; they found a 50% increased pooled relative risk for asthma over 21 studies (meta RR = 1.50; 95% CI 1.44–1.56) and a 43% increased risk for COPD over three studies (meta RR = 1.43; 95% CI 1.31–1.56).

The current study was motivated by a sentinel case reported by a pulmonologist (CS) for toxic inhalation injury caused by exposure to disinfectants applied through fog and later electrostatic spray (ESS) devices during the pandemic. In conjunction with the sentinel case and as early as 2020, poison centers in the United States and globally reported an increase in queries regarding exposure to cleaners, disinfectants, and other products during the COVID-19 pandemic (Chang et al. 2020; Le Roux et al. 2020; Yasseen et al. 2021; Karmali et al. 2024). This study aimed to determine whether the rate of toxic inhalation injuries caused by exposure to cleaning chemicals changed during the COVID-19 pandemic compared to the pre-pandemic period. Inhalation injuries from exposure to disinfectant that was sprayed or fogged are further characterized.

Methods

Data source and surveillance systems

This retrospective cohort study utilized existing surveillance systems for work-related asthma and toxic inhalation (Reeb-Whitaker et al. 2022; Sack et al. 2023). The data source for the surveillance systems was workers' compensation (WC) claims filed for injury following the inhalation of cleaning chemicals. Potential claims were identified for two 30-month periods: the pre-pandemic period of July 1, 2017 through December 31, 2019, and the pandemic period of January 1, 2020 through June 30, 2022. Washington's first laboratory-confirmed COVID-19 case was reported on January 21, 2020 (Washington State Department of Health 2024). This study generalized the start date of the pandemic to January 1, 2020, to align with the quarterly reported payroll data used in case rate calculations.

In Washington State, all employers must obtain WC insurance through the State Fund insurance program administered by the Washington State Department of Labor and Industries (WA L&I n.d.). About 72% of all employees and 99.7% of employers are covered through the State Fund. There are several exemptions to the mandatory State Fund coverage, including employers who meet the requirements to self-insure (RCW 51.12; WA L&I n.d.). The vast majority of the dataset is from the State Fund. Claims from self-insured employers are included when available, as they are provided to L&I, but are limited in number and detail.

Case data for this study was derived from existing work-related asthma and toxic inhalation surveillance systems. The strengths of these surveillance systems include broad population coverage through Washington State Fund industrial insurance, workers' compensation as a stable reporting source, consistent surveillance protocols, longevity, and detailed medical records. Details of the surveillance systems are documented elsewhere (Todorov and Reeb-Whitaker 2021; Reeb-Whitaker et al. 2022; Todorov and Reeb-Whitaker 2024). Briefly, potential asthma and toxic inhalation cases were identified in the WC data using keywords: International Classification of Diseases, Tenth Revision, Clinical Modification (ICD-10-CM) codes; and Occupational Injury and Illness Classification System (OIICS, V1.01.2007) codes. A research analyst reviewed the administrative insurance and medical records to determine if the potential claim met its respective case definition. Work-related asthma (WRA) is asthma that is caused or made worse by workplace exposures. The case definition for WRA is a health care professional's diagnosis consistent with asthma and an association between symptoms and a work-related exposure. Cases that meet the WRA definition are classified according to the Sentinel Event Notification System for Occupational Risks (SENSOR) scheme for WRA (Brooks et al. 1985; Jajosky et al. 1999). The three classifications include: work-aggravated asthma, new-onset asthma with latency, and new-onset asthma without latency, known as Reactive Airways Dysfunction Syndrome (RADS). The case definition for toxic inhalation is an inhalation associated with a work-related exposure, with no specific diagnostic criteria. The analyst assigned up to five exposures to each case, using the Association of Occupational and Environmental Clinics' (AOEC) system, which includes codes for chemicals, dusts, and more (AOEC 2023). The cohort for this study and the term "TI injury" pertained to cases of work-related asthma and/or toxic inhalation (duplicates removed) and assigned at least one exposure code for cleaning materials defined as AOEC code 322 and all sub-codes (AOEC 2023). Examples of cleaning material sub-codes included disinfectant cleaner, bleach, detergent, and general cleaners for floor, oven, carpet, and drain.

When available, the safety data sheets for cleaning products named in the claim were reviewed to determine if the product was marketed as a disinfectant. If the injured worker described their cleaning task as "disinfection" at the time of exposure without specifying the product name, the exposure was assigned a code for disinfectant cleaner. Cases coded as exposed to disinfectant cleaners were further reviewed for reference to their application method, with specific interest in spray, electrostatic spray, or fogging devices.

The industry for the employer at the job-of-injury is available in the WC data and is based on the North American Industry Classification (NAICS) system version 2007. Injury rates were calculated using payroll data submitted to L&I by all active employer accounts for the calculation of insurance premiums. A full-time equivalent (FTE) worker is defined as 500 h per quarter. When calculating total FTEs within the pre- and pandemic periods (2.5 years), one FTE was defined as 5,000 h (2,000 h per year). Statistical differences between the pre- and pandemic periods were done using chi-square tests for categorical data and t-tests for continuous variables, with a level of significance of 0.01. All analyses were done using R Statistical Software (version 4.1.1; R Foundation for Statistical Computing, Vienna, Austria).

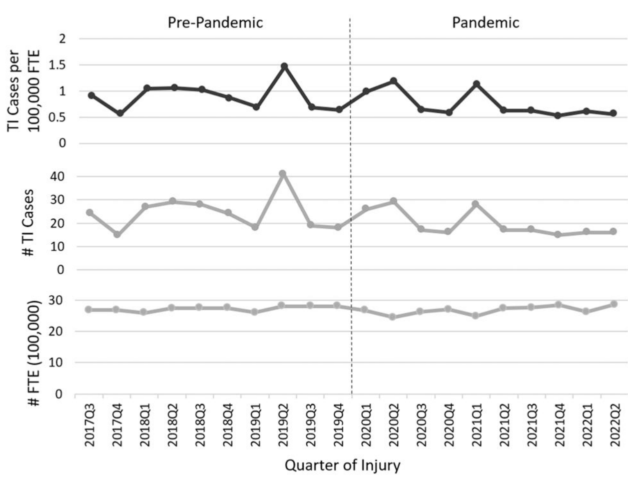

Figure 1. Quarterly toxic inhalation (TI) injury count and rate per 100,000 full-time equivalent (FTE) workers, for the pre-pandemic and pandemic periods.

The Washington State Institutional Review Board approved all protocols and materials used by the surveillance programs, including a consent exemption for public health surveillance.

Results

Case counts, injury rates, and cleaning material types

Overall, 440 TI cases were identified with exposure to cleaning products from July 1, 2017 to June 30, 2022. There were fewer cases of TI injury to all types of cleaning chemicals in the pandemic ($n = 197$) compared to the pre-pandemic ($n = 243$) (Figure 1, Table 1). Similarly, the rate of TI injury during the pandemic was 7.4 injuries per 100,000 FTE, which was slightly lower than the TI injury rate of 8.9 injuries per 100,000 FTE during the pre-pandemic (Poisson exact confidence intervals, chi-squared $p = 0.27$, Supplemental, Table S1).

The types of cleaning chemicals to which injured workers reported exposure changed during the pandemic. Disinfectants were the most commonly reported cleaning chemical overall ($n = 134$, Table 1), with their use increasing from 20% among the pre-pandemic cases to 43% among pandemic cases ($p < 0.01$, Table 1). While bleach can be an effective disinfectant, not all bleach products are formulated as disinfectants. Injured workers who referenced the use of bleach and specified the intention to disinfect were counted as using disinfectant. After disinfectants, the next most commonly used cleaning chemicals were bleach used alone in tasks not specified as disinfecting ($n = 70$); bleach mixed with other cleaning chemicals ($n = 65$); floor cleaners, strippers, and waxes ($n = 27$); and cleaning chemicals not otherwise specified ($n = 81$). There were five more cases diagnosed with work-related asthma during the pandemic compared

Table 1. Characteristics of toxic inhalation injuries to cleaning chemicals, Washington State workers' compensation, July 2017–July 2022.

	Pre-pandemic July 2017–Dec 2019	Pandemic Jan 2020–July 2022	p-value[a]	Total
# Cleaning TI cases	243	197		440
# (%) Claim accepted	168 (69%)	124 (63%)		292 (66%)
# (%) Claim compensable	11 (5%)	25 (13%)	*	36 (8%)
# (%) Female	134 (55%)	116 (59%)		250 (57%)
Median (IQR[b]) age at injury (years)	37 (25)	42 (24)		38 (25)
# (%) Exposed to disinfectant	49 (20%)	85 (43%)	*	134 (30%)
# (%) Diagnosed with work-related asthma[c]	27 (11%)	32 (16%)		59 (13%)
# (%) Work-aggravated asthma	21 (9%)	29 (15%)		50 (11%)
# (%) Occupational Asthma (OA)	3 (1%)	2 (1%)		5 (1%)
# (%) RADS	3 (1%)	1 (1%)		4 (1%)

[a]Significant difference between pre- and pandemic values from chi-square test; P-value < 0.01.
[b]IQR = Interquartile range.
[c]OA = occupational asthma with latency; RADS = reactive airways dysfunction syndrome, asthma without latency.

to pre-pandemic, but this change was not statistically significant (Table 1).

Industries most affected

Overall, the pandemic period had fewer cleaning-related TI injuries per 100,000 FTE than the pre-pandemic period. However, the trend varied by industry sector. Large increases in injury rate during the pandemic were observed in "Transportation and Warehousing" (from 7.1 to 18.6 injuries per 100,000 FTE; +162%), "Retail Trade" (from 5.0 to 8.3 injuries per 100,000 FTE, +66%), and "Educational Services" which includes teaching hospitals (from 10.6 to 12.0 injuries per 100,000 FTE; +14%) (Figure 2, Table S1). The industry with the highest pandemic case count ($n = 36$) was "Health Care and Social Assistance," which includes nursing homes (Table S1). Disinfectant use by industry sector was greatest for "Transportation and Warehousing" and "Professional, Scientific, and Tech. Services" (both 64%, Table S1).

Twenty-case series from spray and fog application of disinfectants

Twenty injured workers reported exposures to disinfectant(s) applied with fog or spray during the pandemic period. No similar cases were reported in the pre-pandemic period.

The sentinel case was a janitor employed by a cleaning company contracted to clean a bank (case 1, Table 2). According to the injured worker's report, their routine cleaning protocols were modified due to the pandemic. Following the introduction of an electrostatic sprayer for routine disinfection of touch surfaces, the worker reported progressive throat discomfort, hoarse voice, dry cough, and shortness of breath over three months. The disinfectant was formulated with benzyl alcohol (1–5%) and hydrogen peroxide (0.1–1%). Symptoms worsened acutely after entering a bank recently fogged with a second disinfectant containing undiluted propylene glycol n-propyl ether (5–10%), dodecylbenzene sulfonic acid (3–7%), alcohols C6-C12 ethoxylated (3–7%), hydrogen peroxide (1–5%), and phosphoric acid (1–5%). Evaluation was consistent with irritable larynx syndrome and occupational asthma. Despite maximal medical therapy, speech therapy, and pulmonary rehabilitation, the patient has not been able to return to work and cannot tolerate exposure to cleaning chemicals.

The nineteen additional cases exposed to disinfectant following spray or fog application (cases 2–20, Table 2) experienced health outcomes including respiratory symptoms, work-related asthma, chemical bronchitis, and chemical pneumonitis. Active ingredients in the disinfectants include hydrogen peroxide, sodium dichloroisocyanurate, quaternary ammonia compounds, and thymol (Table 2). In the education industry, there was a cluster of five university workers from a single health clinic exposed upon reentry to the building after fogging of a thymol-based disinfectant (cases 16–20). In the transportation industry, there was a cluster of 13 cases (cases 2–14) in transit bus operators exposed to residual disinfectant upon entering a bus before and during their shift. No operator directly sprayed disinfectant. Bus operators reported that they had been chronically exposed over periods ranging from 5 to 12 months in 2020 and 2021; one injured worker reported that the buses were sprayed with disinfectant three times per day. Regarding the use of respiratory protection, the sentinel case reported the use of a surgical mask to prevent exposure to SARS-CoV-2. Case 15, a cleaner, directly operated a spray bottle, and their use of respiratory protection is unknown. Among the remaining 18 cases in the case series, none directly applied disinfectant (they entered the space after spraying was completed). Therefore, the use of a respirator would not have been mandated; the use of respiratory protection is unknown for each of these cases.

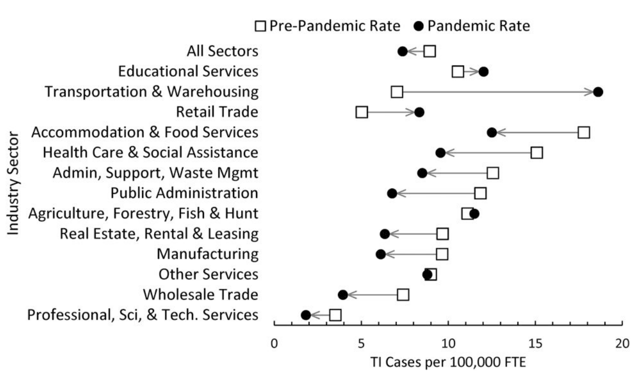

Figure 2. Change in the rate of toxic inhalation (TI) injuries for exposure to cleaning chemicals, including disinfectants, in the pre-pandemic period compared to the pandemic period, by industry.

Discussion

This retrospective study of Washington State workers' compensation claims included a quantitative and qualitative assessment of occupational toxic inhalation injuries caused by cleaning chemicals in relation to the COVID-19 pandemic. While other studies have reported an increase in exposure to cleaning products

Table 2. Case series for toxic inhalation (TI) injury following exposure to disinfectant applied through spray or fog.

Case[a]	Gender, Age[b]	Employer[c]	Application Method, Timeline[d]	Active ingredient in disinfectant	Examples of reported symptoms[e] and notable health outcome(s)
1	F, 40	Janitorial Services	ESS and fog 3 months	# 1: hydrogen peroxide # 2: dodecylbenzene sulfonic acid, hydrogen peroxide	Irritable larynx syndrome, occupational asthma
2 3 4 5 6 7 8	F, 40 F, 40 F, 40 F, 50 F, 60 F, 40 F, 60	County Bus #1	ESS 12 months	Sodium dichloroisocyanurate	Headache, nausea & throat irritation. 2 cases work-aggravated asthma; 1 case contact dermatitis
9 10 11	F, 40 F, 50 M, 50	County Bus #2	Fog 5 months	Thymol	Headache, nausea, shortness of breath.
12	M, 60	County Bus #3	Spray, unspecified	Quaternary ammonia compound (each of 2 products)	Cough, shortness of breath & acute chemical bronchitis.
13	F, 30	County Bus #4	Fog 9 months	Quaternary ammonia compound	Persistent breathing problems after 3 months exposure, patient lost to follow-up.
14	M, 16-20	County Bus #5	Spray, unspecified	Quaternary ammonia compound	Severe allergic reaction including hives.
15	F, 40	School Bus #1	Spray bottle, 6 wk	Quaternary ammonia compound	Shortness of breath, dyspnea, wheeze. Diagnosed with work-aggravated asthma.
16 17 18 19 20	F, 60 F, 50 F, 40 F, 30 M, 30	Univ. Clinic	Fog Single application	Thymol	Headache, nausea, burning/irritation eyes, nose, and throat. Shortness of breath. 1 case of chemical pneumonitis.

[a]Two workers had direct exposure to disinfectants through operation of an ESS (case 1) or use of spray bottle (case 15); all other workers were exposed indirectly.
[b]Age is given by decade.
[c]Each county bus employer is a unique establishment.
[d]Timeline = length of exposure during which product was routinely used.
[e]Symptoms are those most commonly reported at initial health care visit. For employers with more than one case, symptoms are summarized for all employees.
ESS = electrostatic sprayer.

among the general population during the pandemic, to the authors' knowledge, this is the first study to examine the impact on workers. Twenty cases were identified during the pandemic for toxic inhalation injuries caused by aerosolization of disinfectants through fog and electrostatic spray application.

Pandemic and industry-specific data trends

In contrast to data from poison centers, which reported significant increases in calls for exposure to cleaning chemicals during the pandemic, this study documents an overall decrease in the rate of WC claims filed for cleaning chemical-related TI injury. There are several potential explanations for this unexpected finding. One reason for the discrepancy is that this study did not include dermal or ingestion pathways, whereas ingestion was the most common exposure route in the poison center data (Chang et al. 2020). The decline in occupational case counts could be related to overall exposure patterns in the working versus the general population. While there wasn't a significant change in the number of employed people during the pandemic period (−1.7% FTE difference), there was a reduced opportunity for occupational exposure to cleaning chemicals due to state restrictions on business activity, along with a shift to remote work. Among employed adults in Washington State, 6% reported working from home in 2019 compared to 20% in 2020 (Ruggles et al. 2024). These findings are likely affected by reporting bias. Job precarity can dissuade workers from filing WC claims, and this would have been true during the pandemic (Azaroff et al. 2002). The Healthcare and Social Assistance and Public Administration sectors were overwhelmingly focused on the COVID-19 response and may not have had the capacity to file WC claims for injuries that were not infectious or severe. In some industries, such as the health care sector, prior knowledge and training in the use of disinfectants may have mitigated the risk of injury from these products. Finally, most hospitals utilize self-insurance rather than State Fund workers' compensation insurance and, therefore, may be under-represented in the dataset.

Despite the overall downward trend, four industries experienced an increase in TI injury rates for exposure to cleaning materials during the pandemic. The greatest rate increase occurred in Transportation and Warehousing, followed by Retail Trade and Educational Services. The rapid adoption of spray and fog technology on buses during the pandemic may have contributed to the injury risk in the Transportation and Warehousing industry. Overall, these injuries disproportionately affected women (57%).

Disinfectants and health effects reported in the case series

All 20 cases reported adverse health effects following exposure to disinfectants that had been applied with spray or fog. Among the disinfectants were a variety of active ingredients, including quaternary ammonia compounds, natural plant-based compounds, and hydrogen peroxide. Disinfectants fall into two broad chemical groups: oxidizing and non-oxidizing. The sentinel case and seven coach operators were exposed to active ingredients of HP and sodium dichloroisocyanurate, respectively, both of which are oxidizing chemicals and irritants. Published case reports for aerosolized exposure to HP include symptoms of dyspnea, cough, and nasal burning in dental clinic workers following exposure to dry fogging of HP during the pandemic (Hesam et al. 2022); interstitial lung disease in a dairy worker with chronic exposure to vapors from an HP water bath (Kaelin et al. 1988); and one case each of acute chemical pneumonitis and interstitial lung disease, respectively, following direct exposure to HP through a nebulizer (Nguyen and Gordon 2015; Manfra et al. 2023). Studies in hospital workers found that exposure to vapors from a sporicidal disinfectant containing HP and peracetic acid (both oxidizing) was associated with significant increases in work-related eye, upper-, and lower-airway symptoms and that mixtures of these chemicals were associated with acute and chronic irritation, wheeze, and shortness of breath (Hawley et al. 2017; Blackley et al. 2023). In the case series, four workers were diagnosed with work-related asthma, three of whom were exposed to an oxidizer-based disinfectant.

Within the case series, injured workers also reported exposure to non-oxidizing disinfectants, including nine who reported exposure to thymol and three who reported exposure to QACs. Thymol is a phenol derived from plant-based volatile oils that can be marketed as a botanical "green" disinfectant and is effective against SARS-CoV-2 (National Center for Biotechnology Information 2004; EPA n.d.-b). Thymol is a suspected asthmagen as it occurs in thyme oil, a known asthmagen (Salehi et al. 2018; AOEC 2023); it is also a natural constituent in the hop plant (*Humulus lupulus*), and exposure to hops is associated with work-related asthma (National Center for Biotechnology Information 2004; Reeb-Whitaker and Bonauto 2014). In the case series, injured workers exposed to thymol reported symptoms of headache and shortness of breath, severe allergic reaction, and chemical pneumonitis. Lastly, QACs are known to cause asthma and chronic obstructive lung disease (COPD), and injured workers exposed in this study reported work-related asthma, persistent breathing problems, and acute chemical bronchitis (Arnold et al. 2023; Frantz 2023).

Spray and fog application reported in the case series

Injured workers reported exposure to disinfectants applied through ESS, foggers, and in one case, a hand-held spray bottle. ESS has been historically used in agriculture, food processing, and healthcare, with contemporary adoption occurring across many industries during the COVID-19 pandemic (Chen and O'Keefe 2020). ESS generates aerosols that are electrically charged as they exit the spray nozzle, which promotes their adherence to directly sprayed surfaces as well as to the back or side surfaces in a "wrap-around" fashion (Chen and O'Keefe 2020). Compared to manual or conventional trigger sprayers, ESS are more efficient and effective when applying disinfectants (Ganesh et al. 2010; Archer et al. 2018; Jiang et al. 2018; Cadnum et al. 2019).

ESS and fog application of disinfectants are hazardous to workers because the aerosolized chemicals behave like small particles that are easily inhaled and can penetrate the lungs. Although the particle size is unknown for all cases presented in this study, ESS and fog techniques are expected to generate particles that are smaller than 100 µm, whereas the average particle size for manual and conventional sprayers is larger than 100 µm (EPA n.d.-b). By mandate, ESS must generate spray droplet particles $\geq$ 40 µm volume median diameter (VMD) in accordance with the U.S. Environmental Protection Agency (EPA) (EPA n.d.-b). Foggers typically generate particles smaller than

ESS and are appropriate for use when decontamination of whole-room air is desired, and to some extent for surface decontamination. Particle sizes from foggers were documented to range from 0.5 to 12 µm in one aerosolized HP fog system (Scarano et al. 2020). The U.K. Health and Safety Executive (HSE) suggests that fogged disinfectants can remain suspended in the air for 45 to 60 min or longer, depending upon the droplet size (HSE n.d.).

The health effects from aerosolized HP and QACs are of particular interest as they are the most commonly used active ingredients in disinfectants that target SARS-CoV-2. At the time of writing, the US EPA's List N Tool for COVID-19 disinfectants includes 27 products compatible for application through fog, mist, vapor, or ESS, and more than half are formulated with HP or QACs (EPA n.d.-a). In the case series, six of the nine disinfectants were formulated with HP or QACs.

Injury prevention for spray and fog applications

Safe reentry

Contextual exposure information, such as injured worker statements, employer correspondence, and exposure assessment reports in the workers' compensation record, was used to inform prevention strategies discussed here. One prevention strategy is to estimate safe reentry after disinfectants are sprayed or fogged; failure to do this contributed to injury in all but one of the injured workers in the case series. A longer time to reentry might have prevented the sentinel case, as the janitor was exposed upon entry to a space previously fogged with an HP-based disinfectant. Guidance on selecting the right mathematical model, including well-mixed box models to estimate concentration as well as concentration decay are available from the American Industrial Hygiene Association (AIHA® 2009). An online tool, IHMOD 2.0, is a free Excel-based application that can assist in these calculations (AIHA 2022).

Hesam et al. (2022) documented concentrations of hydrogen peroxide (HP) at 30 min intervals after dry fog application in a dental office and found HP remained above the U.S. Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) of 1 ppm in six clinic rooms through the first 60 min (OSHA; Hesam et al. 2022). They concluded that not calculating the spray time in accordance with the room volume resulted in worker exposure to high concentrations of HP (Hesam et al. 2022). By reducing the spray time, the contaminant is reduced to a concentration that can be cleared by the ventilation before reentry. Even when disinfectant concentrations are low or below established occupational exposure limits, studies have documented irritant, upper-, and lower-respiratory effects in workers (Hawley et al. 2017; Blackley et al. 2023).

Over-application of disinfectant

Multiple operators from two metro bus employers described similar exposure scenarios to residue from aerosolized disinfectant, described as dry white powder. One disinfectant was QAC-based, and with feedback from the product manufacturer, the employer concluded the residue was caused by over-application of the sprayed disinfectant. Injured workers reported that surfaces throughout buses, driver area(s), and windshield(s) were coated with residue, and deposits around air vents suggest particle re-circulation. As a result of their low volatility, quaternary compounds are easily adsorbed to dust, where they are unlikely to degrade, and can lead to long-term contamination (Zheng et al. 2020). In a residential setting during the pandemic, Zheng et al. (2020) documented the median total QAC concentration in dust samples to be 62% (58.9 ug/g) greater during the pandemic compared to pre-pandemic, illustrating how airborne exposure to these compounds can increase with long-term use and underscoring their persistent presence. For the bus applications described in the case series, the re-circulation of quaternary-based dust particles could prolong exposure and is a valid concern. Hazard recognition and training are needed for applicators and coach operators to prevent, recognize, and correct abnormal outcomes of disinfectant application, such as particulate residue and particulate recirculation.

The bus environment is an inherent risk factor

The bus environment and similar configurations on trains may be an inherent risk factor for injury from ESS or fog application. These transportation spaces can be small, enclosed, and have a density of high-touch surfaces with complex shapes that may be targeted for disinfection. Purwar et al. (2022) demonstrated that deposition from electrostatic spray varies with the substrate being sprayed and that vertical dripping on hard and vertical surfaces is common. ESS overspray that runs or drips may affect disinfectant dwell time and impact product efficacy. With ESS, the concept for a "wrap-around" effect in which charged particles adhere to the backside of sprayed surfaces originates from outdoor pesticide applications

(Zhao et al. 2008; Latheef et al. 2009; Mathews et al. 2014; Martin et al. 2019). In food safety, charged particles were more effective than uncharged spray at coating the backside of small test coupons sized less than 4 in. (Lyons et al. 2011). However, on large objects of 8 in diameter, the wrap-around effect is minimal for ESS sprayers and foggers (Wood et al. 2021). Users should recognize that small, enclosed indoor spaces may be inherently prone to product over-application and that there are limitations to the benefits of the "wrap-around" effect of ESS.

Guidelines for disinfection with spray or fog

The US Centers for Disease Control and Prevention (CDC) *2008 Guideline for Disinfection and Sterilization in Healthcare Facilities* does not support spray or fog of chemicals such as formaldehyde, phenol-based agents, or quaternary ammonia to decontaminate surfaces or disinfect air in patient rooms (Rutala et al. 2024). In a 2024 update to the 2008 guidelines, the CDC's position regarding contemporary disinfection technology is that "more research is required to clarify the effectiveness and reliability of fogging, UV irradiation, and ozone mists to reduce norovirus environmental contamination," and they concluded with "No Recommendation/unresolved issue" on this topic (Rutala et al. 2024). The World Health Organization (WHO 2020) interim guidance does not recommend routine application of disinfectants by spray or fog for indoor or outdoor environments for COVID-19.

Because dirt and debris will inactivate disinfectants, resources to carry out manual cleaning must be summoned prior to any spray or fog disinfection. From a practical perspective, some employers may find that after manual debris cleaning, a round of manual disinfecting can be as efficient as a spray or fog process that requires reentry wait times and post-spray wipe downs. Research is needed to evaluate real-world disinfectant application and efficacy in bus and similar environments to inform the use of ESS and fog technology in the transportation industry. The surveillance of adverse health effects from these practices is also needed. The identification of 20 cases of TI injuries related to the use of ESS and fog technology underscores the potential hazards associated with these devices, particularly for non-applicators.

Limitations

A probable limitation of this study is case underreporting, which is common in occupational injury and illness surveillance and may lead to an underestimate of the true burden of injury (Azaroff et al. 2002). Underutilization of workers' compensation insurance is common (Wuellner and Bonauto 2026). Workers may be dissuaded from filing a claim, may not believe workers' compensation will accept their claim, or experience other barriers to reporting a claim to the WC system (Azaroff et al. 2002; Miedinger et al. 2010). Finally, workers may have been disinclined to visit a doctor during the pandemic out of concern for exposure to SARS-CoV-2 in the clinic setting; this behavioral change would contribute to underreporting. An injured worker's stated use of cleaning chemicals was self-reported within the claim records and may have been absent or described in insufficient detail. Descriptions of spray and fog application were similarly self-reported, but did include statements from workers, employers, and exposure assessment investigations.

Conclusion

Infectious disease outbreaks require effective and efficient methods of disinfection; however, the application of cleaning chemicals may carry significant health risks for applicators and other workers. While this study does not show a significant change in the overall rate of toxic inhalation injury for workers in Washington State during the COVID-19 pandemic, some industries, including Transportation & Warehousing, did experience a large increase in injury rates caused by exposure to cleaning chemicals. Among all cleaning material types, the proportion of injuries from disinfectants significantly increased during the pandemic.

A total of 20 injured workers with exposure to disinfectants applied through spray and fog technology during the pandemic were characterized. Research to establish disinfectant efficacy from electrostatic spray or fog, particularly in bus and similar environments, is needed to inform thoughtful adoption of these technologies. Case data shows that prevention is needed regarding hazard awareness when disinfectants are applied through electrostatic spray or fog; staff training to recognize and correct over-application of disinfectant from electrostatic spray; applicator training to avoid over-application; and a need to preplan, estimate, and uphold safe reentry time for each unique spray or fog application.

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Author contributions

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Data availability statement

A de-identified dataset that supports the findings of this study is available from the corresponding author upon reasonable request.

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