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Health Impact of Chemical Disinfectant Exposures: A Review

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Abstract: Chemical disinfectant, such as sodium hypochlorite, bleach and quaternary is crucial for infection prevention. This applies to healthcare settings as well as other settings where the transmission of pathogens can potentially endanger the health of humans and/or animals. Ongoing interdisciplinary research is needed to ensure the effectiveness of disinfectants, understand the process of disinfection, and determine the appropriate timing, methods, and locations for implementing disinfection precautions. To ensure the long-term benefits of disinfection, it is crucial to utilize active substances responsibly and assess their impact on target organisms and the environment through close evaluation and monitoring. Given the worldwide risk posed by communicable diseases, as well as the emergence and resurgence of pathogens that are resistant to multiple drugs, the importance of chemical disinfection is consistently growing. This consensus paper focuses on important factors related to chemical disinfection strategies in healthcare settings, specifically for vulnerable patients.

Keywords: Bleach; Disinfectant; Health Effect; Sodium Hypochlorite; Quaternary

Introduction

Infection control aims to block the transmission of microorganisms or pathogen in two directions: vertical transmission or pathogens in two directions: vertical transmission, which involves the propagation of pathogens from generation to generation, and lateral transmission, which involves the transfer of pathogen resistance to other pathogens of the same generation or the spread and expansion of the pathogen in its surroundings (Bhasin et al., 2023; Selam et al., 2023).

To prevent vertical transmission, proper use and regulation of antibiotics are essential, which requires antibiotics stewardship to ensure their responsible and appropriate use. To prevent lateral transmission, infection control measures such as health workers, hygiene management, cleaning, disinfection, antiseptics, and sterilization procedures are crucial.

These measures help minimize the spread of pathogens within healthcare settings and other environments, reducing the risk of infections and antimicrobial resistance (Dhama et al., 2021; Dindarloo et al., 2020). Doctors specializing in infection control, particularly those who serve as medical directors, typically possess a strong understanding of pathogens, infectious diseases, and the appropriate use of antibiotics. However, their knowledge and interest in disinfection techniques may vary, and this area might receive less attention in their training or practice (Kim et al., 2023).

The COVID-19 pandemic has emphasized the critical importance of proper cleaning and disinfection in both healthcare settings and public environments. Non-pharmaceutical public health measures, such as physical distancing, hand hygiene, respiratory hygiene (covering coughs and sneezes), wearing face coverings,

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and increased surface cleaning and disinfection, have been highlighted as essential interventions in controlling the transmission of SARS-CoV-2 (Deverick et al., 2017; Slaughter et al., 2019).

By using these preventive measures concurrently, the risk of COVID-19 transmission can be significantly reduced. Cleaning and disinfection of frequently-touched surfaces, such as doorknobs, handrails, and electronic devices, play a crucial role in breaking the chain of infection and preventing the spread of the virus (Thomas et al., 2022).

It's important to strike a balance between effective infection control measures and potential health risks associated with disinfectant use (Rauchman et al., 2023). Regular cleaning with milder alternatives, along with targeted use of stronger disinfectants when necessary, can help maintain a clean and safe environment while minimizing potential health hazards. Therefore, (1) What are the potential health effects of disinfectant exposure? Are there alternative disinfectants that pose lower risks of long-term adverse health effects?

Method

The study search was conducted in Google Scholar, PubMed, Scopus, and the Web of Science from 2010 to 2023. The search strategy is outlined in Table 1. The MeSH terms and keywords included disinfectant, health effects, sodium hypochlorite, bleach, quaternary, and hospital. Relevant articles and reviews are cited as references.

Table 1. Search strategies for four databases

Databases	The seach strategy
PubMed	(Disinfectant [MeSH Terms]) AND (Health effects) AND ((Sodium hypochloride) OR (Bleach) OR (Quaternary)) AND (Hospital[MeSH Terms])
Web of Science	(“Disinfectant”) AND (“Health effects”) AND (“Sodium hypochloride” OR “Bleach” OR “Quaternary”) AND (“Hospital”)
Scopus	(“Disinfectant”) AND (Health effects”) AND (“Sodium hypochloride” OR “Bleach” OR “Quaternary”) AND (“Hospitall”)
Google Scholar	(“Disinfectant”) AND (“Health effects”) AND (“Sodium hypochloride” OR “Bleach” OR “Quaternary”) AND (“Hospital”)

Study selection criteria

To be eligible, studies needed to meet the following criteria: (1) inclusion of both in vitro and in vivo investigations; (2) examination of sodium hypochlorite or bleach or quaternary as a disinfectant; (3) accurate evaluation of the disinfectant's efficacy before and after application; and (4) publication in the English language.

Study exclusion criteria

The study conducted by author SA and.... followed a well-defined set of exclusion criteria to ensure that only relevant and high-quality studies were included. The exclusion criteria were as follows; (1) studies examining disinfectants other than sodium hypochlorite, bleach, and quaternary; (2) studies that employed unclear or ambiguous disinfectant procedures; (3) studies utilizing physical disinfection methods such as ultraviolet or short laser disinfection; (4) studies that did not report measurement results relevant to the evaluation of disinfectant efficacy; (5) studies that lacked control groups; and (5) only studies reported in English were included in the review.

Additionally, to ensure the reliability and accuracy of the review process, the search and selection of studies were conducted independently by two authors (LA and SA). In case of any disagreements or uncertainties during the study selection, a third investigator would reassess the study to reach a consensus and maintain the quality and integrity of the review process.

By applying these rigorous criteria and involving multiple investigators in the study selection process, the study aimed to provide a comprehensive and reliable assessment of the effects of sodium hypochlorite and bleach as disinfectants based on the most and high-quality research available in the literature.

Data extraction

The data extraction process for the review involved collecting information on various aspects related to disinfectants from the selected articles. The following data points were extracted (Moola et al., 2020): (1) Concentration of Disinfectant: The different concentrations of the disinfectants used in the studies were recorded. This information helps in understanding the impact of varying disinfectant strengths on the effectiveness of the disinfection process. (2) Disinfectant Methods: The specific methods or procedures used for disinfection in each study were documented. This includes details on how the disinfectant was applied or used in the experiments. (3) Disinfectant Duration: The duration or contact time of the disinfectant with the target surface or material was noted. This parameter is essential in assessing the optimal time required for effective disinfection. (4) Location: The location or setting where the disinfection experiments were conducted was recorded. This may include laboratory conditions, simulated real-world environments, or other specific locations. (5) Results: The outcomes or results of each study regarding the effectiveness of the disinfection process were extracted. This could include data on pathogen reduction, microbial growth inhibition, or any other relevant findings.

The data extraction process was conducted independently by two reviewers (LA and SA), ensuring a rigorous and thorough evaluation of each study's information. Any discrepancies or disagreements that arose during data extraction were resolved through discussion and consensus between the two reviewers. This collaborative approach helps to maintain the accuracy and reliability of the extracted data, minimizing the risk of bias and errors (Evidence Partners. Better, faster study: evidence partners, 2020).

Table 2. Article selection and data extraction

Title	Main Findings
Cleaning agent usage in healthcare professionals and relationship to lung and skin symptoms (Ameth et al., 2022).	Two hundred and thirty healthcare workers who were exposed to cleaning agents were compared with 77 who had no, or minimal, exposure. Exposed workers had an increased risk of respiratory symptoms (adjusted OR = 2.17; 95% CI: 1.18-4.14) and skin symptoms (adjusted OR = 1.77; 95% CI: 1.00 - 3.17). Washing instruments manually, using aerosol products, cleaning operating rooms, cleaning sanitary rooms, preparing disinfectants, and filling devices with cleaning products were cleaning tasks associated with various respiratory symptoms.
Environmental cleaning and disinfection of hospital rooms: A nationwide survey (Han et al., 2021)	The analysis involving EVS (Environmental Services) personnel from different hospitals across 26 US states. The analysis focused on the use of disinfectants and disinfection practices in healthcare settings.
A Multicenter Randomized Trial to Determine the Effect of an Environmental Disinfection Intervention on the Incidence of Healthcare-Associated Clostridium difficile Infection (Amy et al., 2017)	The study you mentioned involved 7 intervention hospitals and 8 control hospitals. The intervention aimed to improve the removal of fluorescent markers in *Clostridioides difficile* infection (CDI) and non-CDI rooms, as well as reduce the recovery of *C. difficile* from high-touch surfaces in CDI rooms. The results showed that the intervention was successful in increasing the removal of fluorescent markers in both CDI and non-CDI rooms, and it also decreased the recovery of *C. difficile* from high-touch surfaces in CDI rooms. This indicates that the intervention had a positive impact on the cleanliness and reduction of *C. difficile* contamination in the affected rooms. However, despite these positive outcomes, the study did not find any reduction in the incidence of healthcare-associated CDI in the intervention hospitals during both the intervention and post-intervention periods. This means that even though the intervention improved cleaning and reduced contamination, it did not lead to a decrease in the actual occurrence of healthcare-associated CDI in those hospitals.
Domestic use of bleach and infections in children: a multicenter cross-sectional study (Casas et al., 2015)	The use of bleach in households in Spain and Finland and its association with the prevalence of infections among children. In the study, bleach use was found to be common in Spain, with 72% of households (n=1945) reporting its use, while it was uncommon in Finland, with only 7% of households (n=279) reporting its use. The study found that the prevalence of infections (both recurrent and once-off infections) was higher among children living in households that used bleach. Three specific types of infections showed significant combined associations with bleach use.
Significant impact of terminal room cleaning with bleach on reducing nosocomial Clostridium difficile (Hacek et al., 2010).	There was a 48% reduction in the prevalence density of C. difficile infections after the implementation of a bleaching intervention. The confidence interval for this reduction was 36% to 58%. The p-value for the reduction was less than 0.0001, indicating that the observed reduction is statistically significant. This finding suggests that the bleaching intervention was highly effective in reducing the occurrence of *C. difficile* infections. The prevalence density refers to the number of *C. difficile* infections per unit of population or per unit of time, and a reduction of 48% indicates a substantial improvement in controlling the spread of *C. difficile* in the targeted setting. It's important to note that the confidence interval provides a range within which the true effect of the intervention is likely to lie with a certain level of confidence. In this case, with a 95% confidence level, the true reduction in prevalence density is expected to be somewhere between 36% and 58%.

Title	Main Findings
Disinfection by 1% sodium hypochlorite through cold fogging: an innovative appropriate technology against COVID-19 in public health (Gupta et al., 2022).	The infection rate among healthcare workers (HCWs) was significantly lower at an average of 2.9%. This suggests that the innovation was effective in reducing the risk of infections among HCWs in those hospitals.
Assessment of antibiotic- and disinfectant-resistant bacteria in hospital wastewater, south Ethiopia: a cross-sectional study (Fekadu et al., 2015).	The detection of certain pathogenic and potentially pathogenic bacteria in hospital effluents, as well as the effectiveness of different disinfectants against these bacteria. It also mentions the minimum inhibitory concentration (MIC) of ethanol against specific bacteria and the antibiotic resistance profiles of Salmonella isolates from two different hospitals.
Staphylococcus aureus dry-surface biofilms are not killed by sodium hypochlorite: implications for infection control (Almatroudi et al., 2016)	The effects of hypochlorite exposure on *S. aureus* bacteria, particularly on plate counts, biofilm biomass, and the presence of live cells. It also provides information about the results of prolonged incubation and the characteristics of post-exposure S. aureus isolates compared to their parent strains.
Surface Disinfection Practice in Public Hospitals in the Era of COVID-19: Assessment of Disinfectant Solution Preparation and Use in Addis Ababa, Ethiopia (Selam et al., 2023)	he findings from a study conducted in twelve public hospitals, focusing on the handling and use of sodium hypochlorite solution (SHS) as a disinfectant. The study reveals several practices related to the preparation, storage, and application of SHS in these hospitals.
Effect of Sodium Hypochlorite on Biofilm-Producing Organisms Isolated from A Hospital Drinking Water (Bhasin et al., 2023)	The culture positivity, microbial growth patterns, and biofilm production of organisms isolated from samples. It also mentions the most common organism found and its association with biofilm production and resistance to chlorine compounds.
Preventing nosocomial infections in resource-limited settings: An interventional approach in healthcare facilities in Burkina Faso (Duvernay et al., 2020)	The results of an intervention to improve hygiene practices in healthcare facilities, particularly focusing on the use of sodium hypochlorite solutions for disinfection.

By documenting and synthesizing these various data points from the selected articles (Table 2), the study aims to provide a comprehensive and evidence-based understanding of the effectiveness of disinfectants, their optimal concentrations and methods, and their impact on different locations and settings. This information can then be used to inform best practices for disinfection and infection control in various contexts (Moola et al., 2020).

Result and Discussion

Results

In total, the electronic search identified articles from four databases (PubMed, Web of Science, Google scholar and Scopus). After duplicates had been removed, 219 articles were obtained. After titles and abstracts had been analyzed, 52 articles remained. After full analyzed the eligibility, 11 studies were included in the analysis. Detailed study selection was presented in Figure 1. Of the included studies, the most commonly used disinfection method was immersion followed by spray. The concentration of two disinfectants, sodium hypochlorite and bleach range from 0.05% to 5,25% and 0.13% to 2.5%, respectively. In addition, the disinfection duration ranged from 30 s to 24 h, To evaluate the disinfection efficacy of three disinfectants.

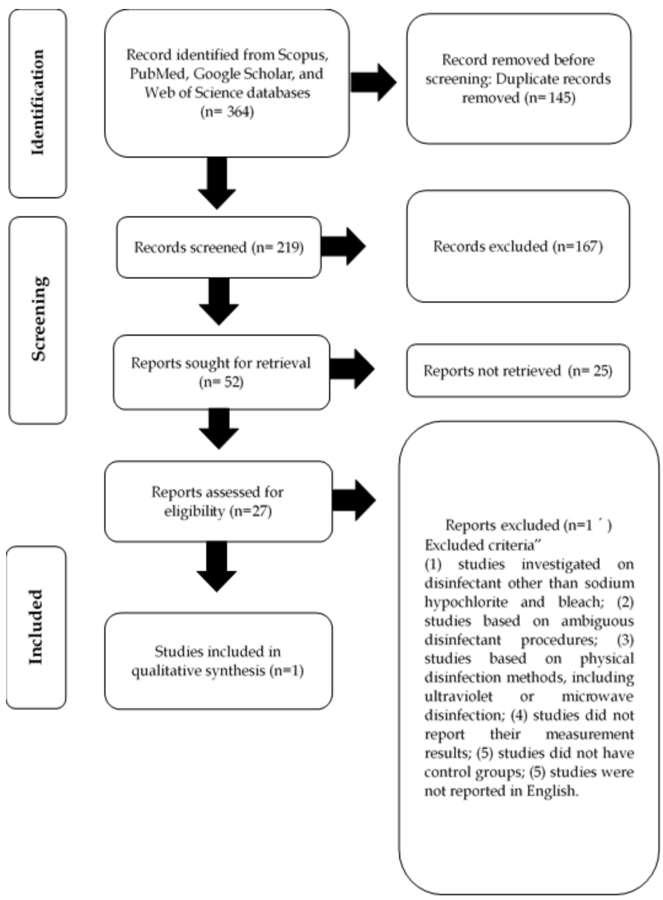

Figure 1. Prisma diagram for article selection process

Discussion

The potential toxic effects of sodium hypochlorite, a common cleaning agent found in household bleach, when ingested in large amounts or at high concentrations (Bhattachryya et al., 2023; Chhetri et al., 2019). When hypochlorite salt, such as NaOCl, is dissolved in water, hypochlorous acid (HOCl) is indeed the predominant active species. This occurs due to the pH-dependent disassociation of hypochlorite ions (OCl^-) into hypochlorous acid. Hypochlorous acid is an effective disinfectant with powerful oxidizing agent with antimicrobial properties. Its effectiveness is attributed to its ability to penetrate the cell walls essential cellular components (Guridi et al., 2019; Kawata et al., 2021).

The toxicity of hypochlorite can occur in three circumstances: (1) Ingestion of hypochlorite solutions by accident may cause gastrointestinal distress; (2) The inhalation of hypochlorite solutions or vapors can cause respiratory issues; (3) When hypochlorite salt or its solutions come into direct contact with skin or mucous membranes, it can cause irritation and corrosion (Slaughter et al., 2019; Zhang et al., 2021).

Here are the key points: (1) Symptoms of Ingestion: Ingesting sodium hypochlorite, especially at concentrations below 6%, can lead to various symptoms, including nausea, vomiting, and a burning sensation in the mouth. Serious Toxicity: Serious toxicity occurs when significant amounts of sodium hypochlorite are ingested. For children, ingestion of 5 mL/kg or more can lead to severe toxicity, while in adults, ingesting 150-200 mL or more can also result in serious adverse effects (Thomas et al., 2022; Asmither et al., 2018) (2) Effects on the Upper Digestive Tract: In cases of ingestion, sodium hypochlorite can cause redness, edema (swelling), and ulceration in the oral cavity (mouth), nasopharynx (the upper part of the throat behind the nose), and esophagus (the food pipe). In severe cases, there is a risk of gastric (stomach) perforation, which is a serious complication where a hole develops in the stomach wall (Han et al., 2021; Goldish et al., 2019; Romanovski et al., 2020). (3) Respiratory complications: Complications that can arise from sodium hypochlorite ingestion include coughing, shortness of breath, and aspiration pneumonia, which occurs when stomach contents are inhaled into the lungs. Additionally, there is a risk of upper airway edema (swelling) that can impede breathing (Su et al., 2019; Han et al., 2023; Ulin et al., 2020). (4) Severe Cases: In more severe instances of sodium hypochlorite poisoning, pulmonary edema (fluid accumulation in the lungs) may occur. This can lead to symptoms such as difficulty breathing and chest discomfort (Starke et al., 2021; Kim et al., 2022). (5) Systemic Effects: Systemic effects of sodium hypochlorite poisoning may include metabolic acidosis (a disturbance in the body's acid-base balance), hypernatremia (high sodium levels in the blood), and hyperchloremia (elevated chloride levels in the blood) (Gupta et al., 2022; (Klarczyk et al., 2023). (6) Other Symptoms: Tachycardia (rapid heart rate), hypotension (low blood pressure), and convulsions (seizures) have also been reported in severe cases of sodium hypochlorite ingestion (Garrido et al., 2022; Luongo et al., 2020).

Given the severity of these symptoms, it is crucial to exercise extreme caution when handling household bleach and other cleaning products containing sodium hypochlorite. These products should be stored out of reach of children and used according to the manufacturer's instructions to minimize the risk of accidental ingestion or exposure (Dang et al., 2022) In case of ingestion or significant exposure to cleaning agents, immediate medical attention should be sought. As always, prevention is the best approach, and proper safety measures should be followed when using any potentially hazardous substances (Deverick et al., 2017; Pandian et al., 2022).

In order to minimize the risk of toxicity, it is important to follow safety guidelines when handling hypochlorite. This includes appropriate protective gear, proper ventilation, and secure storage of hypochlorite solutions away from incompatible substances. It is also important to read and follow the manufacturer’s instructions and seek medical attention if any adverse effects occur (Maheswari et al., 2022; Moyns et al., 2023; Soave et al., 2021).

Hence, recommendations and precautions related to the use of household bleach (sodium hypochlorite) as a disinfectant in laboratory and cleaning settings. Here are the key points: (1) Recommended Working Dilution: The recommended working dilution for household bleach is 5250 parts per million (ppm), which is achieved by preparing a 1:10 dilution of household bleach with 5.25% sodium hypochlorite. This diluted solution is suitable for various disinfection purposes, including cleaning floors, spills, benchtops, and contaminated clothing (Song et al., 2019; Thomas et al., 2022). (2) Appropriate Use: The diluted bleach solution is appropriate for general disinfection tasks in laboratory and cleaning settings. However, it is important to note that bleach should not be used on electronic equipment, optical equipment, or unpainted stainless-steel surfaces. (3) Proper Disposal: Undiluted bleach and other disinfectants should not be poured down the drain or mixed with other materials. It is crucial to handle and dispose of bleach and other chemicals properly to avoid environmental contamination (Casas et al., 2015; Tyan et al., 2019). (4) Disposal of Diluted Bleach: Only 1:10 dilutions of bleach that have been mixed with adequate levels of protein, such as those found in tissue culture media containing fetal bovine serum, can be safely poured down the drain. This indicates that the presence of protein can help neutralize the potential harmful effects of the bleach before disposal (Ye et al., 2023; Zhang et al., 2021). (5) Hazards of Undiluted Bleach: Undiluted bleach is substantially more reactive than the diluted form and can pose significant hazards. When mixed with certain substances, such as Luria broth in a ~1:1 ratio, undiluted bleach has been reported to generate toxic gases like cyanogen and chloramine (Holm et al., 2019; Wilkinson et al., 2023). (6) Biosafety Manual: It is advised to refer to the Biosafety Manual for additional information and guidance on selecting appropriate disinfectants and proper bleach use, particularly concerning prions and prion-like proteins (Lii et al., 2021; Schmidt et al., 2019; Stanton, 2018).

These guidelines emphasize the importance of using bleach responsibly and with proper dilution for disinfection purposes. Bleach is a powerful disinfectant, but it should be handled with care to prevent potential adverse effects and environmental harm. Always follow recommended safety protocols and manufacturer's instructions when using bleach or any other chemicals (Slaughter et al., 2019; West et al., 2019).

Conducting a careful history is crucial in the context of hypochlorite exposure. This includes gathering information about the specific product used, its concentration and the amount involved. The characteristic chlorine smell produced by hypochlorite bleach can also serve as a diagnostic clue (Stubbs et al., 2023). These details are important for healthcare professionals to be aware of in order to accurately assess and manage potential adverse effects(Boyce & Havill, 2022; Caon et al., 2022; Chen et al., 2020).

Conclusion

Sodium hypochlorite is rarely accumulated in the body (in vivo), indicating that it is generally eliminated or excreted without significant build-up. The COVID-19 pandemic has led to a substantial increase in the use of disinfectants containing sodium hypochlorite. As a result, certain occupational groups and the general public have experienced a significant rise in opportunities for exposure compared to pre-pandemic levels. Due to the increased usage and potential for exposure, continuous monitoring of the health effects of disinfectants like sodium hypochlorite is recommended. This monitoring is crucial to assess and respond to any possible health impacts on both the public and individuals exposed to the chemical.

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