Monitoring and improving the effectiveness of surface cleaning and disinfection

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Disinfection of noncritical environmental surfaces and equipment is an essential component of an infection prevention program. Noncritical environmental surfaces and noncritical medical equipment surfaces may become contaminated with infectious agents and may contribute to cross-transmission by acquisition of transient hand carriage by health care personnel. Disinfection should render surfaces and equipment free of pathogens in sufficient numbers to prevent human disease (ie, hygienically clean).

There is excellent evidence in the scientific literature that environmental contamination plays an important role in the transmission of several key health care–associated pathogens, including methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant *Enterococcus* (VRE), *Acinetobacter* sp, norovirus, and *Clostridium difficile*.[1-4] All of these pathogens have been demonstrated to persist in the environment for days (in some cases months), frequently contaminate the environmental surfaces in rooms of colonized or infected patients, transiently colonize the hands of health care personnel, be transmitted by health care personnel, and cause outbreaks in which environmental transmission was deemed to play a role. Importantly, a study by Stiefel et al demonstrated that contact with the environment was just as likely to contaminate the hands of health care providers as was direct contact with the patient.[5] Further, admission to a room in which the previous patient had been colonized or infected with MRSA, VRE, *Acinetobacter* or *C difficile* has been shown to be a risk factor for the newly admitted patient to develop colonization or infection.[6-8] The purpose of this article, which is adapted from other publications,[4,9,10] is to discuss the available options for monitoring environmental cleaning-disinfection and discuss methods for improving environmental cleaning-disinfection.

IMPORTANCE OF PRODUCT AND PRACTICE

The disinfectants used in health care facilities are 1-step products, meaning they clean and disinfectant in 1-step rather than requiring 2 independent steps (ie, cleaning, followed by disinfection).[10] In general, no precleaning is necessary unless a spill or gross contamination is present, in which case cleaning precedes the use of a disinfectant. Disinfectants are intended for use on hard, nonporous surfaces; however, some products are Environmental Protection Agency (EPA)–registered for application to soft surfaces, such as hospital privacy curtains.[11] Hospitals should avoid the use of noncleanable surfaces, such as fabric chairs, in clinical areas and use a cleanable covering fabric (eg, vinyl). Cleaning is an important component of the cleaning-disinfection process because 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. In this article, we use the term cleaning-disinfection to reference this 1-step process for cleaning and disinfecting a noncritical item.[10] Cleaning refers to the removal of surface debris (eg, dust, organic material), whereas disinfection refers to the use of a disinfectant or germicide designed to kill microorganisms. Cleaning-disinfection or environmental cleaning, which refers broadly to an organized process for cleaning, disinfecting, and monitoring,[12,13] is a horizontal control measure. Horizontal controls are broad-based approaches to infection prevention because they attempt reduction to all infections caused by all pathogens and include hand hygiene, environmental control, and minimizing unnecessary use of invasive devices.[14] Often cleaning is enhanced by detergents and surfactants. Surfactants enhance the cleaning efficacy of the

Table 1
Properties of an ideal disinfectant

Ideal properties
1. Broad spectrum: it should have a wide antimicrobial spectrum, including kill claims for the pathogens that are the common causes of HAIs and outbreaks.
2. Fast acting: it should have a rapid kill and short kill-contact time listed on the label.
3. Remains wet: it 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: it should be active in the presence of organic matter (eg, blood, sputum, feces) and compatible with cotton, microfiber, soaps, detergents, and other chemicals encountered in use.
5. Nontoxic: it should not be irritating to the user, visitors, and patients. It should not induce allergic symptoms (especially asthma and dermatitis). The toxicity ratings for disinfectants are danger, warning, caution, and none. Everything being equal, choose products with the lowest toxicity rating.
6. Surface compatibility: it should be proven compatible with common health care surfaces and equipment.
7. Persistence: it should have sustained antimicrobial activity or residual antimicrobial effect on the treated surface.
8. Easy to use: it 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: it should have an odor deemed acceptable by users and patients or no odor.
10. Economical: costs should not be prohibitively high, but when considering costs of disinfectant should also consider product capabilities, cost per compliant use, and so forth.
11. Solubility: it should be soluble in water.
12. Stability: it should be stable in concentrate and use dilution.
13. Cleaner: it should have good cleaning properties.
14. Nonflammable: it should have flash point >150°F.

NOTE. Modified with permission from Molinari et al[17] and Rutala and Weber.[10]
Abbreviation: *HAI*, health care–associated infection.

disinfectant and ensure complete and even coverage of the surface, preventing beading that occurs with some liquids.[10,15] It is important to achieve even and thorough coverage of a surface to result in even and complete disinfection. Multiple studies have shown 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 of cleaning contaminated surfaces in patient rooms (mean 32% of objects cleaned) has been linked to an overall 120% increased risk of infection to the next occupant in that room.[1,6,16]

Although the process of selecting an optimal health care product or disinfectant used for low-level disinfection of noncritical items is commonplace in health care facilities, there are a very limited number of articles in the peer-reviewed literature on this topic.[10] The disinfectant or the product, is 1 of the 2 components essential for effective disinfection. Table 1 identifies the characteristics of the ideal disinfectant. Studies support the use of disinfection rather than the use of a nongermicidal detergent on environmental surfaces in health care.[18,19] One recent study showed that daily use of a disinfectant applied to environmental surfaces with a 80% compliance is superior to a nongermicidal detergent because it results in significantly reduced rates of health care–associated infections (HAIs) caused by *C difficile*, MRSA, and VRE.[20] Nongermicidal detergents are not recommended for multiple reasons,[19] including detergent wipes transfer significant amounts of epidemiologically important pathogens (eg, MRSA, *C difficile*) over surfaces[21] and disinfectants are more effective than detergents in reducing microbial contamination.[22] Similarly, results have demonstrated efficient transfer of *C difficile* spores from contaminated-to-clean surfaces by nonsporicidal wipes and overused sporicidal wipes.[23] To date, the perfect product for health care surface disinfection has not been introduced; however, there is a wide array of excellent disinfectants that offer a range of characteristics (Table 2).

To keep patients as safe as possible, health care 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 of their facility. The product selected should be effective against the microorganisms that are the most common causes of HAIs and outbreaks (Table 3), according to nationally reported data. Because vegetative bacteria (eg, *S aureus*, *Enterococcus*, *Escherichia coli*, coagulase-negative *Staphylococcus*, *Pseudomonas aeruginosa*, *Klebsiella* spp, *Enterobacter* spp) are the pathogens that

cause most HAIs (79.1%),[26,28] health care disinfectants should be effective against these pathogens.[10]

The other component, the practice, is thorough application such that the disinfectant contacts all hand-contact or touchable surfaces. It also involves 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 ≥1 minute for vegetative bacteria). Other factors that affect practice and performance include sufficient contact time, concentration, surface type, ease of use, organic soil and hard water, porosity of the surface, compatibility of the disinfectant with the wipe used, and sufficient cleaning time. The combination of product and practice results in effective surface disinfection, including the reduction of patient risk via microbial removal and inactivation and improved patient outcomes.[10]

DISINFECTION USING LOW-LEVEL DISINFECTANTS

It has long been recommended in the United States that environmental surfaces in patient rooms be cleaned and disinfected on a regular basis (eg, daily, 3 times per week), when surfaces are visibly soiled, and after patient discharge (terminal cleaning).[29] There are now data that demonstrate daily disinfection of high-touch surfaces (compared with cleaning when soiled) was associated with a significant reduction in the frequency of pathogens on investigators' hands after contact with the surfaces and the mean number of bacteria acquired.[30] Disinfection is generally performed using an EPA-registered hospital disinfectant, such as a quaternary ammonium compound, chlorine, or phenol (Table 2). Newer products effective against health care–associated pathogens include improved hydrogen peroxide (HP) and peracetic acid–HP.[11,31-33]

MONITORING AND IMPROVING THE THOROUGHNESS OF CLEANING-DISINFECTION

The cleaning-disinfection of noncritical surfaces in hospitals is essential for reducing microbial contamination and reducing HAIs.[12,13,18] A recent Agency for Healthcare Research and Quality review offers an overview of the monitoring modalities,[12,13] which include visual inspection, microbiologic methods, fluorescent

Table 2
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 • Damage to some instruments (eg, hardens rubber, deteriorates 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[24]
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 d)[25] • 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 and stains fabrics • Potential hazard is production of trihalomethane • 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
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[24]
Peracetic acid and hydrogen peroxide	• Bactericidal, fungicidal, virucidal and sporicidal (eg, *Clostridium difficile*) • Active in the presence of organic material • Environmental friendly by-products (acetic acid, O_2, H_2O) • EPA registered • Surface compatible	• Lack of stability • Potential to material incompatibility (eg, brass, copper) • More expensive than other disinfecting actives • Odor

NOTE. Modified with permission from Rutala and Weber.[10]
Abbreviation: *EPA*, Environmental Protection Agency.

markers, and adenosine triphosphate (ATP) assays. At present, polymerase chain reaction–based technology has a limited role for assessing environmental contamination, is investigational, and does not differentiate between the presence of viable and nonviable microorganisms.[13]

Hospital cleanliness continues to attract patient attention, and in the United States it is still primarily assessed via visual cleanliness (eg, dust, organic debris) of surfaces, which is not a reliable indicator of microbial contamination.[34,35] ATP bioluminescence measures organic debris (each unit has its own reading scale, <250-500 relative light units), but it is not a reliable indicator of microbial contamination.[13] A validation study of ATP used to audit cleaning of flexible endoscope channels demonstrated that an endoscope assessed as clean by ATP (<250 relative light units) could be contaminated with a million (10^6) microorganisms.[36] Fluorescent marking is done with a transparent, easily cleaned, environmentally stable marking solution that fluoresces when exposed to an ultraviolet (UV) light. It is applied by the infection preventionist or environmental service manager after the patient is discharged and is unknown to the environmental service staff. After

Table 3
Most prevalent pathogens causing HAIs

Recommended organisms (% of HAIs caused)	Why organisms are relevant
Staphylococcus aureus (15.6%)	Most prevalent overall
Escherichia coli (11.5%)	contributors to HAIs
Coagulase-negative *Staphylococcus* (11.4%)	(NHSN-CDC)[26]
Klebsiella (8.0%)	
Pseudomonas aeruginosa (7.5%)	
Enterococcus faecalis (6.8%)	
Candida albicans (5.3%)	
Enterobacter spp (4.7%)	
Other *Candida* spp (4.2%)	
Enterococcus faecium (4.1%)	
Enterococcus spp (3.0%)	
Proteus spp (2.5%)	
Serratia spp (2.1%)	
Acinetobacter baumannii (1.8%)	
Clostridium difficile spores*	
Norovirus	Most common causes of
Aspergillus	outbreaks and ward closures
Rotavirus	by causative pathogen, which
Adenovirus	are relatively hard to kill[27]
(Insert facility-specific pathogens here [eg, *Burkholderia cepacia*])	Other pathogens of concern in your facility

NOTE. Modified from Rutala and Weber.[10]
Abbreviations: *CDC*, Centers for Disease Control and Prevention; *HAI*, health care–associated infection; *NHSN*, National Healthcare Safety Network.
*Over the last decade, an increasing incidence of *C difficile* has been recognized, and in many health care facilities it is the most common cause of HAI.

environmental service cleaning, the markings are reassessed by the infection preventionist or environmental service manager, thoroughness of the cleaning is monitored, and immediate feedback is provided to the person(s) cleaning-disinfecting the room (eg, 4 of 10 marker surfaces wiped, 40% compliance with thoroughness of cleaning-disinfection). Microbiologic methods have also been used to evaluate microbial contamination of surfaces. This method can be costly and pathogenic specific. Although there are no accepted criteria for defining a surface as clean using microbiologic methods, some investigators have suggested that microbial contamination should be 2.5 to <5 colony forming units (CFU)/cm^2.[37,38] Studies have shown that this level of contamination may be easily achievable because the microbial burden of room surfaces in 1 hospital went from 57 CFU/Rodac (replicate organism detection and counting) (2.3 CFU/cm^2) to 8 CFU/Rodac (0.3 CFU/cm^2) prior to and after cleaning.[39] Based on surface cleaning-disinfection practices that are used in the United States, a revised stricter pass benchmark may need to be considered (<1 CFU/cm^2).

Studies have demonstrated suboptimal cleaning by aerobic colony counts and the use of the ATP bioluminescence and fluorescent markers.[6,35] For example, Carling et al assessed the thoroughness of terminal cleaning in the patient's immediate environment in 23 acute care hospitals (1,119 patient rooms) by using a transparent, stable solution that fluoresces when exposed to handheld UV light.[40] The overall thoroughness of cleaning, expressed as a percent of surfaces evaluated, was 49% (range for all hospitals, 35%-81%). Using a similar design, Carling et al assessed the environmental cleaning in intensive care unit rooms in 16 hospitals (2,320 objects) and demonstrated that only 57.1% of sites were cleaned after discharge of the room's occupant.[41] A study using ATP bioluminescence assays and aerobic cultures demonstrated that medical equipment frequently had not been disinfected as per protocol.[42]

ATP bioluminescence and fluorescent markers are preferred to aerobic plate counts because they provide an immediate assessment of cleaning effectiveness. Two recent reviews reported ATP as a quick and objective monitoring method; however, it was poorly standardized with low specificity and sensitivity in detecting bacteria.[13,43,44] In a comparison study of the 4 methods to assess cleaning, we found that the fluorescent marker was the most useful tool in determining how thoroughly a surface was wiped because it mimicked the microbiologic data better than ATP. For example, compared with microbiologic data (when <62.5 CFU/Rodac defines clean), 72% were classified as clean with fluorescent markers, compared with 27% were classified as clean compared with ATP (Rutala et al, unpublished results, 2015).

SURFACE DISINFECTION, CONTACT TIME, WIPES AND WIPE METHOD

Surface disinfection of noncritical surfaces and equipment is normally performed by manually applying a liquid disinfectant to the surface with a wipe or mop. Noncritical patient care equipment is disinfected using an EPA-registered hospital disinfectant using the label's safety precautions and use directions (Table 2). Many diluted EPA-registered hospital disinfectants have a label contact time of 10 minutes (eg, quaternary ammonium compound). However, multiple scientific studies have demonstrated the efficacy of hospital disinfectants against pathogens with a contact time of at least 1 minute.[10,29] Health care facilities should ensure that the frequency for disinfecting noncritical patient care surfaces be done minimally when visibly soiled and on a regular basis (eg, after use on each patient or once daily or once weekly).[29] Data indicate that daily disinfection of high-touch surfaces, compared with disinfecting when soiled, reduces the acquisition of pathogens on hands after contact with surfaces and the mean number of bacteria acquired.[30] For example, a hospital's policy for reusable blood pressure cuffs kept in the patient room could be that they are cleaned when visibly soiled and at discharge before use for another patient. Similarly, for rolling blood pressure cuffs, the policy could be they are cleaned daily and when visibly soiled, when used on a contact precaution patient, and when used on nonintact skin. If dedicated, disposable equipment is not available, disinfect noncritical patient care equipment after using it on a patient who is on contact precautions before using this equipment on another patient.

The wipes used for surface disinfection are generally cotton, cellulose-based, nonwoven spunlace, and microfiber. The disinfectants are usually applied with a spray (ie, spray-and-wipe procedure), wipes (eg, cotton, microfiber) soaked in a disinfectant-filled bucket, or a premoistened wipe (eg, disposable wipe). All of these methods combine the antimicrobial action of the disinfectant with the physical removal of microorganisms by wiping. The efficacy of the wipe method has been recently evaluated using *C difficile* spores. The wipe methods (ie, saturated cloth; spray [let disinfectant sit for 10 seconds] and wipe; spray, wipe, spray [let disinfectant sit for 1 minute], and wipe; disposable wipe; spray, wipe, spray, and let air dry) all demonstrated similar reductions in *C difficile* spores using a disinfectant active against *C difficile* spores.[22] The wipe should have sufficient wetness to achieve the disinfectant contact time. Discard the wipe if it no longer leaves the surface visibly wet for ≥1 minute. Other practices to consider include the following: when the wipe is visibly soiled, flip to a clean-unused side and continue until all sides of the wipe have been used (or get another wipe); dispose of the wipe or cloth wipe appropriately; do not place the cleaning cloth back into the disinfectant solution after using it to wipe a surface; and do not dip a used wipe into the clean container of presaturated wipes. If a disposable wipe is used, ideally the wipe should keep the surface wet long enough to meet EPA-registered contact times (eg, bacteria: 1 minute). For disposable wipes, the premoistened wipe should keep the surface area wet for 1-2 minutes, and the surface coverage will depend on the size of the wipe (eg, 12- × 12-in wipes keep 5.156 sq m wet for 2 minutes; 6- × 5-in equipment wipe keeps 0.622 sq m wet for 2 minutes). The disposable wipe size should be based on use from small surfaces (eg, blood pressure cuff) to large

surfaces (eg, mattress covers). Additionally, the substrate for the disposable wipe should be durable so that it does not easily tear or fall apart, and the top should be kept closed so the wipes do not dry out. Change the reusable cleaning cloths after every room and use at least 3 cloths per room.[10,45] Boyce et al also found that smooth surfaces (eg, overbed tables) were cleaned more thoroughly (as measured by ATP) than rough or irregular surfaces, and the rooms cleaned with only 2 disinfectant wipes had higher ATP readings than those cleaned with 3, 4, or 5 wipes.[46] If the reusable wipe is not changed, accumulation of bacteria can occur and increase the chance of cross-contamination.

In addition, the antimicrobial activity of some disinfectants will be affected by certain fabrics or cloths. Quaternary ammonium compounds interact with cotton and microfiber cloths via electrostatic attractions, resulting in lower concentrations of the active ingredient delivered to the surface. For example, cotton rags or disposable cellulose-based wipes with quaternary ammonium compounds may release lower amounts of active quaternary ammonium compounds ($\geq$30% lower) than nonwoven spunlace wipes than is indicated by testing the solution.[47] Engelbrecht et al found that the quaternary ammonium compound concentration was reduced by up to 85% after exposure to cotton towels.[48] Even though cotton and microfiber retain the quaternary ammonium compound, 1 study has shown they provide equivalent removal-inactivation of MRSA from a surface as nonwoven spunlace wipes (eg, 4.41 $\log_{10}$ reduction with cotton and QUAT (a quaternary ammonium compound), 4.60 $\log_{10}$ reduction with spunlace, 4.51 $\log_{10}$ reduction with microfiber, 4.40 $\log_{10}$ reduction with cellulose; Rutala et al, unpublished results, 2013). Additional investigations are necessary to ensure a minimum effective concentration is present to achieve the antimicrobial label claim.

An issue that has been receiving repeated attention in the media is the contact times for disposable wipes when there are varying times listed for bacteria, fungi, and mycobacteria. Some persons have suggested that hospitals should use the longest kill time on the product as the required wet-contact kill time (eg, 5 minutes for *Mycobacterium bovis*). The CDC's "Guideline for Disinfection and Sterilization in Healthcare Facilities" used the time necessary to kill bacteria on surfaces (ie, 1 minute), not the kill time for more difficult to inactivate pathogens, such as *M tuberculosis* or *M bovis*, which does not have an environmental surface mode of transmission.[29] Because bacteria (with the exception of *C difficile* spores) to include multidrug-resistant bacteria (eg, MRSA, VRE) cause approximately 80% of HAIs and removal or inactivation of bacteria on surfaces is important in preventing environmentally mediated HAIs, bacterial kill times should dictate the wet-contact kill times in health care facilities. Therefore, for low-level disinfectant products used on noncritical environmental surfaces or noncritical medical instruments, the recommended wet-contact kill times would be $\geq$1 minute.

IMPROVING ROOM CLEANING AND DISINFECTION AND DEMONSTRATING THE EFFECTIVENESS OF SURFACE DECONTAMINATION IN REDUCING HAIS

Investigators have reported that intervention programs aimed at improving surface cleaning and disinfection reduced HAIs.[18] Such interventions have generally included multiple activities: disinfectant product substitutions and interventions to improve the effectiveness of cleaning and disinfection (eg, improved housekeeper education, monitoring the thoroughness of cleaning [eg, by use of ATP assays or fluorescent dyes] with feedback of performance to the environmental service workers, use of cleaning checklists).[18,49-51] Health care facilities must also allow adequate time for room processing to ensure adherence to all steps recommended by institutional policies and professional organization

guidelines. We have found that collaboration between infection prevention and environmental services staff and management is critical to an effective environmental cleaning program. This includes ensuring that environmental services staff recognize the importance of their job and the relationship of adhering to proper work procedures to the reduction of microbial contamination and HAIs. The assignment of cleaning responsibility (eg, medical equipment to be cleaned by nursing; environmental surfaces to be cleaned by environmental services) is also important to ensure all objects and surfaces in a patient room are decontaminated, especially the surfaces of medical equipment (eg, cardiac monitors). Improved environmental cleaning has been demonstrated to reduce the environmental contamination with VRE,[51] MRSA,[52] and *C difficile*.[53] Further, all studies have only focused improvement on a limited number of high-risk objects. Therefore, a concern of published studies is that they have only demonstrated improved cleaning of a limited number of high-risk objects (or targeted objects), not an improvement in the overall thoroughness of room decontamination, which is the objective.

To our knowledge only 1 study has objectively evaluated what constitutes high-touch objects in a patient room, and no study has demonstrated epidemiologically what constitutes a high-risk object. Examples of what the literature refers to as high-touch objects include bed rails, intravenous poles, call buttons, door knobs, floors, and bathroom facilities,[13] but a study demonstrated high-touch objects in the intensive care unit were the bed rail, bed surface, and supply cart, whereas the high-touch surfaces in a patient ward were the bed rail, over-the-bed table, intravenous pump, and bed surface.[54] Importantly, the level of microbial contamination of room surfaces was statistically similar regardless of how often they were touched before and after cleaning. Until research identifies which objects and surfaces pose the greatest risk of pathogen transmission, all noncritical surfaces that are touched must be cleaned-disinfected.[39]

NO-TOUCH (OR MECHANICAL) METHODS FOR ROOM DECONTAMINATION

As previously noted, multiple studies have demonstrated that environmental surfaces and objects in rooms are frequently not properly cleaned, and these surfaces may be important in transmission of health care–associated pathogens. Further, although interventions aimed at improving cleaning thoroughness have demonstrated effectiveness, many surfaces remain inadequately cleaned and therefore potentially contaminated. For this reason, several manufacturers have developed room disinfection units that can decontaminate environmental surfaces and objects. These no-touch systems generally use 1 of 2 methods: UV light or HP vapor-mist.[4] These technologies supplement, but do not replace, standard cleaning and disinfection because surfaces must be physically cleaned of dirt and debris.

UV light for room decontamination

UV radiation has been used for the control of pathogenic microorganisms in a variety of applications, such as control of legionellosis, and the disinfection of air, surfaces, and instruments.[4,55] At certain wavelengths, UV light will break the molecular bonds in DNA, thereby destroying the organism. UV radiation has peak germicidal effectiveness in the wavelength range of 240-280 nm. Mercury gas bulbs emit UV-C at 254 nm, whereas xenon gas bulbs produce a broad spectrum of radiation that encompasses the UV (100-280 nm) and the visible (380-700 nm) electromagnetic spectra.[56] The efficacy of UV radiation is a function of many different parameters, such as dose, distance, direct or shaded exposure, exposure time, lamp placement, pathogen, carrier or surface tested,

inoculum method, organic load, and orientation of carriers (eg, parallel vs perpendicular). Data demonstrate that several UV systems have effectiveness (eg, eliminate >3 $\log_{10}$ vegetative bacteria [MRSA, VRE, *A baumannii*] and >2.4 $\log_{10}$ *C difficile*) at relatively short exposure times (eg, 5-25 minutes for bacteria, 10-60 minutes for *C difficile* spores).[56-58] The studies also demonstrated reduced effectiveness when surfaces were not in direct line of sight.[56-60]

HP systems for room decontamination

Several systems which produce HP (eg, HP vapor, aerosolized dry mist HP) have been studied for their ability to decontaminate environmental surfaces and objects in hospital rooms. HP vapor has been used increasingly for the decontamination of rooms in health care.[61-71] These investigators found that HP systems are a highly effective method for eradicating various pathogens (eg, MRSA, *M tuberculosis*, *Serratia*, *C difficile* spores, *C botulinum* spores) from rooms, furniture, and equipment.

Comparison of UV irradiation vs HP for room decontamination

The UV and HP systems have their own advantages and disadvantages,[4] and there is now ample evidence that these no-touch systems can reduce environmental contamination with health care–associated pathogens. However, each specific system should be studied and its efficacy demonstrated before being introduced into health care facilities. The main advantage of both types of units is their ability to achieve substantial reductions in vegetative bacteria. Another advantage is their ability to substantially reduce *C difficile* spores because low-level disinfectants (eg, quaternary ammonium compounds) have only limited or no measurable activity against spore-forming bacteria.[10] Both systems are residual free, and they decontaminate all exposed surfaces and equipment in the room.

The major disadvantages of both decontamination systems are the substantial capital equipment costs, the need to remove personnel and patients from the room therefore limiting their use to terminal room disinfection (must prevent or minimize exposure to UV and HP), the staff time needed to transport the system to rooms to be decontaminated and monitor its use, the need to physically clean the room of dust and debris, and the sensitivity to use parameters. There are several important differences between the 2 systems. The UV-C systems offer faster decontamination, which reduces the down time of the room before another patient can be admitted. The HP systems have been demonstrated to be more effective in eliminating spore-forming organisms. Whether this improved sporicidal activity is clinically important is unclear because studies have demonstrated that although environmental contamination is common in the rooms of patients with *C difficile* infection, the level of contamination is relatively low (also true for MRSA and VRE). Importantly, the HP and UV systems were demonstrated to reduce the incidence of HAIs.[61,72-75] Based on data that demonstrated a reduction of colonizations and infections associated with these technologies, we recommend they be used for terminal room decontamination after discharge of patients on contact precautions. Because different UV and HP systems vary substantially, infection preventionists should review the peer-reviewed literature and choose only devices with demonstrated bactericidal capability as assessed by carrier tests or the ability to disinfect actual patient rooms. Ultimately, one would select a device that has demonstrated the ability to reduce HAIs.[75]

FUTURE DIRECTIONS FOR NO-TOUCH TECHNOLOGIES

Novel technologies have dramatically improved the likelihood of developing a self-disinfecting surface or a continuous room disinfection strategy. These strategies include the development of self-disinfecting surfaces, such as surfaces impregnated or coated with a heavy metal (eg, silver, copper) or a germicide (eg, quaternary ammonium compounds).[76-78] The use of such technology could minimize the impact of poor cleaning and disinfecting practices during routine and terminal room cleaning and disinfection. Other novel methods for room disinfection are being investigated. For example, visible light disinfection through light-emitting diodes can be applied continuously to environments to provide microbial reductions even while the environments are occupied. The light-emitting diodes release a wavelength of light that is antimicrobial (405 nm) and not hazardous to patients and staff.[79] Another potential method for continuous room decontamination uses continuous low-dose HP (eg, 0.5 ppm HP vapor).

CONCLUSION

Environmental contamination plays an important role in the transmission of several epidemiologically important pathogens, such as MRSA, VRE, and *C difficile*. Disinfection should render surfaces and equipment free of pathogens in sufficient numbers to cause human disease (ie, hygienically clean). This requires thorough cleaning-disinfecting of the patient environment using effective products and processes and no-touch technologies that reduce the incidence of HAIs.

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