COMMENTARY

Selection of the Ideal Disinfectant

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Healthcare-associated infections (HAIs) remain an important source of morbidity and mortality, with an estimated 1.7 million infections and 99,000 deaths annually.[1] A major source of nosocomial pathogens is thought to be the patient's endogenous flora, but an estimated 20%–40% of HAIs have been attributed to cross infection via the hands of healthcare personnel.[2] Contamination of the hands of healthcare personnel could in turn result from direct patient contact or indirectly from touching contaminated environmental surfaces. Healthcare personnel have frequent contact with the environmental surfaces in patients' rooms, providing ample opportunity for contamination of gloves and/or hands.[3] Two recent studies demonstrated that contact with the environment was just as likely to contaminate the hands of healthcare workers as direct contact with the patient.[4,5] Donskey[6] reviewed the scientific literature and found that improving surface cleaning and disinfection reduces HAIs. Another recent article showed that daily disinfection of surfaces (vs standard cleaning of surfaces when visibly soiled) with a sporicidal disinfectant in rooms of patients with *Clostridium difficile* and methicillin-resistant *Staphylococcus aureus* (MRSA) reduced acquisition of pathogens on gloved hands after contact with room surfaces.[7] While disinfectants are used to prevent transmission of pathogens from both noncritical and semicritical items, the purpose of this article is to assist the user in the selection of the optimal disinfectant for use with environmental surfaces and noncritical patient care items (devices that contact only intact skin, such as stethoscopes). The same characteristics for an ideal low-level disinfectant shown in Table 1 would be used for high-level disinfectants; however, the contact time would be longer, and the antimicrobial spectrum would be broader (eg, may include *C. difficile* spores). To date, the perfect product for healthcare disinfection has not been introduced; however, there is a wide array of disinfectants that offer a range of characteristics. The remainder of this article will review the 5 key criteria that should be used when evaluating disinfecting products available today.

While the process of selecting an optimal healthcare disinfectant used for low-level disinfection of noncritical items is commonplace in healthcare facilities, there are no articles in the peer-reviewed literature on this topic. Disinfectant selection, or the product, is one of the 2 components essential for effective disinfection. The other component, the practice, is thorough application such that the disinfectant contacts all surfaces, as well as proper training of hospital staff (especially environmental services and nursing) and adherence to the manufacturer's label instructions (except in the cases where an institution may prepare a formal risk assessment to follow alternate contact times, such as more than or equal to 1 minute for vegetative bacteria). The combination of product and practice results in effective surface disinfection—or reduction of patient risk—and improved patient outcomes. The 5 key considerations when selecting a disinfectant are summarized below (Table 2).[8,9]

1. KILL CLAIMS FOR THE MOST PREVALENT HEALTHCARE PATHOGENS

To keep patients as safe as possible, healthcare facilities must consider what pathogens are the most common causes of HAIs, the most common causes of outbreaks and ward closures, and the unique pathogens in their facility. The product selected should be effective against the microorganisms that are the most common causes of HAIs and outbreaks (see Table 3), according to nationally reported data. Since vegetative bacteria (such as *S. aureus*, *Enterococcus*, *Escherichia coli*, coagulase-negative *Staphylococcus*, *Pseudomonas aeruginosa*, *Klebsiella* species, *Enterobacter* species) are the pathogens that cause the vast majority of HAIs (79.1%),[10,11] healthcare disinfectants should be effective against these pathogens. It is reasonable to check the product label to ensure that the disinfectant under evaluation is Environmental Protection Agency (EPA) registered to kill as many of the pathogens listed in Table 3 as possible.

When evaluating a disinfectant, it is important to note that disinfectant testing for antibiotic-resistant pathogens (eg, MRSA) is not necessary, as antibiotic-resistant pathogens are not more resistant to disinfectants than antibiotic-sensitive pathogens at the manufacturer's recommended use dilution.[12,13] However, there are some pathogens that are

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TABLE 1. Properties of an Ideal Disinfectant

1. *Broad spectrum.* Should have a wide antimicrobial spectrum, including kill claims for the pathogens that are the common causes of HAIs and outbreaks.
2. *Fast acting.* Should have a rapid kill and short kill/contact time listed on the label.
3. *Remains wet.* Should keep surfaces wet long enough to meet listed kill/contact times with a single application or meet wet times recommended by evidence-based guidelines.
4. *Not affected by environmental factors.* Should be active in the presence of organic matter (eg, blood, sputum, feces) and compatible with soaps, detergents, and other chemicals encountered in use.
5. *Nontoxic.* Should not be irritating to the user, visitors, and patients. Should not induce allergic symptoms (especially asthma and dermatitis). The toxicity ratings for disinfectants are danger, warning, caution, and none. Ideally, choose products with the lowest toxicity rating.
6. *Surface compatibility.* Should be proven compatible with common healthcare surfaces and equipment.
7. *Persistence.* Should have sustained antimicrobial activity or residual antimicrobial effect on the treated surface.
8. *Easy to use.* Should be available in multiple forms, such as wipes (large and small), sprays, pull tops, and refills; directions for use should be simple and contain information about personal protective equipment as required.
9. *Acceptable odor.* Should have an odor deemed acceptable by users and patients.
10. *Economical.* Costs should not be prohibitively high but when considering the costs of a disinfectant one should also consider product capabilities, cost per compliant use, and so on.
11. *Solubility.* Should be soluble in water.
12. *Stability.* Should be stable in concentrate and use dilution.
13. *Cleaner.* Should have good cleaning properties.
14. *Nonflammable.* Should have a flash point above 150°F.

NOTE. Modified from Molinari et al[8] and Rutala and Weber.[9] HAI, healthcare-associated infection.

important causes of HAIs either endemically (*C. difficile* spores) or epidemically (eg, norovirus, adenovirus) that are intrinsically more resistant to disinfectants (Table 3). To comply with the Occupational Safety and Health Administration bloodborne pathogen rule for cleaning blood spills, a disinfectant must be EPA registered as tuberculocidal. Diluted bleach solutions (1 : 10 to 1 : 100) and EPA-registered disinfectants that are labeled as effective against both human immunodeficiency virus (HIV) and hepatitis B virus (HBV) are appropriate disinfectants to clean contaminated surfaces, provided that such surfaces have not become contaminated with agent(s) or volumes or concentrations of agent(s) for which higher-level disinfection is recommended (see https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=INTERPRETATIONS&p_id=21010).

All disinfectants used in healthcare should be EPA registered, which can be confirmed on antimicrobial products listings and manufacturer's label claims. Independent assessment of new disinfectants using appropriate methodologies to validate label claims can be useful when it is part of a rigorous scientific investigation. Validation of label claims by individual hospitals is neither recommended nor feasible. A trial evaluation to test the acceptability of a proposed disinfectant to be introduced into a healthcare facility is often useful. The EPA lists contain disinfectants effective against certain bloodborne/body fluid pathogens to include *Mycobacterium tuberculosis*, HIV, HBV, hepatitis C virus, and products classified as sterilizers. Listings also include EPA-registered products effective against MRSA, vancomycin-resistant *Enterococcus faecalis* or *Enterococcus faecium* (VRE), human norovirus, and *C. difficile* spores. The lists are organized alphabetically by product name and by numerical order of their EPA registration number (see http://www.epa.gov/oppad001/chemregindex.htm).

There are 3 types of disinfectant products that are EPA registered on the basis of submitted efficacy data: limited, general or broad-spectrum, and hospital disinfectants. When a disinfectant is represented in its labeling for use in hospitals (ie, hospital disinfectant), medical clinics, dental offices, or any other medical-related facility, it must show effectiveness against 2 gram-negative microorganisms (*Salmonella choleraesuis* ATCC 10708, *P. aeruginosa*) and 1 gram-positive microorganism (*S. aureus* ATCC 6538). In addition to the efficacy data for a public health claim, the applicant is required to submit supporting data pertaining to product chemistry and toxicologic hazards.[14] Product testing for the EPA requires testing under hard-water conditions (eg, up to 400-ppm hardness, $CaCO_3$) in the presence of 5% serum concentration to simulate the product's effectiveness under in-use conditions. If the product is tested under additional conditions, it may be listed on the label. Some of the issues associated with current testing that have been raised include unrealistic contact times (10 minutes is too long for hospital use), long lists of irrelevant organisms on product labels (eg, many spread primarily by methods other than contaminated environmental surfaces), soil load (eg, a standardized level of soil should be added to the disinfectant test), test methodology (eg, suspension vs carrier tests), composition of test surface (eg, glass, stainless steel, formica), testing does not include physical removal (eg, label claims for disinfectants based on tests that do not include wiping), and product volume to surface area (eg, wet-contact time).[15] Currently used disinfectants for environmental surfaces and noncritical patient care equipment with their advantages and disadvantages are shown in Table 4.

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TABLE 2. Key Considerations for Selecting the Optimal Disinfectant for Your Facility

Consideration	Questions to ask	Score (1–10)
Kill claims	Does the product kill the most prevalent healthcare pathogens, including those that • Cause most HAIs? • Cause most outbreaks? • Are of concern in your facility?	
Kill and wet-contact times	How quickly does the product kill the prevalent healthcare pathogens? Does the product keep surfaces visibly wet for the kill times listed on its label?	
Safety	Does the product have an acceptable toxicity rating? Does the product have an acceptable flammability rating? Is a minimum level of personal protective equipment required? Is the product compatible with the common surfaces in your facility?	
Ease of use	Is the product odor considered acceptable? Does the product have an acceptable shelf life? Does the product come in convenient forms to meet your facility's needs (eg, liquids, sprays, refills, multiple wipe sizes)? Does the product work in the presence of organic matter? Is the product water soluble? Does the product clean and disinfect in a single step? Are the directions for use simple and clear?	
Other factors	Does the supplier offer comprehensive training and ongoing education, both in person and virtual? Does the supplier offer 24-7 customer support? Is the overall cost of the product acceptable (considering product capabilities, costs of infections that may be prevented, and costs per compliant use)? Can the product help standardize disinfectants used in your facility?	

NOTE. When determining the optimal disinfecting product for surface disinfection in your facility, consider the 5 components shown, give each product a score (1 is worst and 10 is best) in each of the 5 categories, and select the product with the highest score as the optimal product choice (maximum score is 50). HAI, healthcare-associated infection.

Another issue that must be considered is the "order of susceptibility of microorganisms to disinfectants" model and its limitations. The traditional hierarchy developed by Spaulding is still widely used but is based on disinfectant knowledge from 1957.[16] Today, our understanding of the resistance profiles of pathogens (eg, viruses, protozoans, spores) by disinfectants is more informed, and an updated guide has been proposed (Table 5).[17] However, it is important to recognize that this hierarchical scale is only a guide to microbial susceptibility of pathogens to disinfectants, and it may vary depending on the type of microorganisms, how they are presented for disinfection (eg, in suspension or dry on carrier),[18] the test method (eg, quantitative carrier tests),[19] and the active ingredient and how it is formulated (eg, surfactants, chelating agents).[17] For example, for nonsporicidal disinfectant formulas, mycobacteria (marker strains *Mycobacterium bovis* or *Mycobacterium terrae*) are considered the most resistant vegetative bacteria. However, while alcohols can inactivate mycobacteria, they are less active against small, nonenveloped viruses, such as poliovirus.[20] This means that a product EPA registered to kill *M. tuberculosis* with a 1-minute contact time may not be capable of inactivating other pathogens traditionally considered to be "more susceptible" (such as poliovirus and norovirus) within the 1-minute time frame. Because of the variation in the susceptibility of microorganisms to disinfectants, users should check disinfecting labels for the relevant kill claims (those that cause most HAIs and outbreaks) in addition to considering the historically accepted hierarchy model.

Due to the constant evolution of pathogens causing infections, especially emerging pathogens (eg, Middle East respiratory syndrome coronavirus [MERS-CoV]), a new or emerging pathogen will likely not have an EPA-registered disinfectant on the market to kill it. Manufacturers may not make claims about any emerging pathogen without EPA approval, and it can take 18–24 months for a manufacturer to obtain label claims for new pathogens (see http://www.epa.gov/oppad001/disinfection_hier.htm). Until an EPA-approved claim is avail-

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TABLE 3. Most Prevalent Pathogens Causing Healthcare-Associated Infections (HAIs)

Recommended organism (% of HAIs caused)	Why organisms are relevant
Staphylococcus aureus (15.6%) *Escherichia coli* (11.5%) Coagulase-negative *Staphylococcus* (11.4%) *Klebsiella* (8.0%) *Pseudomonas aeruginosa* (7.5%) *Enterococcus faecalis* (6.8%) *Candida albicans* (5.3%) *Enterobacter* species (4.7%) Other *Candida* species (4.2%) *Enterococcus faecium* (4.1%) *Enterococcus* species (3.0%) *Proteus* species (2.5%) *Serratia* species (2.1%) *Acinetobacter baumanni* (1.8%)	Most prevalent overall contributors to HAIs (NHSN/CDC)[11]
Clostridium difficile spores[a] Norovirus *Aspergillus* Rotavirus Adenovirus	Most common causes of outbreaks and ward closures by causative pathogen, which are relatively hard to kill[40]
Facility-specific pathogens, eg, *Burkholderia cepacia*	Other pathogens of concern in your facility

NOTE. CDC, Centers for Disease Control and Prevention; NHSN, National Healthcare Safety Network.
[a] Over the past decade, an increasing incidence of *C. difficile* has been recognized, and in some healthcare facilities it is the most common cause of HAIs.

able, users may need to refer to the hierarchy of microbial susceptibility to select the appropriate disinfectant for the emerging pathogen (Table 5). If the microbiologic class of a new microbe is established, the class-specific test organism(s) would serve as a surrogate for evaluating disinfectant efficacy. The label claim (ie, registration) would be based on the use of a validated EPA-approved test that assessed the efficacy of disinfectants against the class-specific test organism.[20] For example, an EPA claim against poliovirus or hepatitis A virus could be used for MERS-CoV as well as data in peer-reviewed literature that demonstrated inactivation of coronavirus.[20-22] Until a new or emerging microbe could be placed in a microbiologic class, it is suggested that only disinfectants with a mycobactericidal claim be allowed by the EPA.[20] For example, the severe acute respiratory syndrome agent, prior to isolation and characterization as a coronavirus, would necessitate the use of a disinfectant with a mycobactericidal label claim for surface disinfection. Once the agent is characterized and placed into a microbial class (eg, as a coronavirus), all EPA products with a label claim against viruses (eg, test agent, poliovirus) would be acceptable. In the event that there is not a validated test organism in a class, the next most resistant class should be used for purposes of registering disinfectants. For example, if a surrogate for an enveloped virus is not validated, then a small, nonenveloped virus (eg, poliovirus) could be used instead. Using this accumulated knowledge of microbial susceptibility should discourage unnecessary testing, listing irrelevant organisms on labels, and "bug-of-the-month" testing.[15]

Survival of pathogens on environmental surfaces is critical to the potential of that surface to act as a reservoir or source of the pathogen. There are many factors that determine the survival of pathogens on inanimate surfaces as well as their transfer to other surfaces. It is beyond the intent of this article to review that data, but the factors include temperature, relative humidity, topography, porosity, suspending medium, higher inocula, duration of contact, surface material (eg, plastic, steel), other microbes, biofilms, product volume to surface area, type of microbe, disinfectant residual, microbial load, and contacting surface (eg, bare hands or gloves).[15,23]

2. FAST KILL TIMES AND ACCEPTABLE WET-CONTACT TIME TO ENSURE PROPER DISINFECTION OF NONCRITICAL SURFACES AND PATIENT CARE EQUIPMENT

Each disinfectant requires a specific length of time it must remain in contact with a microorganism to achieve complete disinfection. This is known as the kill time (or contact time), and kill times for each microorganism will be listed clearly on the label of EPA-registered disinfectants. Fast kill times are important because they give you confidence that you are killing the prevalent and most common healthcare-associated pathogens before the disinfecting solution can dry or be removed and before patients or staff are likely to retouch the surface. Ideally, the contact time should be greater than or equal to the kill time.

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For example, some disinfectants may have a kill time for vegetative bacteria of 30 seconds to 1 minute, which means that the bacteria listed on the label will be disinfected within 1 minute. Other products, often concentrated formulas that require dilution before use, are registered by the EPA for use against bacteria and viruses (eg, HBV, HIV) with a contact time of 10 minutes. Such a long contact time is not practical for disinfection of environmental surfaces in a healthcare setting because most healthcare facilities apply a disinfectant and allow it to dry, which normally takes 1.5–2 minutes.

The EPA's position is that "By law, all applicable label instructions on EPA-registered products must be followed. If the user selects exposure conditions that differ from those on the EPA-registered product label, the user assumes liability from any injuries resulting from off-label use and is potentially subject to enforcement action under FIFRA."[9] According to this position, kill times for the organisms listed on the label must be followed. However, scientific studies of hospital disinfectants have demonstrated microbial reduction against pathogens causing HAIs with a contact time of 30–60 seconds.[9,18,24-26] Currently, there are EPA-registered disinfectants available with contact times of 1–3 minutes against most pathogens known to cause HAIs and outbreaks (see http://www.epa.gov/oppad001/chemregindex.htm). Disinfectant manufacturers must work to obtain EPA approval for shortened contact times so that disinfecting products will be used correctly and effectively in the healthcare environment. In the instances where an institution chooses to use a product with a nonachievable label claim (eg, 10 minutes), it should prepare a formal risk assessment (see http://disinfectionandsterilization.org/files/2012/12/SurfDisRiskAssess2011.pdf) to be presented to surveyors (eg, The Joint Commission) when challenged.

Another issue is which pathogen on the disinfectant label should be used to identify contact time (eg, bacteria, *Candida*, mycobacteria, spores) for surfaces in healthcare facilities. The Centers for Disease Control and Prevention guideline based the minimum 1-minute contact time for disinfection of noncritical surfaces on demonstration of bactericidal activity for vegetative bacteria, such as *S. aureus*, *Enterococcus*, *E. coli*, coagulase-negative *Staphylococcus*, *P. aeruginosa*, *Klebsiella* species, *Enterobacter* species, and so on. These vegetative bacteria are the pathogens that cause the vast majority of HAIs (approximately 80%).[10,11] Furthermore, contaminated surfaces with organisms such as *Candida*, nontuberculous mycobacteria, and other fungi have rarely been shown to be a risk factor for HAIs. The only exception to this principle of low-level disinfectants for at least 1 minute on environmental surfaces is the use of EPA-registered disinfectant effective against *C. difficile* spores or norovirus for disinfecting the rooms of patients with one of these pathogens (see http://www.epa.gov/oppad001/chemregindex.htm).

Wet-contact time is also a critical component of product evaluation because if the product evaporates too quickly, it will not remain in contact with microorganisms for the necessary kill/contact time. The best disinfecting products will have a wet-contact time greater than or equal to the kill times listed on the label. Most aqueous-based products (eg, quaternary ammonium compounds, phenolics, sodium hypochlorite, improved hydrogen peroxide) will keep standard surfaces wet for approximately 2 minutes, while alcohol-containing solutions will dry faster. Wet time for different disinfectants will vary depending on the size of the surface area, the product formulation (eg, inclusion of surfactants may elongate wet time), and the amount of product loaded onto the wipe/cloth.

The amount of disinfectant left on the surface is important, as it affects the contact time and the concentration of active ingredients delivered to the surface. Below a certain amount of liquid per surface area, the desired antimicrobial affect will not be achieved. Thus, "damp dusting" using a barely wet cotton cloth or disposable disinfectant wipe will not result in the desired antimicrobial reduction, as the surface was not wetted for the contact time with an appropriate use dilution of the disinfectant.[27] Similarly, results have demonstrated efficient transfer of *C. difficile* spores from contaminated to clean surfaces by nonsporicidal wipes and overused sporicidal wipes.[28] In contrast, wiping with sporicidal agents eliminated more than 3.90-$\log_{10}$ *C. difficile* spores by inactivation and/or physical removal.[29]

It is important to note that while disinfectant wet-contact time is critical for thorough surface disinfection, nothing is more important than the thoroughness of cleaning/disinfecting all hand contact surfaces (eg, environmental surfaces or patient care equipment), as current studies demonstrate that less than 50% of high-risk objects are cleaned/disinfected at terminal cleaning.[30,31] Wiping all hand-contact or touchable surfaces and equipment—and not just perceived high-risk surfaces and equipment—is essential because high-risk surfaces and equipment have not been epidemiologically defined. In addition, high-touch surfaces have only recently been defined,[3] but there was no significant difference in microbial contamination of high-, medium-, and low-touch surfaces.[3]

Persistence or sustained antimicrobial activity of the disinfectant would also be a desirable characteristic (Table 1).[32] The persistent antimicrobial would be self-sustaining once in place and, unlike improved environmental cleaning, does not require an ongoing behavior change or education of personnel. Sustained antimicrobial activity or continued disinfection may eliminate the problem of recontamination, unlike no-touch methods, which can be used only for terminal disinfection. Some disinfectants have demonstrated sustained antimicrobial activity,[33,34] but current products have limitations (eg, costs, removed by contact or touch), and their use has not been demonstrated to lead to reductions in HAIs compared with disinfectants without persistence. Disinfectant manufacturers should work to obtain EPA approval for persistent antimicrobial activity on healthcare surfaces and equipment.

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TABLE 4. Summary of Advantages and Disadvantages of Disinfectants Used as Low-Level Disinfectants

Disinfectant active	Advantages	Disadvantages
Alcohol	Bactericidal, tuberculocidal, fungicidal, virucidal Fast acting Noncorrosive Nonstaining Used to disinfect small surfaces, such as rubber stoppers on medication vials No toxic residue	Not sporicidal Affected by organic matter Slow acting against nonenveloped viruses (eg, norovirus) No detergent or cleaning properties Not EPA registered Damages some instruments (eg, harden rubber, deteriorate glue) Flammable (large amounts require special storage) Evaporates rapidly, making contact time compliance difficult Not recommended for use on large surfaces Outbreaks ascribed to contaminated alcohol[41]
Sodium hypochlorite	Bactericidal, tuberculocidal, fungicidal, virucidal Sporicidal Fast acting Inexpensive (in dilutable form) Not flammable Unaffected by water hardness Reduces biofilms on surfaces Relatively stable (eg, 50% reduction in chlorine concentration in 30 days)[42] Used as the disinfectant in water treatment EPA registered	Reaction hazard with acids and ammonias Leaves salt residue Corrosive to metals (some ready-to-use products may be formulated with corrosion inhibitors) Unstable active (some ready-to-use products may be formulated with stabilizers to achieve longer shelf life) Affected by organic matter Discolors/stains fabrics Potential hazard is production of trihalomethane Unpleasant odor (some ready-to-use products may be formulated with odor inhibitors); irritating at high concentrations
Improved hydrogen peroxide	Bactericidal, tuberculocidal, fungicidal, virucidal Fast efficacy Easy compliance with wet-contact times Safe for workers (lowest EPA toxicity category, IV) Benign for the environment Surface compatible Nonstaining EPA registered Not flammable	More expensive than most other disinfecting actives Not sporicidal at low concentrations

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Iodophors	Bactericidal, mycobactericidal, virucidal Not flammable Used for disinfecting blood culture bottles	Not sporicidal Shown to degrade silicone catheters Requires prolonged contact to kill fungi Stains surfaces Used mainly as an antiseptic rather than disinfectant
Phenolics	Bactericidal, tuberculocidal, fungicidal, virucidal Inexpensive (in dilutable form) Nonstaining Not flammable EPA registered	Not sporicidal Absorbed by porous materials and irritate tissue Depigmentation of skin caused by certain phenolics Hyperbilirubinemia in infants when phenolic not prepared as recommended
Quaternary ammonium compounds (eg, didecyl dimethyl ammonium bromide, dioctyl dimethyl ammonium bromide)	Bactericidal, fungicidal, virucidal against enveloped viruses (eg, HIV) Good cleaning agents EPA registered Surface compatible Persistent antimicrobial activity when undisturbed Inexpensive (in dilutable form)	Not sporicidal In general, not tuberculocidal and virucidal against nonenveloped viruses High water hardness and cotton/gauze can make less microbicidal A few reports documented asthma as result of exposure to benzalkonium chloride Affected by organic matter Multiple outbreaks ascribed to contaminated benzalkonium chloride[41]

NOTE. Modified from Rutala and Weber.[43] EPA, Environmental Protection Agency; HIV, human immunodeficiency virus.

TABLE 5. Hierarchy of Microbial Resistance to Disinfectants and Sterilants

Microorganism	Examples
Prions	Creutzfeldt-Jakob disease agent, scrapie
Bacterial spores	*Bacillus*, *Geobacillus*, *Clostridium*
Protozoan oocytes[a]	*Cryptosporidium*
Helminth eggs[a]	*Ascaris*, *Enterobius*
Mycobacteria	*Mycobacterium tuberculosis*, *M. chelonae*
Small, nonenveloped viruses	Poliovirus, parvovirus, papilloma virus, norovirus
Protozoal cysts[a]	*Giardia*, *Acanthamoeba*
Fungal spores	*Aspergillus*, *Penicillium*
Gram-negative bacteria	*Pseudomonas*, *Escherichia*
Vegetative fungi and algae	*Aspergillus*, *Candida*, *Trichophyton*
Vegetative helminthes and protozoa[a]	*Ascaris*, *Giardia*
Large, nonenveloped viruses	Adenovirus, rotavirus
Gram-positive bacteria	*Staphylococcus*, *Enterococcus*
Enveloped viruses	Herpes, influenza, HIV, HBV

NOTE. Microorganisms are listed from the most resistant (prions) to the most susceptible (enveloped viruses) to disinfectants.[17] This hierarchical scale is only a guide to microbial susceptibility of pathogens to disinfectants, and it may vary depending on several factors (see text). Modified from McDonnell and Burke.[17] HBV, hepatitis B virus; HIV, human immunodeficiency virus.

[a] Many of the microbes listed are not causes of healthcare-associated infections.[17]

3. SAFETY

Beyond the antimicrobial activity and contact times for the disinfectant, its safety is essential (Table 1). Safety has several components, including toxicity, flammability, personal protective equipment (PPE), and compatibility. The product should be nontoxic and should not cause any harm to users, patients, and visitors. The toxicity ratings for disinfectants are danger, warning, caution, and none. The facility should ideally choose a product with the lowest toxicity rating. In addition, one should check the safety data sheet (SDS) for the product's flammability rating and chose the product with the lowest flammability rating. The disinfectant label should contain information on what PPE is required when using the product. Most facilities would prefer a product that requires the least PPE but still offers the staff complete protection from exposure to adverse health effects. Facilities should select disinfectants with an acceptable compatibility profile to ensure that they will not cause damage during routine use to common healthcare surfaces, such as plastic, stainless steel, and other materials.

4. EASE OF USE

Ease of use is another consideration that healthcare facilities should evaluate before choosing a disinfectant (Table 1). The easier a product is to use, the more likely it is for staff to achieve compliant usage and thoroughly apply the disinfectant to all hand-contact surfaces. Disinfecting products should be effective in the presence of environmental factors, such as organic matter (eg, blood); have an acceptable odor profile (some disinfectants are specially formulated with odor inhibitors, and some products have an odor that some staff would suggest signals a clean environment); be stable (have a substantial use life in concentrated form and at the use dilution); be soluble in water; have simple directions for use; and have good cleaning properties.

To facilitate use in healthcare for surfaces and equipment, the disinfectant should be available in multiple forms. Convenient forms include wipes (large and small, durable; cotton, disposable, microfiber), sprays, pull tops, and so on. Ideally, the wipe stays wet long enough to meet the EPA-registered contact time (eg, at least 1 minute). The premoistened wipe should keep the surface area wet for 1–2 minutes, and that information should be supplied by the manufacturer (eg, a 12 × 12-inch wipe keeps a 55.5-ft^2 surface wet for 2 minutes, or a 6 × 5-inch wipe keeps a 6.7-ft^2 surface wet for 2 minutes). The wipe size used should be based on the size of surface to be wiped (eg, for small equipment use a small wipe, for a large surface like a mattress use a large wipe). The wipe should be composed of a durable substrate so it will not tear easily or fall apart, and the top of premoistened-wipe containers should be kept closed so the wipes will not dry out.

In addition, the antimicrobial activity of some disinfectants will be affected by certain fabrics or cloths. That is, cotton rags or disposable cellulose-based wipes with quaternary ammonium compounds may release lower amounts of active quaternary ammonium compounds (more than or equal to 30% lower) compared with nonwoven spunlace wipes than is indicated by testing the solution.[35] Even though cotton and microfiber retain the quaternary ammonium compound, one study has shown that they provide equivalent removal/inactivation of MRSA from a surface as nonwoven spunlace wipes (eg, 4.41-log_{10} reduction with cotton and quaternary ammonium compound, 4.60-log_{10} reduction with spunlace,

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4.51-$\log_{10}$ reduction with microfiber, and 4.40-$\log_{10}$ reduction with cellulose; W. A. Rutala, M. F. Gergen, and D. J. Weber, unpublished data, 2013).

The directions for disinfectant use should be simple and contain information about active ingredients, inert ingredients (eg, detergents, perfumes, dyes, stabilizers), potential hazards of the product, first aid, use dilution, contact time, and PPE required during the mixing and application of the product. All chemical disinfectants have an SDS listing the safety precautions.

The disinfectants used in healthcare facilities are 1-step products, that is, they clean and disinfect in 1 step rather than requiring 2 independent steps (ie, cleaning followed by disinfection). Disinfectants are intended for use on hard, nonporous surfaces, and some products are EPA registered for application to soft surfaces, such as hospital privacy curtains.[36] Cleaning is an important component of the cleaning/disinfecting process, as dust, dirt, and organic matter interfere with the effectiveness of the disinfectant by altering the antimicrobial activity of the disinfectant or protecting the pathogen from exposure to the disinfectant. Cleaning is often enhanced by detergents and surfactants. Surfactants enhance the cleaning efficacy of the disinfectant and ensure complete and even coverage of the surface, preventing beading that occurs with some liquids.[37] Even and thorough coverage of a surface results in even and complete disinfection. Multiple studies have shown that 10%–50% of the surfaces in patient rooms colonized or infected with *C. difficile*, MRSA, and VRE are contaminated with these pathogens, and a lack of thoroughness in cleaning contaminated surfaces in patient rooms (mean, 32% of objects cleaned) has been linked to an average 120% increased risk of infection to the next occupant in that room.[38,39]

5. OTHER FACTORS

After the user has considered the antimicrobial activity, kill and wet-contact times, safety, and ease of use of the disinfectant, he or she should consider other factors, such as the training and support offered by the manufacturer, costs, and standardization. The best suppliers go beyond delivering a disinfectant to the hospital and will offer on-site training for staff who use the disinfectant, ongoing education (protocols, bilingual directions for use materials, consultative services that will facilitate compliance), and substantial customer support.

When calculating the costs of disinfectants, one must consider not only the product costs but also the product capabilities, costs of infections, and costs per use. Product capabilities include what the product kills, how quickly it kills, whether it has an acceptable wet time, and whether it is a 1-step disinfectant (ie, cleans and disinfects in a single step), which saves time and labor and eliminates the need for 2 products (ie, a cleaner and a disinfectant). Cost per use considers how many wipes it takes to do the job, and cost of infections considers the cost avoidance of an HAI by killing the pathogens that cause the HAI.

Standardizing or minimizing the number of disinfectants used in healthcare is also important, as the number of products and active ingredients used by staff should be minimal so as to lessen confusion and aid in compliance. Limiting the number of products in a single healthcare facility may be useful for training and compliance with appropriate use. This will help staff achieve success during state and Joint Commission audits by limiting the contact times and usage instructions staff must know. Since there is no way to routinely know what pathogens persist on a surface, the ideal is to use the same product facility-wide that is registered to kill the pathogens causing HAIs (Table 2). However, this may not be possible due to limitations with sporicides (eg, surface compatibility, respiratory irritation, costs) that restrict their use to patient rooms with special pathogens (eg, *C. difficile* spores, norovirus). Thus, since low-level disinfectants are generally active against bacteria, enveloped viruses, and some fungi, a second disinfectant may be needed for these special pathogens. Currently, hospitals minimally use 2 or 3 disinfectants. If 2 disinfectants are used, one would be used for surface disinfection of noncritical surfaces and equipment in all patient rooms (including *C. difficile* and norovirus patients; this product should have a *C. difficile* spore and norovirus claim), and 1 high-level disinfectant would be used for high-level disinfection of semicritical items. If 3 disinfectants are used, 2 would be used for noncritical surfaces and equipment (1 for general use on noncritical surfaces and equipment, and 1 for noncritical surfaces and equipment of *C. difficile* and norovirus patients that has a label claim for *C. difficile* spores and norovirus), and 1 high-level disinfectant would be used for semicritical items (eg, endoscopes).

CONCLUSIONS

Disinfection of noncritical environmental surfaces and equipment is an essential component of an infection prevention program. Disinfection should render surfaces and equipment free of pathogens in sufficient numbers to cause human disease (ie, hygienically clean). While the perfect disinfecting product may not yet exist, a careful process of selection and appropriate use of current disinfectants are necessary to reduce harm to patients and staff. When determining the optimal disinfecting product for surface disinfection, consider the 5 components listed above and give each product a score (1 is worst and 10 is best for the 5 components, so the maximum score is 50) in each of the categories: (1) relevant kill claims; (2) appropriate wet-contact and kill times; (3) safety; (4) ease of use; and (5) other factors, such as customer support, costs, and standardization. Finally, select the product with the highest score as the best product choice for your hospital or other healthcare facility (Table 2).

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REFERENCES

1. Rutala WA, Weber DJ. Are room decontamination units needed to prevent transmission of environmental pathogens? *Infect Control Hosp Epidemiol* 2011;32:743–747.
2. Weinstein RA. Epidemiology and control of nosocomial infections in adult intensive care units. *Am J Med* 1991;9(suppl 3B): S179–S184.
3. Huslage K, Rutala WA, Sickbert-Bennett E, Weber DJ. A quantitative approach to defining high-touch surfaces in hospitals. *Infect Control Hosp Epidemiol* 2010;31:850–853.
4. Stiefel U, Cadnum JL, Eckstein BC, Guerrero DM, Tima MA, Donskey CJ. Contamination of hands with methicillin-resistant *Staphylococcus aureus* after contact with environmental surfaces and after contact with the skin of colonized patients. *Infect Control Hosp Epidemiol* 2011;32:185–187.
5. Guerrero DM, Nerandzic MM, Jury LA, Jinno S, Chang S, Donskey CJ. Acquisition of spores on gloved hands after contact with the skin of patients with *Clostridium difficile* infection and with environmental surfaces in their rooms. *Am J Infect Control* 2012;40:556–558.
6. Donskey CJ. Does improving surface cleaning and disinfection reduce health care–associated infections? *Am J Infect Control* 2013;41(suppl 5):S12–S19.
7. Kundtrapu S, Sunkesula V, Jury LA, Sitzlar BM, Donskey CJ. Daily disinfection of high-touch surfaces in isolation rooms to reduce contamination of healthcare workers' hands. *Infect Control Hosp Epidemiol* 2012;33:1039–1042.
8. Molinari JA, Gleason MJ, Cottone JA, Barrett ED. Comparison of dental surface disinfectants. *Gen Dent* 1987;35(3):171–175.
9. Rutala WA, Weber DJ; Healthcare Infection Control Practices Advisory Committee. *Guideline for Disinfection and Sterilization in Healthcare Facilities, 2008.* http://www.cdc.gov/ncidod/dhqp/pdf/guidelines/Disinfection_Nov_2008.pdf. Accessed May 19, 2014.
10. Kang J, Sickbert-Bennett EE, Brown VM, Weber DJ, Rutala WA. Relative frequency of healthcare-associated pathogens by infection site at a university hospital from 1980–2008. *Am J Infect Control* 2012;40:416–420.
11. Sievert DM, Ricks P, Edwards JR, et al. Antimicrobial-resistant pathogens associated with healthcare-associated infections: summary of data reported to the National Healthcare Safety Network at the Centers for Disease Control and Prevention, 2009–2010. *Infect Control Hosp Epidemiol* 2013;34:1–14.
12. Rutala WA, Stiegel MM, Sarubbi FA, Weber DJ. Susceptibility of antibiotic-susceptible and antibiotic-resistant hospital bacteria to disinfectants. *Infect Control Hosp Epidemiol* 1997;18(6): 417–421.
13. Weber DJ, Rutala WA. Use of germicides in the home and health care setting: is there a relationship between germicide use and antimicrobial resistance. *Infect Control Hosp Epidemiol* 2006;27: 1107–1119.
14. Sanders FT. Environmental protection agency's role in the regulation of antimicrobial pesticides in the United States. In: Rutala WA, ed. *Disinfection, Sterilization and Antisepsis: Principles and Practices in Healthcare Facilities.* Washington, DC: Association for Professionals in Infection Control and Epidemiology, 2001:28–40.
15. Sattar SA. Assessing the microbicidal activities of disinfectants and antiseptics: making label claims more relevant and reliable. In: Rutala WA, ed. *Disinfection, Sterilization and Antisepsis: Principles, Practices, Current Issues, New Research, and New Technologies.* Washington, DC: Association for Professionals in Infection Control and Epidemiology, 2011:371–377.
16. Spaulding EH. Chemical disinfection and antisepsis in the hospital. *J Hosp Res* 1957;9:5–31.
17. McDonnell G, Burke P. Disinfection: is it time to reconsider Spaulding? *J Hosp Infect* 2011;78:163–170.
18. Best M, Kennedy ME, Coates F. Efficacy of a variety of disinfectants against *Listeria* spp. *Appl Environ Microbiol* 1990;56(2): 377–380.
19. Sattar SA, Springthorpe VS. Recent developments in methods for testing the germicidal activity of disinfectants and antiseptics. In: Rutala WA, ed. *Disinfection, Sterilization and Antisepsis: Principles, Practices, Challenges, and New Research.* Washington, DC: Association for Professionals in Infection Control and Epidemiology, 2004:180–188.
20. Rutala WA, Weber DJ. Registration of disinfectants based on relative microbicidal activity. *Infect Control Hosp Epidemiol* 2004; 25:333–341.
21. Hulkower RL, Casanova LM, Rutala WA, Weber DJ, Sobsey MD. Inactivation of surrogate coronaviruses on hard surfaces by health care germicides. *Am J Infect Control* 2011;39:401–407.
22. Sattar SA, Springthorpe VS, Karim Y, Loro P. Chemical disinfection of non-porous inanimate surfaces experimentally contaminated with four human pathogenic viruses. *Epidemiol Infect* 1989;102:493–505.
23. Kramer A, Schwebke I, Kampf G. How long do nosocomial pathogens persist on inanimate surfaces? a systematic review. *BMC Infect Dis* 2006;6:130.
24. Sattar SA, Jacobsen H, Springthorpe VS, Cusack TM, Rubino JR. Chemical disinfection to interrupt transfer of rhinovirus type 14 from environmental surfaces to hands. *Appl Environ Microbiol* 1993;59(5):1579–1585.
25. Weber DJ, Barbee SL, Sobsey MD, Rutala WA. The effect of blood on the antiviral activity of sodium hypochlorite, a phenolic, and a quaternary ammonium compound. *Infect Control Hosp Epidemiol* 1999;20(12):821–827.
26. Rutala WA, Barbee SL, Aguiar NC, Sobsey MD, Weber DJ. Antimicrobial activity of home disinfectants and natural products against potential human pathogens. *Infect Control Hosp Epidemiol* 2000;21(1):33–38.
27. Exner M, Vacata V, Hornei B, Dietlein E, Gebel J. Household cleaning and surface disinfection: new insights and strategies. *J Hosp Infect* 2004;56(suppl):S70–S75.
28. Cadnum JL, Hurless KN, Kundrapu S, Donskey CJ. Transfer of *Clostridium difficile* spores by nonsporicidal wipes and improperly used hypochlorite wipes: practice + product = perfection. *Infect Control Hosp Epidemiol* 2013;34:441–442.

https://doi.org/10.1086/676877 Published online by Cambridge University Press

29. Rutala WA, Gergen MF, Weber DJ. Efficacy of different cleaning and disinfection methods against *Clostridium difficile* spores: importance of physical removal versus sporicidal inactivation. *Infect Control Hosp Epidemiol* 2012;33:1255–1258.
30. Carling PC, Parry MF, Bruno-Murtha AL, Dick B. Improving environmental hygiene in 27 intensive care units to decrease multidrug-resistant bacterial transmission. *Crit Care Med* 2010; 38:1054–1059.
31. Carling PC, Parry MF, Rupp ME, et al. Improving cleaning of the environment surrounding patients in 36 acute care hospitals. *Infect Control Hosp Epidemiol* 2008;29:1035–1041.
32. Weber DJ, Rutala WA. Self-disinfecting surfaces: review of current methodologies and future prospects. *Am J Infect Control* 2013;41:S31–S35.
33. Rutala WA, White MS, Gergen MF, Weber DJ. Bacterial contamination of keyboards: efficacy and functional impact of disinfectants. *Infect Control Hosp Epidemiol* 2006;27:372–377.
34. Rutala WA, Weber DJ. New disinfection and sterilization methods. *Emerg Inf Dis* 2001;7:348–353.
35. MacDougall KD, Morris C. Optimizing disinfectant application in healthcare facilities. *Infect Control Today* 2006;June:62–67.
36. Rutala WA, Gergen MF, Sickbert-Bennett EE, Williams DA, Weber DJ. Effectiveness of improved hydrogen peroxide in decontaminating privacy curtains contaminated with multidrug-resistant pathogens. *Am J Infect Control* 2014;42:426–428.
37. Anonymous. How to select an ideal disinfectant. *Infect Control Today* 2009;June. http://www.infectioncontroltoday.com/articles/2009/05/how-to-select-an-ideal-disinfectant.aspx. Accessed May 20, 2014.
38. Otter JA. The role played by contaminated surfaces in the transmission of nosocomial pathogens. *Infect Control Hosp Epidemiol* 2011;32:687–699.
39. Carling PC. Methods for assessing the adequacy of practice and improving room disinfection. *Am J Infect Control* 2013;41:S20–S25.
40. Hanson S, Stamm-Balderjahn S, Zuschneid I, et al. Closure of medical departments during nosocomial outbreaks: data from a systematic analysis of the literature. *J Hosp Infect* 2007;65:348–353.
41. Weber DJ, Rutala WA, Sickbert-Bennett EE. Outbreaks associated with contaminated antiseptics and disinfectants. *Antimicrob Agents Chemother* 2007;51:916–919.
42. Rutala WA, Cole EC, Thomann CA, Weber DJ. Stability and bactericidal activity of chlorine solutions. *Infect Control Hosp Epidemiol* 1998;19(5):323–327.
43. Rutala WA, Weber DJ. Disinfectants used for environmental disinfection and new room decontamination technology. *Am J Infect Control* 2013;41:S36–S41.

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