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State of the Science Review

Do we know how best to disinfect child care sites in the United States? A review of available disinfectant efficacy data and health risks of the major disinfectant classes

Stephanie M. Holm MD, MPH [a,b,c], Victoria Leonard RN, PhD [d], Timur Durrani MD, MPH [a,d,e], Mark D. Miller MD, MPH [a,d]

[a] University of California San Francisco Division of Occupational and Environmental Medicine, San Francisco, CA
[b] University of California Berkeley Division of Epidemiology, Berkeley, CA
[c] University of California San Francisco Benioff Children's Hospital Oakland, Oakland, CA
[d] Western States Pediatric Environmental Health Specialty Unit–University of California San Francisco, San Francisco, CA
[e] California Poison Control System, San Francisco, CA

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Background: Children in child care settings have a high infectious burden. They are frequently exposed to sanitizing and disinfecting agents, whose toxicities have not been studied in these settings. Current guidance on the preferred disinfection agents for child care is vague.

Methods: This article combines 2 different sources of information: the Environmental Protection Agency registration data on the efficacy of hospital-grade disinfectants and a review of the research on the toxicities of the most common of these disinfectants to summarize information that could be used for more evidence-based early care and education disinfection regulations and guidelines.

Results: Coverage of these organisms varied both between disinfectant classes (defined by active ingredient), as well as within classes. The 3 most common active ingredients in the database—quaternary ammonias, bleaches, and hydrogen peroxides—had 251, 63, and 31 products, respectively. Quaternary ammonias and bleaches are both known asthmagens, with the potential for toxic gas release when mixed. Quaternary ammonias may also cause reproductive toxicity. Disinfectant-grade peroxides have relatively low inhalational toxicity.

Conclusions: A clear rationale is needed to establish policies for determining preferable disinfection products for use in child care settings, based on efficacy against relevant pathogens, toxicity, ease of use, and cost. When other factors are equal, the use of peroxide-based disinfectant products is recommended to minimize inhalational toxicity.

BACKGROUND

Six million US children under the age of 5 are in center-based child care.[1] Child care facilities have a difficult task in balancing the use of cleaning and disinfection agents for infection control with the potential health risks posed to children and staff by frequent use of these agents. They are charged with caring for a population with immature immune systems who do not respect personal boundaries, may not contain their bodily fluids, and have high hand-oral behavior. Not surprisingly, children in out-of-home care contract more infections than those who are cared for at home.[2] However, attempting to control these infections routinely exposes the children and their caregivers, who are mostly women of childbearing age,[3] to a variety of chemicals with potential health risks for both of these populations.

Most states have regulations for early care and education settings that mandate frequent disinfection with bleach or an Environmental Protection Agency (EPA)–registered hospital-grade disinfectant.[4] These guidelines often defer to or use the American Academy of Pediatrics and American Journal of Public Health guidelines, *Caring for Our*

Address correspondence to Stephanie M. Holm, MD, MPH, UCSF Division of Occupational and Environmental Medicine, 2330 Post St #460, San Francisco, CA 94115.
E-mail addresses: stephanie.holm@ucsf.edu, stephaniemholm@gmail.com (S.M. Holm).

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Children,[3] to delineate which surfaces (such as changing tables) should be disinfected or sanitized and when. Guidelines recommend that many surfaces be disinfected daily, but toileting and diapering areas must be disinfected after each use, meaning that these areas, uniquely, require disinfection with children present. Thus children in out-of-home child care have high exposure to disinfectants and would be at substantially increased risk of any potential adverse effects.

In facilities with multiple young children, changing tables are frequently used multiple times in an hour, because healthy infants have 8 or more diaper changes in a day.[5] Most commonly, these surfaces are then disinfected each time with bleach, which is used by 65% to 93% of child care centers.[1,6] However, it has been shown that volatiles can stay in the air for up to 20 minutes after a cleaning task.[7] If facilities kept to a rigid schedule that allowed for the appropriate bleach dwell time of 10 minutes before the next diaper change, everyone in the room would be exposed to lingering volatile compounds in the air for at least 30 minutes, especially the next child laid on the table.

Toxicity from disinfectant exposure to children and their caregivers, meaning any potential adverse health outcome, can be minimized by using the least toxic disinfectant that will accomplish the necessary disinfection in the shortest dwell time, along with careful practices such as ensuring adequate ventilation and the use of closed dilution systems for diluting product concentrates without direct product contact. Thus it is important that we as a society, and especially child care providers who care for vulnerable young children, know which products are effective for a given task but also which can achieve the necessary disinfection while maximizing the health and safety of children and staff in child care facilities.

Background on the efficacy of disinfectants

Published literature shows that having a written surface-cleaning and food-prep policy is associated with a decreased quantity of aerobic bacteria and coliforms on high-touch surfaces in early care and education environments (log mean aerobic plate count of 3.3 vs 3.8, $P < .01$).[8] It has also been shown that rooms with higher levels of fecal hand contamination and contamination on sinks and faucets present higher diarrhea risk.[9] Studies in elementary schools show that a combination of improved hand hygiene and surface disinfection can reduce rates of absence for gastrointestinal illness (rate ratio [RR] 0.91, confidence interval [CI] 0.87-0.94).[10]

A recent study randomized 12 child care facilities to have toys and linens disinfected every 2 weeks. The study group, those centers that had the intervention, had fewer viruses and bacteria remaining on surfaces than the control centers (control centers were more likely to be positive for adenovirus, odds ratio (OR) 2.4 (CI 1.1-5.0), rhinovirus OR 5.3 (CI 2.3-12.4), and respiratory syncytial virus (RSV) OR 4.1 (CI 1.5-11.2), but there was no difference in absences or any symptoms.[11] This suggests there was increased exposure to disinfectants with no clear reduction in symptomatic illness. Similarly, a randomized double-blind trial in households with preschoolers showed that use of antibacterial products for hand washing, laundry, and cleaning did not decrease the rates of runny nose, cough, sore throat, fever, vomiting, diarrhea, boils, or pink eye.[12] A large, multicenter study of domestic use of bleach and infections in children showed that passive exposure to bleach in the home may even have adverse effects on school-age children's health by increasing the risk of respiratory and other infections.[13] Thus children may be unnecessarily exposed to antimicrobial products without apparent benefit. In addition, it is worth recognizing that exposure to common childhood illnesses may also be important for immune system development.[14]

There are no controlled studies of surface disinfection in early care and education settings. Studies evaluating disinfection in the field of bioterrorism have developed a body of research comparing multiple disinfectants against potential bioagents.[15] However, this research suffers from varied results depending on protocol specifics, and the organisms are frequently not relevant to early care and education settings. Moreover, data on comparisons between specific products are very limited, and results can vary greatly depending on many factors such as the types and characteristics of the surfaces treated. Much of the work done to test different disinfectant products is done by the manufacturers and is proprietary in nature.

However, because all disinfectants must be registered by the EPA to be a registered hospital-grade disinfectant, the registration information is publicly available. The Pesticide Product Labeling System (PPLS) database contains information sheets on each registered product and the organisms against which each product is registered, although in a difficult to survey manner. Thus this system can be queried to determine the efficacy of each disinfectant product, meaning which organisms the product is known to disinfect.

Health effects of disinfectants

A recent study of 14 child care facilities in the District of Columbia serving 1900 children showed that all of the sites had detectable chloroform levels in the air, most likely occurring as a byproduct of bleach use.[1] Bleach continues to be the most common disinfectant used in child care settings,[1,6] perhaps partially because people associate the smell of bleach with cleanliness.[16] In a study funded by the California Air Resources Board,[6] air was monitored in a group of 40 early care and education facilities. Results showed that 7.5% of facilities had ventilation rates below the recommended levels, and many had chloroform levels above the California EPA Office of Environmental Health Hazard Assessment safe harbor guidelines for cancer risk, based on their calculation of no significant risk levels for young children. Levels of formaldehyde, a known carcinogen, were also noted to be high, above the California recommended 8-hour and chronic exposure limits in 87.5% of facilities. These levels were much higher indoors than out, suggesting that products found indoors are to blame. The report suggested using mitigation strategies to reduce chemical exposures,[6] which could include modification of cleaning and disinfecting procedures. Children in those centers may even have higher exposures than the adults that surround them because children's breathing zones are lower to the floor, where heavier gases settle, and children breathe more air per kilogram of body weight than do adults, increasing their exposure to any air pollutants.[17]

These elevated levels of harmful compounds and frequent use of cleaners and disinfectants are particularly concerning in light of accumulating evidence for health risks in adults who are chronically exposed to these products. Janitors and cleaners have the highest rates of occupational asthma, estimated at 625/1,000,000 person-years.[18] Many large epidemiologic studies have shown that there are increased rates of asthma in workers with cleaning product exposure,[19-27] with a particularly high risk for asthma among those who have to mix disinfectants (OR 4.0; CI 1.34-12.0).[28] There is also longitudinal evidence for development of asthma after exposure to cleaning products: 13,000 adults were followed up for 11 years, and the risk for development of asthma was higher in those with exposure to cleaning chemicals (hazard ratio 2.6 for men and 2.0 for women).[29] Moreover, a recent study in a large cohort of nurses found a relationship between disinfectant use and the risk of developing chronic obstructive pulmonary disease.[30] Outside of the realm of occupational exposures, people who clean their own home generally have higher rates of lower respiratory symptoms if they use bleach frequently (OR 1.37, CI 1.11-1.68)[31] or multiple kinds of cleaning sprays (OR 1.86, CI 1.01-3.33; OR 1.67, CI 1.08-2.56).[32,33] Even in those without asthma, there is evidence for respiratory effects related to cleaning products. After exposure to fragrances that are found in many cleaning products, 47% of adults (15/32) with or without asthma had nasal symptoms, and mild asthmatics also reported a difference in chest symptoms.[34] A comparison of 40 cleaners and 40 control subjects showed that cleaners had higher exhaled breath levels of peroxide (0.26 vs 0.07), ammonium (857 vs 541), and pH (8.17 vs 8.06) despite no difference in symptoms or forced expiratory volume in 1 second (FEV_1)—which may be signs of subclinical inflammation.[35]

Data regarding the effects of cleaning product use in children are more limited, although they still provide cause for concern. Multiple cross-sectional studies have found that children whose homes were cleaned with bleach were not more likely to have asthma; however, none of these controlled for whether the child was present during the bleach cleaning tasks or other cleaning behaviors.[13,36,37] Conversely, a few cross-sectional studies have found elevated risk of high fractional exhaled nitric oxide (a marker of airway inflammation) or asthma with increased use of cleaning sprays or disinfectants.[38,39] In most studies, children whose homes have higher levels of volatile organic compounds, of the sort that can result from cleaning products, have a higher risk of asthma.[40,41] This suggests that when children have exposure to the cleaning products (either by being present during cleaning tasks or if levels persist), they do have increased risk of asthma. Longitudinal studies have shown a relationship between increased chemical exposure either prenatally or postnatally and increased risk of wheeze. In the Pollution and Asthma Risk: an Infant Study birth cohort, monitoring babies prospectively to look at asthma risks, there was a trend toward a relationship between daily cleaning spray use at home and wheeze by the time the child was 18 months (OR 1.50, CI 0.97-2.32).[42] The Avon Longitudinal Study of parents and children, which has data from 7,000 children, showed that those children whose mothers reported more frequent use of chemical exposures at home (many of which were cleaning products) had higher risk of persistent wheeze at age 3.5. (OR 2.3, CI 1.2-4.4).[43]

Research questions

To summarize information that could be used for evidence-based early care and education disinfectant regulations and guidelines, we examine 2 research questions in this article: First, how effective are currently required disinfectants against commonly encountered organisms in early care and education settings? Second, what are the health risks of exposure to the most common disinfectants to children and their caregivers?

METHODS

Efficacy review using the PPLS system

The EPA classifies antimicrobial agents as pesticides with registration information in the PPLS database. The EPA has very specific testing guidelines that must be met for certification as a hospital-grade disinfectant,[44] which requires that it be shown to disinfect against *Staphylococcus aureus* and *Pseudomonas aeruginosa*. There is no method for searching the database for all products of a particular class such as hospital-grade disinfectants or by specific organism. However, the EPA maintains lists of antimicrobial agents effective against the following pathogens: HIV type 1, hepatitis B, hepatitis C, norovirus, methicillin-resistant *Staphylococcus aureus*, vancomycin-resistant *Enterococcus* spp., *Clostridium difficile*, Ebola virus, and avian influenza. From that list, we obtained the manufacturer codes of every manufacturer that made a product effective against any one of those listed organisms, with the presumption that all manufacturers of antimicrobials would be expected to make at least one product effective against at least one of these organisms. The PPLS labeling sheets for all products from each of those manufacturers were then reviewed by the primary author, as were all products from any manufacturers that one of the listed manufacturers transferred a product to. Product sheets for a total of 1,907 products from 143 manufacturers were initially screened.

We screened out all products that were not hospital-grade disinfectants because most state child care regulations mandate the use of hospital-grade disinfectants only in child care settings. We chose not to include wipe or towelette products because data suggest that efficacy varies wildly with the wetness of the wipe,[45] leaving us with a total of 529 products. Thus a product's data were included in this summary if the product is for use as a surface disinfectant on hard, nonporous surfaces, does not require the use of specialized equipment to make the active agent, is not a wipe or towelette, and either explicitly states that it is a hospital-grade disinfectant or lists disinfection efficacy against both *Staphylococcus aureus* and *Pseudomonas aeruginosa* (which are the requirements for certification as a hospital-grade disinfectant).[44] From each PPLS sheet, we recorded the active ingredients and their concentrations, instructions for use as a hospital-grade disinfectant, when the product was last registered, and whether it was registered to have efficacy against some common child care pathogens. Because no definitive list of child care pathogens with environmental transmission could be located, one was created using the "Bleach-free Disinfection and Sanitizing for Child Care" guideline's list,[46] the *Red Book*'s table of organisms spread via other routes,[47] and the authors' clinical experience. This yielded the following list of likely encountered pathogens in child care settings: *Bordetella pertussis*, *Campylobacter jejuni*, *Escherichia coli*, *Salmonella* spp., *Shigella* spp., methicillin-resistant *Staphylococcus aureus*, *Entamoeba histolytica*, *Giardia* spp., coxsackie virus, HIV, hepatitis A, hepatitis B, hepatitis C, influenza, norovirus, RSV, rhinovirus, and rotavirus.

Literature review of toxicities

Peer-reviewed articles addressing the health effects of cleaning and disinfecting products were located using PubMed and CrossRef. The following searches were performed, and articles for all relevant citations were downloaded for review: child care AND cleaning, daycare AND cleaning, asthma and LEED, asthma AND swimming, asthma AND cleaning, [disinfecting agent] AND hospital disinfection, [disinfecting agent] AND asthma, [disinfecting agent] AND efficacy, [disinfecting agent] AND disinfect, [disinfecting agent] AND toxicity, and [disinfecting agent] AND health effects. The disinfecting agents searched for were bleach/sodium hypochlorite, quaternary ammonium, and peroxide because these are the most commonly used agents.

RESULTS

Efficacy data

The EPA PPLS database contains 529 antimicrobial products that are registered as hospital-grade disinfectants. These products have 14 main classes of active ingredients (or a combination thereof): bleach, quaternary ammonium compounds, peroxides, chlorine dioxide, citric acid, ethanol, hydrochloric acid, hypochlorous acid, lactic acid, phenols, sodium chlorite, and thymol. There are differences in the pathogens covered between classes of disinfectant but also within each group (Fig 1). Further detail on the products within each class of disinfectants is available in the Supplemental Data 1.

There is no class of products that covers all of these organisms well. The best coverage against *Bordetella pertussis* is from the class of peroxide/peroxyacetic acid products, and only 17% of these have registered efficacy against *B pertussis*. Against *Campylobacter jejuni*, the best coverage comes from quaternary ammonia products (26%); against *E coli* from ethanols and hydrochloric acids (100%); against *Salmonella enterica* from citric acids, hydrochloric acids, lactic acids, and sodium chlorite (100%); against *Shigella* spp. from hydrochloric acids (100%); against methicillin-resistant *Staphylococcus aureus* from

	Bleaches	Chlorine Dioxide	Citric Acid	Ethanol	Hydrochloric Acid	Hypochlorous Acid	Peroxides	Peroxide/Peroxyacetic Acid mixture	Lactic Acid	Other	Phenols	Quaternary Ammonia Compounds	Sodium Chlorite	Thymol	Combination Products
Number of products	63	4	8	3	4	4	31	18	9	15	24	251	3	10	82
Bacteria:															
Bordetella Pertussis	2%	0%	0%	0%	0%	0%	3%	17%	0%	7%	8%	14%	0%	0%	1%
Campylobacter jejuni	9%	0%	13%	0%	0%	0%	3%	6%	11%	13%	0%	26%	0%	0%	7%
Escherichia coli	80%	0%	63%	100%	100%	50%	77%	28%	78%	80%	42%	75%	0%	60%	48%
Salmonella enterica	98%	75%	100%	33%	100%	75%	90%	61%	100%	87%	96%	98%	100%	90%	95%
Shigella spp.	53%	0%	13%	0%	100%	0%	29%	0%	11%	7%	38%	64%	0%	0%	16%
methicillin-resistant Staphylococcus aureus	70%	50%	50%	33%	0%	75%	74%	28%	33%	40%	63%	71%	100%	100%	56%
Parasites:															
Entamoeba histolytica	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Giardia spp.	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Viruses:															
coxsackie virus	0%	0%	0%	0%	0%	0%	0%	0%	0%	7%	0%	0%	0%	0%	2%
human immunodeficiency virus	56%	100%	38%	33%	100%	100%	65%	33%	0%	53%	58%	65%	100%	80%	67%
hepatitis A	52%	25%	13%	33%	100%	0%	3%	0%	0%	13%	0%	1%	100%	0%	11%
hepatitis B	38%	0%	0%	33%	0%	75%	48%	0%	11%	20%	8%	53%	0%	0%	21%
hepatitis C	36%	25%	0%	33%	0%	75%	48%	0%	11%	13%	4%	49%	0%	0%	11%
influenza	84%	50%	50%	100%	100%	75%	87%	33%	100%	67%	54%	81%	100%	40%	63%
norovirus	33%	0%	13%	0%	0%	75%	35%	0%	11%	33%	0%	21%	67%	0%	15%
respiratory syncytial virus	64%	0%	50%	33%	50%	25%	32%	22%	78%	13%	17%	33%	0%	10%	20%
rhinovirus	75%	50%	25%	0%	50%	25%	68%	22%	22%	27%	17%	6%	100%	40%	22%
rotavirus	72%	0%	50%	33%	100%	0%	68%	22%	67%	7%	17%	20%	100%	10%	13%

Percentage of this type of product covering specified organism

- None
- Less than 10%
- 10 to 20%
- 20 to 30%
- 30 to 40%
- 40 to 50%
- 50 to 60%
- 60 to 70%
- 70 to 80%
- 80 to 90%
- 90 to 100%

Fig 1. Summary of disinfectant product efficacy against child care-relevant organisms, using data from the US Environmental Protection Agency (EPA)'s Pesticide Product Labeling Sheets database. The columns show the classes of hospital-grade disinfectant found in the EPA database, grouped by active ingredient, with the number of products in each category listed below the name of the active ingredient. Rows are organisms that are relevant to child care settings. The body of the table shows what percentage of the products in that category list disinfection efficacy against the stated organism on their pesticide product label.

sodium chlorites and thymols (100%); against HIV from chlorine dioxides, hydrochloric acids, hypochlorous acids, and sodium chlorites (100%); against hepatitis A from hydrochloric acids and sodium chlorites (100%); against both hepatitis B and C from hypochlorous acids (75%); against influenza from ethanols, hydrochloric acids, lactic acids, and sodium chlorites (100%); against norovirus from hypochlorous acids (75%); against RSV from lactic acids (78%); against rhinovirus from sodium chlorite (100%); against rotavirus from hydrochloric acids and sodium chlorites (100%); none of the products cover *Entamoeba histolytica* or *Giardia* spp.; and only a few products have registered efficacy against coxsackie virus, meaning the best coverage is from the "other" class, in which 1/15 provides coverage (7%), with active ingredients of sodium chlorite and sodium dichloroisocyanurate dihydrate.

However, it is rare to be targeting an individual organism in a real-world setting, and thus the performance across the entire group becomes important. Only 4 classes of disinfectant had at least 1 product that covered 70% of these organisms: bleaches (13 products), peroxides (1 product), quaternary ammonias (7 products), and combination products (3 products—all of which contain a quaternary ammonia). Table 1 shows an example of a product within each of these classes that has the broadest coverage against this group of organisms.

Literature review of health risks for the most common disinfectant classes

Bleach

It has been known for more than 20 years that large acute exposures to bleach (>30 ppm) cause respiratory symptoms.[49,50] It is thought that the damage to the airways is oxidative in nature[49] but may also include an airways hyperreactivity component through expression of nitric oxide synthase.[51] Bleach can react with organic material to create nitrogenated compounds like chloramines. Chloroform, a known carcinogen, is also released in small amounts with the use of bleach. If used in high temperatures (like washing machines), bleach can release up to twice as much chloroform. Adding surfactants to bleach can significantly increase the chloroform released—after disinfecting a bathroom with surfactant containing bleach, air levels of chloroform were 92 $\mu g/m^3$.[52] Several protective levels have been published; most are applicable to adults in an occupational setting of an 8-hour work shift, not children who may spend more than 8 hours in a child care environment. The National Institute for Occupational Safety and Health has recommended an exposure level of 9.78 mg/m^3 for a short-term exposure limit of 60 minutes for adults in an occupational setting. A recent article on child care settings[53] used the California Prop 65 no significant risk level for adults and calculated a suggested no significant risk level for infants based on body weight and time spent in care settings of 0.4 $\mu g/d$, a level quickly exceeded if air levels after disinfecting approached those in the Odabasi study.[52]

Lower level long-term exposure to bleach is now recognized as another cause of respiratory effects. In controlled adult exposure studies, acute exposure to 0.4 ppm bleach in people with chronic exposure can cause a sustained bronchospasm (drop in FEV_1), and exposure to 1 ppm chlorine gas can create bronchospasm in those without chronic exposure.[54,55] These levels are consistent with those seen during disinfecting, because measured airborne levels during real-world disinfection tasks show chlorine levels that are always detectable, with median levels up to 0.4 ppm and spikes as high as 1.3 ppm.[56] Animal studies have also shown that bleach causes allergic sensitization, with bleach-exposed mice showing more TH2 response and more inflammatory cytokines.[57]

There is also substantial evidence from occupational studies for effects of long-term bleach exposure. Workers who perform cleaning with bleach have increased risk of asthma (RR 2.16, 95% CI 1.03-4.53).[58] Some studies even demonstrated dose-dependent associations (OR for asthma in cleaners with moderate exposure compared with low exposure 3.3 with 95% CI 0.9-11; OR comparing high to low exposure 4.9 with 95% CI 1.5-15).[56] Cleaners who already have asthma are more likely to have lower respiratory symptoms on days they worked with bleach (with reported OR 3.5 and 1.4).[59,60] Similar to findings in rodent studies, some custodial workers show allergic sensitization, with positive skin prick test results for chloramine and

Table 1
Example product from each class with high efficacy against child care–relevant organisms

Product name	Micro-kill germicidal bleach solution	Oxy-1 RTU	REX	Wonder woman formula B germicidal spray
Environmental Protection Agency code	37549-2	74559-9	67619-20	9480-10
Active ingredient	Sodium hypochlorite	Hydrogen peroxide	Quaternary ammonium	Quaternary ammonium/ethyl alcohol/ isopropyl alcohol
Dwell time	30 sec	1 min	2 min	1 min
Bacteria				
Bordetella pertussis	Yes	Yes	Yes (*Bordetella bronchiseptica*)	Yes
Campylobacter jejuni	Yes	No (but does sanitize)	No	Yes
Escherichia coli	Yes	Yes	Yes	Yes
Salmonella enterica	Yes	Yes	Yes	Yes
Shigella spp.	Yes	Yes	Yes	Yes
Methicillin-resistant *Staphylococcus aureus*	Yes	Yes	Yes	Yes
Parasites				
Entamoeba histolytica	No	No	No	No
Giardia spp.	No	No	No	No
Viruses				
Coxsackie virus	No	No	No	No
HIV	Yes	Yes	Yes	Yes
Hepatitis A	Yes	No	Yes (10 min dwell time needed)	No
Hepatitis B	Yes	Yes	Yes	Yes
Hepatitis C	Yes	Yes	Yes	Yes
Influenza	Yes	Yes	Yes (1 min dwell time needed)	Yes
Norovirus	Yes	Yes	Yes (30 sec dwell time needed)	Yes (6 min dwell time needed)
Respiratory syncytial virus	Yes	Yes	Yes	Yes
Rhinovirus	Yes	Yes	Yes (3 min dwell time needed)	Yes

NOTE. The columns show one example of a product in each of the classes of hospital-grade disinfectants found in the Environmental Protection Agency database. Details are given for one of the products in each class of active agents with efficacy against the highest number of this set of child care–relevant organisms (with a minimum threshold of covering ≥70% of the organisms). In the upper portion, rows give information regarding use of each product. In the lower portion, rows are organisms that are relevant to child care settings. The body of the table shows whether that agent covers that organism. If disinfection against that organism requires a different contact time than the general contact time for the product, that is noted. If the product was tested against a surrogate organism, that is noted as well. “Yes” indicates that the PPLS sheet lists this organism as one that the disinfectant has been shown to be active against. “Unknown” would indicate that no data were submitted to the EPA, as was communicated to us in the content of and personal communication that accompanied our Freedom Of Information Act request.[48] “No” indicates that the product was tested, and it did not meet the standard for disinfection (but may have met the standard to sanitize, as indicated in the chart).

formaldehyde,[61] which are disinfection byproducts of bleach. It should be noted, in this context, that child care providers working in facilities that use bleach to sanitize and disinfect typically mix a diluted bleach solution daily, pouring concentrated bleach into a spray bottle for use during the day. In our experience, no child care provider has ever reported using appropriate personal protective equipment for this task. Rather, they stand at a counter and pour the concentrated bleach into a measuring device and then into the spray bottle. Most have not ever been provided Occupational Safety and Health Administration–required training on the proper use of chemicals used in their work that could pose occupational injury or illness.

Low-dose chlorine exposure has also been extensively studied in recent years in the setting of disinfecting swimming pools. The most irritating swimming-related symptom is rhinitis (reported in 74% of elite swimmers), likely related to chlorine exposure, because it improves if swimming is done with nose plugs,[62] although other respiratory symptoms are common as well. Among elite swimmers, there is a higher prevalence of asthma compared with other athletes (20% to 6% in other Olympic elite athletes; 37% to 16% in elite adolescent swimmers compared with control adolescents[63,64] and airway hyperreactivity (6.67% greater drop in FEV_1 after stimulus),[65] thought to be a combination of pool exposures and intense training. People with occupational exposures to pools have also been shown in case reports and case series to have airway obstruction with exposure to pool air generally,[66] or specifically to high chloramines in pool air.[67,68] Healthy adults have also been shown to have decreases in lung function when exposed to pool air during exercise (0.8% FEV_1 decrease).[69] On biopsy, swimmers have similar inflammatory and remodeling changes as mild asthmatics and increased mucin levels.[70] Belgian researchers have found strong evidence of a relationship between chlorine exposure and asthma, or exercise-induced bronchospasm, in children (for children with high immunoglobulin E, OR 1.79 per 100-hour increase in lifetime pool attendance, CI 1.07-2.72),[71] (OR if children swam as infants 3.0, CI 1.3-7.4),[72] (adolescents with highest pool exposure have an OR 3.74, CI 1.40-9.93, population-attributable risk of asthma 63.5%).[73] International data regarding the relationship between swimming and asthma from other locations have been mixed: OR for current asthma with pool attendance 1.54 (CI 1.02-2.31),[74] case report of pool-induced asthma,[75] OR for asthma with swimming before age 2 years 1.10 (CI 0.70-1.73), and for current symptoms OR 1.02 (CI 0.73-1.42),[76] and OR for respiratory symptoms with frequent swimming before age 2 years 0.45 (CI 0.24-0.82).[77] Importantly, there is also clear evidence from other sources that chlorination byproducts can be toxic.[78]

Many products used in early care and education settings are consumer products that are also used in people’s homes. In fact, household cleaning and disinfection products are responsible for many unintentional poisonings in children and are consistently in the top 5 categories for pediatric poisoning exposure. Poison Control Centers report that 267,269 children ≤5 years of age were treated in US emergency departments for household cleaning product–related injuries between 1990 and 2006. The product most commonly associated with injury was bleach (37.1%). Children 1 to 3 years of age accounted for 72.0% of cases. The primary mechanism of injury was ingestion (62.7%). The most common source or container was spray-bottles (40.1%).[79] There have been reported incidents of accidental bleach poisonings in child care settings as well, with diluted bleach being confused with water.[80] A review of California Department of Pesticide Regulation Pesticide Illness Surveillance Program and the Toxic Exposure Surveillance system data found 307 pediatric cases of occupational disinfectant−related illness, with nearly half believed to be due to bleach.[81] Eye and skin irritation were the most commonly reported effects, but 11% also reported respiratory effects.

Bleach, designated as an asthmagen by the Association of Occupational and Environmental Clinics in 2012,[46] can have respiratory effects even in the setting of low-dose long-term exposure. Disinfection byproducts from bleach include the known carcinogen chloroform.

Quaternary ammonium compounds

Some quaternary ammonium compounds (QACs or quats) are mutagenic and have been shown to damage animal DNA and DNA in human lymphocytes at much lower levels than are present in cleaning chemicals (as low as 0.3 mg/L),[82] although carcinogenicity has not yet been shown. Mice whose cages were cleaned with QACs had very low fertility rates.[83] Also, genes have been discovered that mediate resistance to QACs. There has been an association of some of these genes with beta lactamase genes, raising concern for a relationship between disinfectant resistance and antibiotic resistance.[84] One quat, benzalkonium chloride, has also been associated with dermatitis (34% of people reacted to exposure to 7.5% benzalkonium).[85]

Quats also increase the risk for asthma and allergic sensitization. There is evidence from occupational exposures for increased risk of rhinitis (OR 3.2, CI 1.42-7.22) and asthma with exposure to quats (OR 7.5, CI 1.84-31.05; RR 2.16, CI 1.03-4.53),[28,58,86] and surveillance data in France suggest that the number of work-related asthma cases attributable to quat exposure has increased over 2001-2009,[86] thought to be related to increased use of quats, largely in the medical sector.[28] A case series of people with asthma symptoms during cleaning tasks found that more reacted to a controlled exposure to quats (10/44) than any other chemical.[87] Quats are on the Association of Occupational and Environmental Clinics list of asthmagens[88] and may be a more potent asthmagen than bleach, given the apparent higher odds of asthma with quat exposure than with bleach. Thus quats have potential mutagenicity and reproductive toxicity and are known to increase the risk of asthma.

Peroxides

A 2004 review of hydrogen peroxide noted acute toxicities at high concentrations, but at a concentration of 3% or less the only reported toxicity was eye irritation.[89] A review of poison centers noted 670 exposures to 3% hydrogen peroxide, most of which were ingestions, and only 14% had any symptoms at all. Moreover, well over 90% of symptomatic patients had only mild gastrointestinal symptoms.[90] Thus, at the concentrations used in disinfection products, hydrogen peroxide has a low risk of toxicity even when ingested. A ready-to-use peroxide disinfectant was recommended by the San Francisco Asthma Task Force for bleach-free disinfecting based on not having a known association with asthma, not causing any nasal irritation, and being a registered EPA disinfectant with a short dwell time.[46]

The only reports of respiratory toxicity in the literature are of unclear relation to peroxide because they include co-exposures with other chemicals: reports of 2 cases of work-related asthma thought to be related to a peracetic acid−hydrogen peroxide mixture. Both workers were also exposed to quats (a known asthmagen), and one was a smoker. Only the smoker had an inhalational challenge, and FEV_1 did drop (20%) but slowly after the challenge (over the following 50 minutes). Thus it is unclear what role, if any, the peroxide-peracetic acid mixture played,[91] and furthermore it says nothing about the toxicity of peroxide alone.

DISCUSSION

Discussion of the efficacy data

Review of the efficacy data from the PPLS registration sheet made it clear that there is no currently registered disinfectant that will cover all relevant organisms in early care and education settings. Moreover, because hospital-grade registration indicates efficacy only against *S aureus* and *P aeruginosa,* this classification is *not* a good indicator of relevancy for the early care and education setting. The most common classes of disinfectants are bleaches, quaternary ammonium compounds, and peroxides, and these are also the categories that contain products that cover 70% or more of the organisms we identified as relevant.

A disadvantage of using the EPA registration data to evaluate efficacy is that the complete data are not publicly available, only the organisms that the product has been shown to be effective against. It is impossible to know whether products were tested against other organisms and found ineffective, or if they have not been tested at all. This is a limitation of this article, but also a limitation of the current regulatory framework. The PPLS system is difficult to query with no way to search byproduct class or organisms of interest. The PPLS system also does not contain data on inactive ingredients, making it impossible to determine what role inactive ingredients have on either efficacy or toxicity. Finally, none of the EPA data address biofilms. There are multiple recent articles showing that the effectiveness of disinfectants is decreased when attempting to kill organisms within a biofilm, but the effectiveness does not necessarily change in a predictable manner.[92-95] But, in the absence of a separate robust literature, the PPLS system was used to review the existing data and record the efficacy of each product as the best available data source. In addition to the efficacy described above, another factor to consider when selecting a disinfectant agent is real-world use. Many workers may not understand the differences among *cleaning* (removal of visible soiling), *sanitizing* (defined by the EPA as 99.9% reduction in bacteria),[96] and *disinfection* (destroys or irreversibly inactivates bacteria).[44] All disinfectants are less effective in the presence of organic material. Organic material interferes with the action of disinfectants by coating the pathogen, thereby creating a barrier and preventing contact with the disinfectant; or by forming chemical bonds with the disinfectant, thereby reducing the active disinfectant available for attacking microorganisms. Therefore, if there is visible soiling, a surface should be cleaned before disinfection. Other complicating factors regarding the effectiveness of a disinfectant include not only the chemical used but also the concentration,[97] technique (ie, contact time),[98] surface type,[15,99] presence of organic soiling,[100,101] and pathogen.[102,103] Porous materials, in particular, are more difficult to disinfect than nonporous surfaces,[15,46,104] and EPA certification does not certify efficacy on porous surfaces. Many of these factors would be difficult for child care providers to control; however, using products that can achieve disinfection in a shorter contact time is a practical change that could reduce exposure and increase correct use. Many child care providers, in our experience, do not understand dwell time and apply a disinfectant and then wipe it off. Moreover, disinfectants are used in the real world to perform tasks that don't require disinfectants, such as routine cleaning procedures (for which they are often not effective), adding to exposures; this should be minimized.

Discussion of health effects data

Based on this review, peroxide products are preferable when other factors are equal, because they have less respiratory toxicity than bleach or quaternary ammonias. Peroxides also do not present the same concerns for reproductive toxicity that the quats do. We are unable to comment on inactive ingredients because we have no

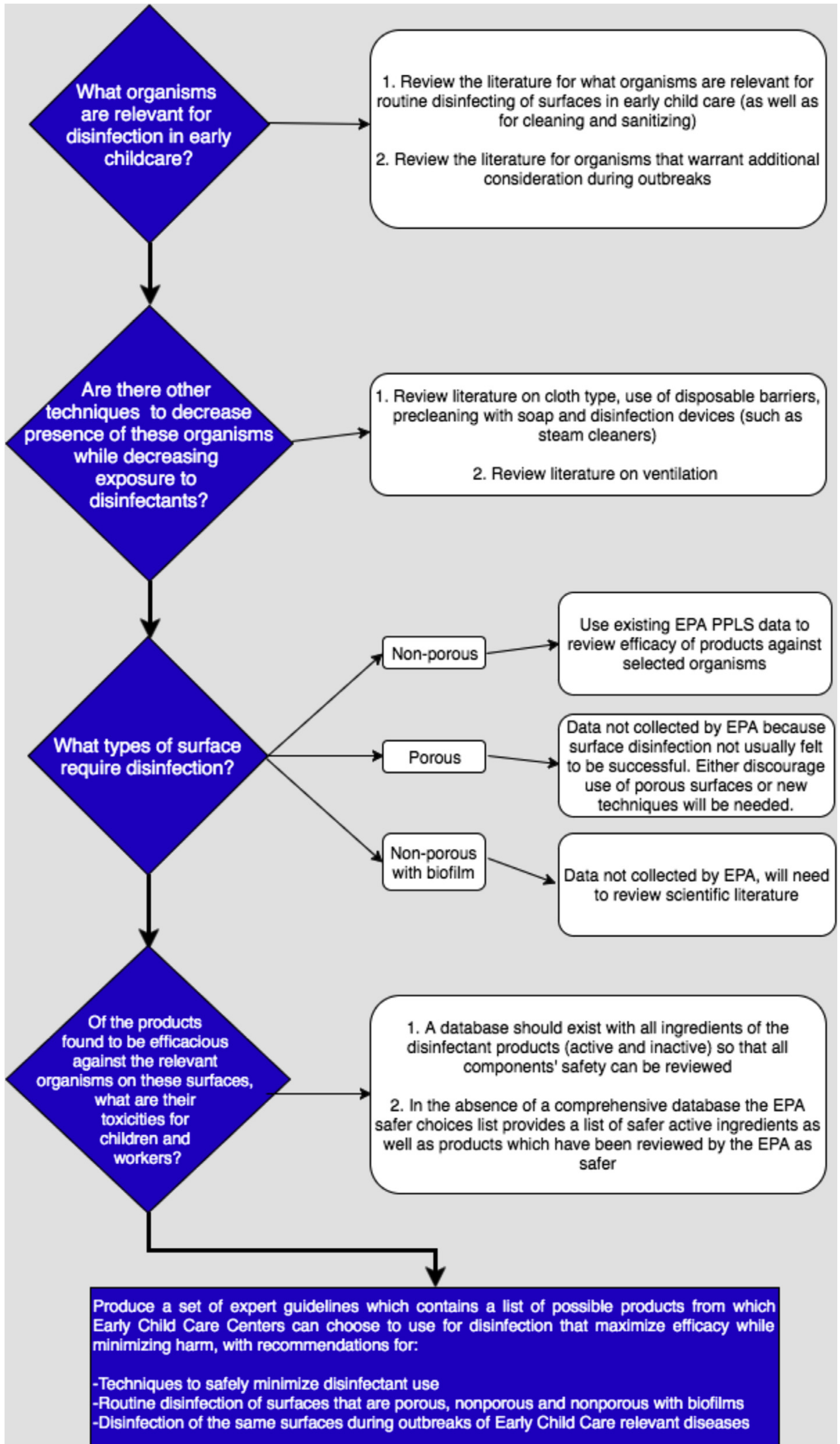

Fig 2. Suggested process for producing an expert guideline regarding appropriate disinfection in child care settings.

information on these. The EPA's Design for the Environment Antimicrobial Pesticide Pilot Project[105] was initiated to provide the public with information on safer antimicrobials, and, in line with our review, they have also identified peroxide as one of the safer active ingredients. The Antimicrobial Pesticide Pilot Project[106] also certifies specific products as safer. To qualify, manufacturers must have submitted their entire list of ingredients, including inactive ingredients, and those ingredients "cannot be listed carcinogens, mutagens or reproductive or developmental toxicants, or persistent, bio-accumulative and toxic chemicals"; they also try to minimize any other human health effects.[106]

Recommendations for developing future guidelines

Child care professionals, administrators, regulators, and policy makers, as well as parents, should be better informed about how to make product decisions based on efficacy, safety, and ease of use. Official guidelines are lacking. The Infectious Disease Society of America does not have recommendations on surface disinfection, the Centers for Disease Control and Prevention guideline for hospital disinfection mentions that medical equipment in nonhospital settings (ie, home care) could be disinfected with bleach, alcohol, or peroxide but contains nothing specific regarding schools or child care settings, or nonmedical equipment.[107] Recently the National Institute for Occupational Safety and Health Cleaning and Disinfecting in Healthcare Working Group acknowledged many gaps in knowledge, including needing more information on what chemicals are best for cleaning and disinfecting which surfaces, how biofilms affect cleaning and disinfection, the need for standardized definitions for green cleaning products, and more study of green cleaning products.[108] The guidelines that exist specifically for schools or child care settings are nontechnical and aimed at school administrators. The main guide used in this area is the American Academy of Pediatrics' *Caring for Our Children*,[3] which includes guidance on where and how often to clean, sanitize, and disinfect; notably toilets are disinfected daily and changing tables after every use. It is worth noting that the common practices of disinfection used in US child care centers are not used worldwide. For example, in Scotland, the official recommendation is to simply clean changing tables with detergent after each use[109] rather than disinfect. And, although *Caring for Our Children* recommends disinfection, it gives no guidance on the type of product except to say that it should either be bleach or an EPA-registered disinfectant. The National Association for the Education of Young Children publishes a table outlining the frequency with which sanitizing and disinfection is to be performed,[110] but this is also based on *Caring for Our Children*. The *Red Book*, [111] the authoritative source on issues regarding pediatric infectious disease does not provide guidance on selection of disinfectants either.

A recent article in the *American Journal of Infection Control* addressed surface disinfection in hospitals.[112] Quinn and her coauthors[112] raise a number of important considerations for choosing a hospital disinfectant, including effectiveness, surface type, product use characteristics, and toxicologic risk. We suggest adapting this framework and applying it very practically to child care settings. With this knowledge, a 4-question process could be used by a panel of experts to produce new guidelines regarding the best disinfectant products for use in child care settings in an evidence-based manner (Fig 2). This would allow individual centers to evaluate the characteristics of those products (including cost and instructions for use, including dwell time) to determine products that the center could afford and use correctly.

CONCLUSION

There is a need for clear, transparent data and analyses that provide practical guidance regarding how best to disinfect in child care settings and what the goals of disinfection should be. Providing adequate control of infectious diseases has been the sole focus of decision making about disinfection procedures in child care, yet exact goals have not been elucidated. This review demonstrates that the current regulations encompass products with a wide range of percent efficacy against relevant organisms. Moreover, studies have identified the potential hazards of exposures related to these procedures for children and staff, and there has been insufficient attention paid to the health risks posed by products used to disinfect. We need to better weigh both the risks and the benefits of disinfection for children and staff in child care facilities.

Appropriate disinfecting procedures are important in child care settings to prevent infectious disease. However, it is perhaps even more critical than in other settings that we are cognizant of how this disinfecting is performed, and where. Child care centers are unique in that, despite potential health hazards, they are required to use products with children present. We need to come together as clinicians, scientists, regulators, teachers, and parents to prioritize learning about which organisms we should be trying to disinfect against in child care settings, which products are available to best do that, and what the potential adverse effects of using those products around our children are.

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SUPPLEMENTARY MATERIALS

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.ajic.2018.06.013.

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