International Journal of Infectious Diseases 67 (2018) 52–57

Contents lists available at ScienceDirect

International Journal of Infectious Diseases

journal homepage: www.elsevier.com/locate/ijid

Review

Environmental cleaning and disinfection of patient areas

Michelle Doll*, Michael Stevens, Gonzalo Bearman

VCU Health Infection Prevention Program, Richmond, VA, USA

Corresponding Editor: Eskild Petersen, Aarhus, Denmark

ARTICLE INFO

Keywords:
Disinfection
Cleaning
Infection prevention
Hospital environment

ABSTRACT

The healthcare setting is predisposed to harbor potential pathogens, which in turn can pose a great risk to patients. Routine cleaning of the patient environment is critical to reduce the risk of hospital-acquired infections. While many approaches to environmental cleaning exist, manual cleaning supplemented with ongoing assessment and feedback may be the most feasible for healthcare facilities with limited resources.

Contents

Introduction

Cleanliness of the patient environment is an important factor in promoting recovery from illness. The hospital environment is predisposed to harbor potential pathogens given the volume of sick patients, the pace and acuity of patient care activities performed by healthcare workers, and the complexity of hospital surfaces and medical equipment requiring routine cleaning. Recent attention to the quality of environmental cleaning in hospitals has revealed that cleaning efforts are often insufficient, leaving microbial contamination present on surfaces (Carling et al., 2008; Dharan et al., 1999; Carling et al., 2010). The ability of potential pathogens to persist for long periods of time on inanimate surfaces has been reviewed previously (Kramer et al., 2006); some organisms are able to survive weeks to months in the hospital environment (Kramer et al., 2006). It has also been well documented that patients are at increased risk of acquiring a multidrug-resistant organism (MDRO) if the previous room occupant was infected, suggesting transmission via the

* Corresponding author at: VCU Health Infection Prevention Program, P.O. Box 980019, Richmond, VA 23298, USA.
E-mail address: Michelle.doll@vcuhealth.org (M. Doll).

https://doi.org/10.1016/j.ijid.2017.10.014

contaminated environment despite routine cleaning efforts (Huang et al., 2006; Shaughnessy et al., 2011; Nseir et al., 2011).

Outbreak reports have provided additional evidence that patients are infected by organisms acquired from the inanimate environment. Furthermore, these reports offer clues to which organisms are associated with specific surfaces and areas within healthcare settings (Weber and Rutala, 1997). Nevertheless, the extent to which the hospital environment contributes to hospital-acquired infections (HAIs) continues to be controversial. Many infections appear to be attributable to the endogenous flora of the patients and/or direct transmission via hands of healthcare providers, rather than to inanimate objects. It is difficult to trace the etiologies of transmission events outside the intensive epidemiological investigations that characterize the reported outbreaks.

Despite evidence of the transmission of infectious organisms from environment to patient, the role of a clean environment in hospital prevention remains controversial. The extent to which environmental contamination contributes to healthcare-associated infections is unclear. Surface cleaning is certainly not a substitute for other infection control practices such as hand washing, limiting medical device usage, and gowning or gloving when indicated. However, routine efforts to decrease the overall bioburden of the hospital environment via cleaning is likely foundational to other efforts; lower levels of infectious organisms on surfaces translates to less contamination of healthcare worker hands and patient care objects as they make contact with the hospital environment.

Essentially all literature related to the optimization of environmental cleaning in healthcare systems comes from countries with relatively abundant resources. In resource-limited healthcare settings, additional challenges may exist that contribute to inadequate cleaning. The minimum standards for environmental health reported in the World Health Organization's *Essential Environmental Health Standards in Health Care* with regard to healthcare centers with limited resources, outline clean water, waste management, and a focus on visible dust and soil as essential temporary measures to protect patients (Adams et al., 2008). A comparison of these minimum standards against other published environmental cleaning recommendations highlights a striking disparity in the conditions of the hospital environment between different regions of the world.

Methods

This is a narrative review of the literature regarding environmental cleaning in the healthcare setting. PubMed was searched using the following terms related to each section of this review: (UV-C OR UVC OR pulsed xenon OR UV light OR hydrogen peroxide) AND (cleaning OR disinfection OR infection OR decontamination), (enhanced cleaning) or (improved cleaning) and (hospital infection), and (Copper) and (cleaning or disinfection) and (hospital infection). These searches returned more than 7000 articles, which were screened for relevance by title. Original research articles were further reviewed by abstract; bibliographies were also considered. Preference was given to studies published after 2012, although articles published prior to 2012 were selectively included in order to provide context to this review of the recent literature (for example, existing expert guidelines on hospital cleaning and disinfection). Studies that were non-clinical were excluded. The vast majority of the studies included in this review were observational or of quasi-experimental 'before-and-after' design. Furthermore, many of the studies using technologies were sponsored by the manufacturer of the technology under investigation. Taken together, this indicates that there is a risk of bias in the included studies.

Hospital surfaces

The contamination of frequently touched hospital surfaces with drug-resistant bacteria such as methicillin-resistant *Staphylococcus aureus* (MRSA) (Knelson et al., 2014; Lin et al., 2016), vancomycin-resistant Enterococcus (VRE) (Knelson et al., 2014; Bonton et al., 1996), carbapenem-resistant *Enterobacteriaceae* (CRE) (Lerner et al., 2013; Weber et al., 2015), *Acinetobacter* species (Weber et al., 2010), and *Clostridium difficile* (Weber et al., 2010; Sitzlar et al., 2013) has been well documented. It has been estimated that 30–40% of HAIs are caused by the contamination of healthcare worker hands; hands are contaminated either from contact with infected or colonized patients, or with their environment (Weber et al., 2010).

Recommendations for surface cleaning vary by region, and should be guided by local needs and resources. The use of detergents (i.e., soap and water) versus disinfectant chemicals has been an area of controversy. The advantages and disadvantages of each product have been reviewed by Rutala and Weber (Rutala and Weber, 2001). Detergent solutions have the potential to become contaminated with bacteria during the cleaning process, which can result in further spread of bacteria across surfaces (Dharan et al., 1999). Even though disinfectants generally reduce bacterial colony counts further than detergents, efficacy is dependent on many factors including concentration, contact time with surfaces, types of bacteria or viruses, and care of mops or cloths (Dharan et al., 1999; Rutala and Weber, 2008). Disinfectants also come with potential toxicity issues. Fumes can irritate the respiratory mucosa and repeated contact has been associated with dermatitis (Rutala and Weber, 2001). Toxicity to the environment is also an important consideration. In contrast to detergents, disinfectant disposal must be done in a way that prevents the release of toxins into the environment (Rutala and Weber, 2001), such as sending the product to a designated waste disposal site/facility. Disinfectants cannot be poured into drains or onto soil for disposal.

Most expert groups will recommend prompt cleaning with a disinfectant solution for surfaces soiled with body fluids (Adams et al., 2008; Rutala and Weber, 2008). Disinfectant solutions are also favored in outbreak situations when the organisms are known to have strong ties to the patient environment and potential resistance to detergent-based cleaning, such as *C. difficile*, MDROs, and norovirus (Centers for Disease Control and Prevention, 2003). It has been argued that high-touch surfaces, such as areas near the patient or frequently touched by healthcare workers, may represent 'critical surfaces' due to their potential for cross-transmission of pathogens, and these surfaces may also benefit from routine cleaning with disinfectants (Dancer, 2014). Otherwise, the decision regarding cleaning agents may be individualized depending on the scenario and available resources. For areas that cannot ensure safe use or disposal of large amounts of disinfectant solution, detergent cleaners may be more appropriate. If disinfectant is used for the routine cleaning of all surfaces, it is important that it does not impart a false sense of security. Bacteria will persist in the environment despite the use of a disinfectant cleaner, and attention to standard infection prevention practices remains essential.

Other potential reservoirs of infection

Water sources including sinks, ice machines, ice baths, and water baths have been implicated in many outbreaks of organisms such as *Pseudomonas aeruginosa*, *Serratia marcescens*, *Acinetobacter* species, *Legionella* species, and non-tuberculous mycobacteria. Direct contact of critical or semi-critical patient care items with these sources should be avoided. Regularly scheduled water or ice changes along with disinfection protocols should be used for various cooling or warming baths. Ice machines should receive regular maintenance and cleaning in accordance with the manufacturer's instructions (Weber and Rutala, 2003).

Fabrics, cloth furniture, and carpets in the hospital setting are problematic because they are difficult to clean or disinfect, are difficult to dry once wet, and can collect dust. These should be avoided in areas where soiling is likely. Vacuuming of carpets or furniture should be done in a way to limit dust spread (i.e. with well-maintained equipment and HEPA filters) (Centers for Disease Control and Prevention, 2003).

A comprehensive discussion regarding potential reservoirs of infection in the hospital setting and recommendations for risk mitigation can be found in the Centers for Disease Control and Prevention *Guidelines for Environmental Infection Control in Health-Care Facilities* (Centers for Disease Control and Prevention, 2003). Furthermore, a concise review of the major reservoirs has been published previously in the International Society for Infectious Disease's *A Guide to Infection Control in the Hospital* (Wendt, 2014).

Monitoring of cleaning

Assessment and feedback of cleaning performance is a critical part of environmental infection prevention. Traditionally, monitoring of cleaning has been accomplished by visual inspection of the area by environmental services management (Boyce, 2014). Several studies have questioned the accuracy of visual inspection compared to both microbiological sampling methods and non-microbiological sampling methods (Malik et al., 2003; Mulvey et al., 2011; Sherlock et al., 2009). The latter include fluorescent markers as surrogates of residual contamination, or quantification of adenosine triphosphate (ATP) levels representing persistence of organic material. However, accuracy assessments are complicated by an uncertainty regarding acceptable levels of residual contamination. It is unknown how clean surfaces must be in order to prevent the transmission of HAIs (Table 1).

A recent study revisiting the visual inspection of surfaces compared visual inspection, fluorescent markers, and ATP with aerobic colony counts; the sensitivity and specificity were calculated for each non-microbial method using the colony count as the gold standard (Snyder et al., 2013). The study found mediocre sensitivity and specificity for each method and poor correlations between the three methods. The authors suggested that given the limitations of all non-microbial monitoring methods, visual inspection may be the most appropriate from a cost perspective (Snyder et al., 2013). Another recent study used both ATP and visual inspection as part of an educational intervention and found that a visually inspected 'dirty' room had significantly higher ATP levels associated with it than a visually inspected 'clean' room (Knape et al., 2015). They argued that visual inspection may be more useful from a quality control perspective, given the ability to rapidly assess entire surfaces within a room and the relative difficulty in interpreting variable and more focal ATP results. However, ATP was hypothesized to be better accepted by staff as a feedback method, given the perceived subjectivity of visual assessments (Knape et al., 2015).

The end goal of monitoring must be to provide feedback on results and improve cleaning effectiveness. In this context, as long as the data are presented in a way that is meaningful and useful to staff, each of the above methods should be an acceptable monitoring strategy. Multiple studies have confirmed that the feedback of data on the quality of cleaning to environmental services staff improves the effectiveness of cleaning (Sitzlar et al., 2013; Goodman et al., 2008; Carling et al., 2006; Smith et al., 2014), albeit with regression of practice towards baseline in the post-intervention period (Smith et al., 2014). In the Virginia Commonwealth University Medical Center, internal monitoring is performed using fluorescent markers and the data are externally validated with a contract company that uses ATP. The results of monitoring are tracked monthly through the Infection Control Committee and are used in ongoing education with environmental services staff to maintain the benefits in cleaning effectiveness. Fluorescent markers are also used in environmental services staff training and competency testing.

In contrast, visual inspection is a good alternative with the benefit of allowing for many more observations than more resource-intensive monitoring processes, provided that the

Table 1
Summary of the strategies for environmental cleaning and disinfection of patient areas.

Cleaning strategy	Advantages	Disadvantages	Limitations	Selected references
Detergent surface cleaning agents	Non-toxic to staff and environment	Inferior microbial killing compared to disinfectants	Can become contaminated with bacteria	Dharan et al. (1999), Rutala and Weber (2001)
Disinfectant surface cleaning agents	Increased reduction in bacterial colony count compared to detergents	Toxic fumes and waste	Efficacy depends on concentrations, contact time – additional training is necessary for use	Rutala and Weber (2008, 2001)
Monitoring cleaning[a] with ATP/fluorescent markers	Objective assessment of surrogate markers of residual contamination after cleaning	Requires purchase of supplies for monitoring	Poor correlation with actual microbial colony counts on surfaces	Snyder et al. (2013)
Monitoring cleaning[a] via direct observation	Easy and inexpensive	Time-consuming, perceived subjectivity	Poor correlation with actual cleanliness of rooms by more objective methods	Knape et al. (2015)
Enhanced cleaning: addition of extra staff to target 'high-touch' surfaces	Effective in decreasing microbial surface contamination on 'high-touch' surfaces	Requires additional human resources	Impact of reduced 'high-touch' surface contamination on infection transmission is unknown	Dancer et al. (2009), Hess et al. (2013)
Enhanced cleaning: dedicated teams for 'high risk' areas	Optimization of existing resources rather than requiring new staff or equipment	Shifts attention to a specific problem area, rather than improving cleaning across all areas	Efficacy difficult to assess in isolation given use in a bundle of other interventions	Sitzlar et al. (2013), Weiss et al. (2009)
Antimicrobial 'self-cleaning' surfaces	Effective in decreasing microbial surface contamination	Expensive	Long-term durability of results unknown; ability to reduce infection transmission requires further study	ECRI Institute (2016), Salgado et al. (2013), Schmidt et al. (2012)
'Touchless' cleaning robots	Effective in decreasing microbial surface contamination	Expensive, requires staff training and human resources for deployment Patients/staff may not be present in the area during robot cleaning	Complex surfaces may be incompletely targeted by robot technology	Doll et al. (2015), Weber et al. (2016)

ATP, adenosine triphosphate; ECRI.
[a] Monitoring is most effective when results are reported back to cleaning staff.

monitoring is done by a trained, impartial observer and results are continually discussed with cleaning staff. Visual observation of actual cleaning practices has also been shown to be effective in improving cleaning practices, as part of a multifaceted intervention to decrease VRE acquisition (Hayden et al., 2006). While it is difficult to perform direct observation of cleaning practices without being detected, in the authors' experience it is not necessary to remain anonymous in these observations, as non-compliance with recommended practices is often the result of lack of understanding of cleaning protocols rather than wrongful intent on the part of the cleaner.

Other interventions to improve manual cleaning

In addition to education and performance feedback, some healthcare centers have studied the effects of adding extra manpower to target frequently touched surfaces within a unit in order to decrease the transmission of hospital-acquired organisms (Dancer et al., 2009; Hess et al., 2013). Dancer et al. added one additional cleaner, working a standard Monday through Friday shift, to existing environmental services staff on two surgical units (Dancer et al., 2009). In a prospective crossover design, the worker was tasked with focusing on 'high-touch' surfaces in the patient environment and unit, working 6 months on the first unit and then 6 months on the second unit. Environmental sampling was performed before, during, and after the interventions to assess for contamination with aerobic bacteria and *S. aureus*. In addition, patients were screened for MRSA. The investigators found significantly decreased microbial surface contamination during the cleaning intervention, as well as lower than expected MRSA rates during the intervention (Dancer et al., 2009). In a similar strategy, researchers in an intensive care unit sent a research team member trained to clean 'high-touch' surfaces into rooms occupied by patients colonized with MRSA or Acinetobacter after routine cleaning by environmental services personnel (Hess et al., 2013). The cleaner was instructed to perform a 'sham' clean in control rooms, and healthcare workers providing patient care in both the intervention and control rooms were subjected to gown/glove sampling for contamination upon room exit. Cleaning of 'high-touch' surfaces was validated by a second researcher, who assessed the effectiveness of combined cleaning efforts using fluorescent markers. The study was able to confirm improved cleaning by increased fluorescent marker removal in rooms with enhanced 'high-touch' cleaning; however, the decrease in healthcare worker gown/glove contamination did not reach statistical significance (Hess et al., 2013).

Dedicated cleaning teams for high-risk areas have been used to improve the cleaning of *C. difficile* patient rooms (Sitzlar et al., 2013; Weiss et al., 2009). In this approach, highly motivated staff are specially trained on *C. difficile*, disinfectant products, and high-touch surfaces. While these specialized cleaning teams were employed in a bundle of multiple other interventions, ensuring the consistency of cleaning was felt to be a major contributing factor to success (Sitzlar et al., 2013). The step-wise roll-out of interventions in the study by Sitzler et al., accompanied by concurrent environmental sampling for *C. difficile*, supported a combination of the dedicated team, daily cleaning, and terminal discharge room evaluations as the most important interventions in a three-phase environmental cleaning improvement effort that also included monitoring and feedback and deployment of an ultraviolet (UV) light-emitting device (Sitzlar et al., 2013). Strategic deployment of human resources for enhanced cleaning may allow the targeting of problem areas or organisms without major increases in required resources.

Antimicrobial 'self-cleaning' surfaces

Antimicrobial surfaces are now being used in both new hospital construction and as covering material for high-touch surfaces. Copper is the most frequently studied antimicrobial material. Several studies have demonstrated a decrease in bacterial burden on copper-containing surfaces compared to standard surfaces (Karpanen et al., 2012; Marais et al., 2010; Mikolay et al., 2010; Schmidt et al., 2012). The ability of copper surfaces to prevent HAIs has also been examined, but with mixed results. One study, although likely underpowered, failed to show a difference in rates (Rivero et al., 2014), while another multicenter project did reveal a decrease in rate from 0.081 to 0.034, which was statistically significant (Salgado et al., 2013). The reduction in HAIs was associated with a decreased bioburden in copper rooms, but not with a change in the rates of colonization with potential pathogens. Coating surfaces of facilities with copper may have some benefit in decreasing the bioburden on these surfaces between cleanings, but requires a substantial financial investment. The cost of coating surfaces of a single hospital room with copper are estimated to be between $5000 and $15 000 (ECRI Institute, 2016). The long-term effect is uncertain given theoretical concerns that bacteria will develop copper resistance. Resistance in this setting has yet to be demonstrated; a 24-week evaluation that specifically tested for copper resistance did not find this in any of the bacteria studied (Rozanska et al., 2017).

Cleaning robots: 'touchless' technologies

Manual cleaning that is performed optimally can effectively clean hospital surfaces. However, manual cleaning is dependent on human behavioral factors, and real-world practice is highly variable. In an effort to reduce the environmental bioburden and decrease the risks of residual pathogenic organisms in patient care areas, interest in 'touchless' technologies has exploded in high-resource healthcare settings. Investment in UV light-emitting robots or hydrogen peroxide aerosols and vapors allows healthcare centers to follow traditional manual cleaners with an automated cleaning process in an attempt to ensure rooms are optimally cleaned. These costly adjuncts are often employed in specific high-risk rooms at terminal discharge, given that they require anywhere from 15 min to a few hours in an empty patient room to complete the disinfection process (Doll et al., 2015). However, as healthcare institutions gain experience with these devices, applications are being expanded from patient rooms to other patient care areas, including operating rooms, dialysis units, and common areas used by patients (Haas et al., 2014; Miller et al., 2015).

Both hydrogen peroxide aerosol- or vapor-producing devices and UV-emitting devices are capable of significantly reducing the quantities of residual bacteria on hospital surfaces (Doll et al., 2015; Weber et al., 2016). There is a growing body of evidence that the reductions in bioburden from hospital surfaces may translate into tangible clinical outcomes (Weber et al., 2016; Passaretti et al., 2013; Anderson et al., 2017). Most studies assessing the ability of 'touchless' devices to decrease infection rates have used a quasi-experimental before-and-after design (Haas et al., 2014). However, Passerrati et al. conducted a robustly designed prospective cohort study using a hydrogen peroxide vapor device in three units that were matched to three control units (Passaretti et al., 2013). Rates of acquisition of MRSA, VRE, and *C. difficile* were assessed in these units over a 3-month pre-intervention period and a 6-month intervention period. The study demonstrated a significantly decreased acquisition of a combined outcome of all organisms, although this was driven largely by a decrease in VRE. Individual acquisition rates for MRSA and *C. difficile* were not significantly impacted (Passaretti et al., 2013).

The first long-awaited, multicenter, randomized controlled trial assessing the ability of a UV device to impact the acquisition of MDROs and *C. difficile* was recently published (Anderson et al., 2017). In this study, nine hospitals participated in a cluster randomized trial of four cleaning strategies: disinfection with quaternary ammonium, disinfection with bleach, and each of these plus UV for terminal cleaning. Bleach was used for all *C. difficile* patient rooms regardless of the randomization group. The study assessed patient acquisition of MDROs from previous room occupants and accumulated 31 226 exposed patients for the analysis. Even with nine healthcare centers and 31 226 patients, the study was unable to show a significant impact of bleach cleaning or bleach plus UV device cleaning for MDROs and/or *C. difficile* when compared to quaternary ammonium cleaning (Anderson et al., 2017). Some of the effect may have been diluted given that all *C. difficile* rooms in the reference arm were cleaned with bleach, as this was their standard infection control practice for this organism. Interestingly, when comparing quaternary ammonium disinfection alone to quaternary ammonium plus UV, the addition of the UV device was associated with a significant decrease in risk of acquisition of all target organisms (Anderson et al., 2017).

The results of these high-quality studies suggest that 'touchless' technologies may add some incremental benefit to standard manual cleaning programs. However, the results are modest in comparison to the smaller, lower quality studies on 'touchless' devices published in the literature (Weber et al., 2016). The expectation of a dramatic clinical benefit is not currently well supported by available data, although any incremental benefit in a multifaceted program to improve environmental cleaning may be valuable. The devices are in no way a substitute for traditional manual cleaning; 'touchless' devices require the removal of most of the bioburden and soil from surfaces to function optimally (Miller et al., 2015). While 'touchless' technologies may help to decrease the adverse effects of variability in cleaning practices by environmental services staff, there is currently no way to bypass the critical human element of the room cleaning process.

Conclusions

The hospital environment can be a source of HAIs, and current cleaning methods are only partially successful in mediating this risk. However, the extent to which the environment contributes to the transmission of infection and the level of cleanliness required to prevent the acquisition of organisms from the environment is unknown. There has been substantial interest in improving the cleaning process in recent years, and publications highlight a variety of strategies to accomplish this. Yet, fundamental issues remain unaddressed. There is an urgent need to overcome the challenges faced by manual cleaners (Bernstein et al., 2016) and to maximize the benefit of manual cleaning efforts. A tiered approach to cleaning that is tailored to the specific needs and resources of healthcare centers would be better defined with a wider representation of the global healthcare community in published studies. Human factors will ultimately determine the quality of environmental cleaning in the hospital and will remain the patient's best defense against invisible threats from the hospital environment.

Funding

None.

Conflict of interest

There were no sources of material or monetary support for this study. The authors have no conflicts of interest.

References

Adams J, Bartram J, Chartier Y. Essential environmental health standards in health care. World Health Organization; 2008 Website: http://www.who.int/water_-sanitation_health/hygiene/settings/ehs_health_care.pdf.pdf. [Accessed March 30, 2017].

Anderson DJ, Chen LF, Weber DJ, Moehring RW, Lewis SS, Triplett PF, et al. Enhanced terminal room disinfection and acquisition and infection caused by multidrug-resistant organisms and *Clostridium difficile* (the Benefits of Enhanced Terminal Room Disinfection study): a cluster-randomised, multicentre, crossover study. Lancet 2017;389:805–14.

Bonton MJ, Hayden MK, Nathan C, van Voorhis J, Matushek M, Slaughter S, et al. Epidemiology of colonization of patients and environment with vancomycin-resistant enterococci. Lancet 1996;348:1615–9.

Boyce JM. The inanimate environment. In: Jarvis WR, editor. Bennett and Brachman's hospital infection. 6th ed. Philadelphia, PA: Williams and Wilkins; 2014. p. 277–92.

Bernstein DA, Salsgiver E, Simon MS, Greendyke W, Eiras DP, Ito M, et al. Understanding barriers to optimal cleaning and disinfection in hospitals: a knowledge, attitudes, and practices survey of environmental services workers. Infect Control Hosp Epidemiol 2016;37:1492–5.

Carling PC, Briggs JL, Perkins J, Highlander D. Improved cleaning of patient rooms using a new targeting method. Clin Infect Dis 2006;42(3):385–8.

Carling PC, Von Beheren S, Kim P, Woods C, Healthcare Environmental Hygiene Study Group. Intensive care unit environmental cleaning: an evaluation in sixteen hospitals using a novel assessment tool. J Hosp Infect 2008;68:39–44.

Carling PC, Parry MF, Bruno-Murhta LA, Dick B. Improving environmental hygiene in 27 intensive care units to decrease multidrug resistant bacterial transmission. Crit Care Med 2010;38(4):1054–9.

Centers for Disease Control and Prevention. Guidelines for environmental infection control in health-care facilities: recommendations of CDC and the Healthcare Infection Control Practices Advisory Committee (HICPAC). MMWR 2003;52(RR-10):1–48.

Dancer SJ, White LF, Lamb J, Girvan EK, Robertson C. Measuring the effect of enhanced cleaning in a UK hospital: a prospective cross-over study. BMC Med 2009;7: 28-7015-7-28.

Dancer SJ. Controlling hospital-acquired infection: focus on the role of the environment and new technologies for decontamination. Clin Microbiol Rev 2014;27:665–90.

Dharan S, Mourouga P, Copin P, Bessmer G, Tschcanz B, Pittet D. Routine disinfection of patients' environmental surfaces. Myth or realtiy?. J Hosp Infect 1999;42:113–7.

Doll M, Morgan DJ, Anderson D, Bearman G. Touchless technologies for decontamination in the hospital: a review of hydrogen peroxide and UV devices. Curr Infect Dis Rep 2015;17: 498-015-0498-1.

ECRI Institute. Antimicrobial copper surfaces for reducing hospital-acquired infection risk. 2016 https://www.ecri.org/Resources/AHCJ/2016_Resources/Antimicrobial_Copper_Surfaces_for_Reducing_Hospital-acquired_Infection_-Risk.pdf, July. [Accessed October 13th, 2017].

Goodman ER, Platt R, Bass R, Onderdonk AB, Yokoe DS, Huang SS. Impact of an environmental cleaning intervention on the presence of methicillin-resistant *Staphylococcus aureus* and vancomycin-resistant enterococci on surfaces in intensive care unit rooms. Infect Control Hosp Epidemiol 2008;29:593–9.

Haas JP, Menz J, Dusza S, Montecalvo MA. Implementation and impact of ultraviolet environmental disinfection in an acute care setting. Am J Infect Control 2014;42(6):586–90.

Hayden MK, Bonten MJ, Blom DW, Lyle EA, van de Vijver DA, Weinstein RA. Reduction in acquisition of vancomycin-resistant enterococcus after enforcement of routine environmental cleaning measures. Clin Infect Dis 2006;42:1552–60.

Hess AS, Shardell M, Johnson JK, Thom KA, Roghmann MC, Netzer G, et al. A randomized controlled trial of enhanced cleaning to reduce contamination of healthcare worker gowns and gloves with multidrug-resistant bacteria. Infect Control Hosp Epidemiol 2013;34:487–93.

Huang SS, Datta R, Platt R. Risk of acquiring antibiotic-resistant bacteria from prior room occupants. Arch Intern Med 2006;166(18):1945–51.

Karpanen TJ, Casey AL, Lambert PA, et al. The antimicrobial efficacy of copper alloy furnishing in the clinical environment: a crossover study. Infect Control Hosp Epidemiol 2012;33:3–9.

Knape L, Hambraeus A, Lytsy B. The adenosine triphosphate method as a quality control tool to assess 'cleanliness' of frequently touched hospital surfaces. J Hosp Infect 2015;91:166–70.

Knelson LP, Williams DA, Gergen MF, Rutala WA, Weber DJ, Sexton DJ, et al. A comparison of environmental contamination by patients infected or colonized with methicillin-resistant *Staphylococcus aureus* or vancomycin-resistant enterococci: a multicenter study. Infect Control Hosp Epidemiol 2014;35:872–5.

Kramer A, Schwebke I, Kampf G. How long do nosocomial pathogens persist on inanimate surfaces? A systematic review. BMC Infect Dis 2006;6:130.

Lerner A, Adler A, Abu-Hanna J, Meitus I, Navon-Venezia S, Carmeli Y. Environmental contamination by carbapenem-resistant Enterobacteriaceae. J Clin Microbiol 2013;51:177–81.

Lin D, Ou Q, Lin J, Peng Y, Yao Z. A meta-analysis of the rates of *Staphylococcus aureus* and methicillin-resistant *S. aureus* contamination on the surfaces of environmental objects that health care workers frequently touch. Am J Infect Control 2016;45:421–9.

Malik RE, Cooper RA, Griffith CJ. Use of audit tools to evaluate the efficacy of cleaning systems in hospitals. Am J Infect Control 2003;31:181–7.

Marais F, Mehtar S, Chalkley L. Antimicrobial efficacy of copper touch surfaces in reducing environmental bioburden in a South African community healthcare facility. J Hosp Infect 2010;74:80–95.

Mikolay A, Huggett S, Tikana L, Grass G, Braun J, Nies DH. Survival of bacteria on metallic copper surfaces in a hospital trial. Appl Microbiol Biotechnol 2010;87:1875–9.

Mulvey D, Redding P, Robertson C, Woodall C, Kingsmore P, Bedwell D, et al. Finding a benchmark for monitoring hospital cleanliness. J Hosp Infect 2011;77:25–30.

Miller R, Simmons S, Dale C, Stachowiak J, Stibich M. Utilization and impact of a pulsed-xenon ultraviolet room disinfection system and multidisciplinary care team on *Clostridium difficile* in a long-term acute care facility. Am J Infect Control 2015;43:1350–3.

Nseir S, Blazejewski C, Lubret R, Wallet F, Courcol R, Durocher A. Risk of acquiring multidrug-resistant Gram-negative bacilli from prior room occupants in the intensive care unit. Clin Microbiol Infect 2011;17:1201–8.

Passaretti CL, Otter JA, Reich NG, Myers J, Shepard J, Ross T, et al. An evaluation of environmental decontamination with hydrogen peroxide vapor for reducing the risk of patient acquisition of multidrug-resistant organisms. Clin Infect Dis 2013;56:27–35.

Rivero P, Brenner P, Nercelles P. Impact of copper in the reduction of hospital-acquired infections, mortality and antimicrobial costs in the Adult Intensive Care Unit. Rev Chilena Infectol 2014;31:274–9.

Rozanska A, Chmielarczyk A, Romaniszyn D, Bulanda M, Walkowicz M, Osuch P, et al. Antibiotic resistance, ability to form biofilm and susceptibility to copper alloys of selected staphylococcal strains isolated from touch surfaces in Polish hospital wards. Antimicrob Resist Infect Control 2017;6:80.

Rutala WA, Weber DJ. Surface disinfection: should we do it?. J Hosp Infect 2001;48 (Suppl):S64–8.

Rutala WA, Weber DJ, Healthcare Infection Control Practices Advisory Committee (HICPAC). Guildeline for disinfection and sterilization in healthcare facilities. 2008.

Salgado CD, Sepkowitz KA, John JF, Cantey [266_TD$DIFF]JR, Attaway HH, Freeman KD, et al. Copper surfaces reduce the rate of healthcare-acquired infections in the intensive care unit. Infect Control Hosp Epidemiol 2013;34:479–86.

Schmidt MG, Attaway HH, Sharpe PA, et al. Sustained reduction of microbial burden on common hospital surfaces through introduction of copper. J Clin Microbiol 2012;50:2217–23.

Shaughnessy MK, Micielli RL, DePestel DD, Arndt [267_TD$DIFF]J, Strachan CL, Welch KB, et al. Evaluation of hospital room assignment and acquisition of *Clostridium difficile* infection. Infect Control Hosp Epidemiol 2011;32:201–6.

Sherlock O, O'Connell N, Creamer E, Humphreys H. Is it really clean? An evaluation of the efficacy of four methods for determining hospital cleanliness. J Hosp Infect 2009;72:140–6.

Sitzlar B, Deshpande A, Fertelli D, Kundrapu S, Sethi AK, Donskey CJ. An environmental disinfection odyssey: evaluation of sequential interventions to improve disinfection of *Clostridium difficile* isolation rooms. Infect Control Hosp Epidemiol 2013;34:459–65.

Smith PW, Beam E, Sayles H, Rupp ME, Cavalieri RJ, Gibbs S, et al. Impact of adenosine triphosphate detection and feedback on hospital room cleaning. Infect Control Hosp Epidemiol 2014;35:564–9.

Snyder GM, Holyoak AD, Leary KE, Sullivan BF, Davis RB, Wright SB. Effectiveness of visual inspection compared with non-microbiologic methods to determine the thoroughness of post-discharge cleaning. Antimicrob Resist Infect Control 2013;2:26.

Weber DJ, Rutala WA. Environmental issues and nosocomial infections. In: Wenzel RP, editor. Prevention and control of nosocomial infections. 3rd ed. Philadelphia, PA: Williams and Wilkins; 1997. p. 491–514.

Weber DJ, Rutala WA. The environment as a source of nosocomial infections. In: Wenzel RP, editor. Prevention and Control of Nosocomial Infections. 4th ed. Philadelphia, PA: Williams and Wilkins; 2003. p. 575–97.

Weber DJ, Rutala WA, Miller MB, Huslage K, Sickbert-Bennett E. Role of hospital surfaces in the transmission of emerging health care-associated pathogens: norovirus, *Clostridium difficile*, and Acinetobacter species. Am J Infect Control 2010;38:S25–33.

Weber DJ, Rutala WA, Kanamori H, Gergen MF, Sickbert-Bennett EE. Carbapenem-resistant Enterobacteriaceae: frequency of hospital room contamination and survival on various inoculated surfaces. Infect Control Hosp Epidemiol 2015;36:590–3.

Weber DJ, Rutala WA, Anderson DJ, Chen LF, Sickbert-Bennett EE, Boyce JM. Effectiveness of ultraviolet devices and hydrogen peroxide systems for terminal room decontamination: focus on clinical trials. Am J Infect Control 2016;44: e77–84.

Weiss K, Boisvert A, Chagnon M, Duchesne C, Habash S, Lepage Y, et al. Multipronged intervention strategy to control an outbreak of *Clostridium difficile* infection (CDI) and its impact on the rates of CDI from 2002 to 2007. Infect Control Hosp Epidemiol 2009;30:156–62.

Wendt C. Patient areas, disinfection and environmental cleaning. In: Bearman GM, Stevens M, Edmond MB, Wenzel RP, editors. A guide to infection control in the hospital. 5th ed. Brookline, MA: International Society for Infectious Diseases; 2014. p. 39–44.