COMMENTARY

Self-Disinfecting Surfaces

David J. Weber, MD, MPH;[1,2] William A. Rutala, PhD, MPH[1,2]

(See the article by Karpanen et al, on pages 3–9.)

Contamination of environmental surfaces in hospital rooms is now recognized as playing an important role in the transmission of several key healthcare-associated pathogens, including methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant enterococci (VRE), *Clostridium difficile*, *Acinetobacter* species, and norovirus.[1-3] All of these pathogens have been demonstrated to persist in the environment for hours to days (and in some cases for months), to frequently contaminate the environmental surfaces in the rooms of colonized or infected patients, to transiently colonize the hands of healthcare personnel (HCP), to be transmitted to patients by HCP, and to cause outbreaks in which environmental transmission was deemed to play a role. Furthermore, hospitalization in a room in which the previous patient had been colonized or infected with MRSA, VRE, *C. difficile*, or *Acinetobacter* species has been shown to be a risk factor for colonization or infection with the same pathogen in the newly admitted patient.[2,3]

Pathogen transfer from an affected patient to a susceptible host occurs most commonly via the hands of HCP, but contaminated surfaces, objects, and air can be directly or indirectly involved in the transmission pathway. These transmission pathways and methods to interrupt transmission have been diagramed.[3,4] Transmission can be greatly reduced by hand hygiene of HCP before and after each patient contact and by appropriate disinfection of shared medical devices between patients. However, reducing or eliminating surface contamination is crucial to preventing acquisition of healthcare pathogens by patients who are newly admitted to rooms previously occupied by colonized or infected patients and to minimizing the risk of contaminating the hands of HCP.

Potential methods of decreasing contamination of environmental surfaces in hospital rooms have included routine and terminal room disinfection with chemical germicides[5] and, more recently, the use of "no-touch" methods of terminal room decontamination with UV light or aerosolized and/or vaporized hydrogen peroxide.[6] Unfortunately, there are major limitations associated with currently available methods of room decontamination. Multiple studies have demonstrated that less than 50% of hospital room surfaces are adequately cleaned and disinfected when chemical germicides are used,[7,8] although with implementation of enhanced performance feedback, education, and other interventions, the frequency of appropriate cleaning can be increased to 71%–77%.[7,8] The major limitation of UV light and hydrogen peroxide is that, because this method requires the removal of patients and HCP from the room, it can be used only for terminal disinfection. Other limitations include the high acquisition costs of room decontamination units and increasing the time of room turnover.[5]

In the past several years, another method of reducing contamination of room surfaces has emerged: self-disinfecting surfaces (Table 1). Such surfaces have also been called "self-sanitizing," and because microbial killing requires direct contact with the surface, the term "contact killing" has also been used. One novel method to achieve contact killing is to cover room surfaces with a transition metal, such as copper or silver. Such metals influence microorganisms by affecting their growth, morphology, and biochemical activities. Toxicity is a result of the blocking of functional groups of important molecules (eg, enzymes), displacement or substitution of essential ions from cellular sites, denaturation and inactivation of enzymes, generation of reactive hydroxyl radicals, and disruption of cellular membrane integrity.[9]

Copper is an essential trace element in most living organisms and has been used for centuries as a medicinal as well as to prevent growth of barnacles and weeds on the hulls of ships.[10] Copper surfaces have been demonstrated to be cidal to important healthcare-associated pathogens, including MRSA, *Acinetobacter* species, *Pseudomonas aerugonosa*, and influenza virus.[10] Experimental inoculation of copper surfaces has demonstrated that dry metallic surfaces were more antimicrobial than were moist surfaces. On dry surfaces, vegetative bacteria were killed within a few minutes. How soiling,

Affiliations: 1. Department of Medicine, University of North Carolina Medical School, Chapel Hill, North Carolina; 2. Department of Hospital Epidemiology, University of North Carolina Health Care, Chapel Hill, North Carolina.

Received October 30, 2011; accepted October 31, 2011; electronically published December 7, 2011.

 0899-823X/2012/3301-0003$15.00. DOI: 10.1086/663648

TABLE 1. Potential Methods to Develop Self-Disinfecting Surfaces

Method	Options
Surface impregnated with a metal	Copper; silver
Surface impregnated with a germicide	Triclosan; antimicrobial surfactant/quarternary ammonium salt
Miscellaneous	Altered topography; light-activated antimicrobial coatings

cleaning, exposure to chemicals, and tarnishing affect the antimicrobial properties of copper has not yet been studied in detail.[10]

In this issue of *Infection Control and Hospital Epidemiology*, Karpanen et al[11] describe the surface contamination levels on 14 types of frequently touched items made of copper alloys that were installed in various locations on an acute care medical ward. Items included door handles, toilet seats, grab rails, light switches, overbed tables, commodes, and other items. The copper items were switched to similar noncopper items halfway through the 24-week study period. Eight of the 14 copper item types had significantly lower microbial counts on their surfaces, compared with microbial counts on items made of standard materials. MRSA, VRE, coliforms, and *C. difficile* were found to contaminate 0.4%–8.1% of surfaces; contamination by VRE and coliforms was statistically reduced on the copper items, whereas no significant reduction was noted for MRSA and *C. difficile*. Other investigators have reported similar results after assessing copper items in hospitals.[12]

There are several limitations to widespread adoption of the use of copper items in healthcare facilities. First, none of the published studies have provided data on the cost of purchasing and installing copper items. Second, the reduction of microbial contamination has been modest in some studies (ie, <1 $\log_{10}$).[11] Third, copper has not been demonstrated experimentally to kill *C. difficile* dormant spores, and the study by Karpanen et al[11] was unable to demonstrate any reduction in *C. difficile* contamination on copper items. Fourth, how soiling, cleaning, exposure to chemicals, low relative humidity, low temperature, and tarnishing affect the antimicrobial properties of copper has not yet been studied in detail. Fifth, it is likely to be impractical or impossible to coat all environmental surfaces and medical devices that could lead to contamination of the hands of HCP with copper. Finally, no studies have yet evaluated the ability of installed copper items to reduce healthcare-associated infection rates. Recently, bacteria isolated from copper coins were shown to demonstrate prolonged survival on dry copper surfaces, which suggests that decreased susceptibility to dry copper surfaces can develop in both gram-positive and gram-negative bacteria.[13]

Silver is toxic to many microbes at low concentrations and for this reason has been used for topical antisepsis (eg, silver nitrate and silver sulfadiazine). The effectiveness of central venous catheters impregnated with silver sulfadiazine-chlorhexidine or silver iontophoretic in preventing central line–associated bloodstream infections has been demonstrated in randomized clinical trials.[14] Other indwelling medical devices (eg, endotracheal tubes and urinary catheters) with a silver compound incorporated have also been developed. Surfacine (Surfacine Development) incorporates a water-soluble antimicrobial compound (silver iodide) in a surface-immobilized coating (a modified polyhexamethlyenebiguanide) that is capable of chemical recognition and interaction with the lipid bilayer of the bacterial outer cell membrane by electrostatic attraction.[15] Microorganisms contacting the coating accumulate silver until the toxicity threshold is exceeded. Surfacine can be applied to inanimate surfaces by dipping, brushing, or spraying without earlier surface treatment. Surfaces to which this agent is applied have been shown to kill 3.3–4.3 $\log_{10}$ of *S. aureus* and 2.2–4.8 $\log_{10}$ of *P. aeruginosa* hours after application of Surfacine.[16] In addition, a greater than 3-$\log_{10}$ reduction in MRSA and VRE was also achieved. Residual activity of Surfacine against VRE has been shown to continue for 13 days after application.[15] However, there are no published studies assessing the ability of this agent to reduce the microbial contamination on environmental surfaces in actual hospital rooms or to decrease the incidence of healthcare-associated infection. More recently, silver nanoparticles have been incorporated into wound dressings, indwelling catheters, bone cement, and other implants, and environmental surfaces with some of these products are now commercially available.[17] However, the effectiveness of silver nanoparticles when incorporated into environmental surfaces has not been assessed in the hospital environment.

Triclosan is a nonionic, colorless substance that has antimicrobial activity at concentrations of 0.2%–2%. Triclosan has a broad range of antimicrobial activity, but it is often bacteriostatic.[18] Its activity against gram-positive organisms (including MRSA) is greater than its activity against gram-negative bacilli. Triclosan has been incorporated into a wide range of home and personal-care objects, including soaps, underarm deodorants, toothpaste, and cutting boards.[19] Triclosan-impregnated cutting boards have been shown to lead to decreases in bacteria applied to boards, including reductions of 0.5–1.0 $\log_{10}$ for *S. aureus* and *Serretia* species and 1.5–1.7 $\log_{10}$ for *Escherichia coli* and *Salmonella* species.[20] When *P. aeruginosa* was grown as a biofilm on discs of polyethylene, teflon, and stainless steel, 1% triclosan was only effective in achieving a reduction in organisms of less than 1 $\log_{10}$.[21] In the laboratory, bacteria with reduced susceptibility to triclosan can be produced fairly readily by serial passage in increasing triclosan concentrations.[22] However, the minimum inhibitory concentrations of such strains generally are

substantially below the concentration of triclosan contained in antimicrobial products. We were unable to find any studies evaluating the use of triclosan-impregnated hospital environmental surfaces.

Recently, an antimicrobial surfactant whose core product is a quaternary ammonium salt, Goldshield (APGoldshield), has been evaluated.[23] Using a carrier test, the agent was demonstrated to kill 0.5–2.4-$\log_{10}$ of MRSA and 0.6–0.9 $\log_{10}$ of *P. aeruginosa* and *E. coli* within 30 minutes on formica and stainless steel.[23] Rechallange after 4 days generally did not demonstrate microbial inactivation, although a statistical reduction was noted for MRSA on formica (but not stainless steel) carriers. No published studies of the use of this agent on environmental surfaces in hospital rooms are available. Data demonstrate that quaternary ammonium disinfectants continue to have persistent antimicrobial activity that extends beyond their wet time on the surface; activity may extend beyond 24 hours, provided that the disinfectant is left on the surface undisturbed.[24]

Another recent potential innovation is the use of an engineered microtopography to inhibit bacterial biofilm formation. One such design is Sharklet AF (Sharklet Technologies), which seeks to use a topography similar to shark skin to inhabit biofilms. Reduced biofilm formation has been described on molds employing Sharklet AF.[25] Urogenic *E. coli* were inhibited on silicone elastomer coupons, which suggests that this method could be used to develop Foley catheters that would inhibit microbial growth.[26] We are unaware of any published studies that assess this new technology to inhibit microbial growth on actual indwelling medical devices or hospital environmental surfaces.

Finally, light-activated antimicrobial coatings have been studied for the continuous disinfection of surfaces. Irradiation of certain compounds (photosensitizers) with visible light results in the production of cytotoxic species, such as singlet oxygen and free radicals. A cellulose acetate coating containing toluidine blue O and rose Bengal has been studied.[27-29] Illumination for a 6-hour period resulted in a reduction of 2–3 $\log_{10}$ in *S. aureus*, but if the organism was suspended in saliva or horse serum, reductions of less than 1 $\log_{10}$ were noted.[27] Exposures periods of 6 hours or more have been demonstrated to inactivate greater than 6 $\log_{10}$ of *S. aureus*, MRSA, *E. coli*, and *C. difficile* (mainly vegetative cells) under experimental conditions.[28] In a clinical environment, a 63.8% reduction in aerobes and an 81.8% reduction in anaerobes has been reported.[29] Silicone polymers containing the light-activated antimicrobial agent methylene blue with gold nanoparticles were effective in reducing the microbial load on surfaces in a clinical environment.[30]

The potential development of self-disinfecting surfaces has tremendous possibilities. Most importantly, the use of such surfaces could minimize the impact of poor cleaning and disinfecting practices during routine and terminal room cleaning and disinfection. However, several cautionary considerations should be noted. First, many of these surfaces have demonstrated only modest killing (<2 $\log_{10}$ reductions in pathogens). Second, the ability of these new surfaces to kill intrinsically more-resistant pathogens, such as *C. difficile* spores and norovirus, has often not been fully evaluated. Third, the cost of installing such surfaces has not been described. Fourth, only incomplete information is available on the durability of such surfaces and whether their antimicrobial activity is affected by temperature, humidity, the frequency of cleaning, and the presence of organic load. Finally, no studies have been published that demonstrate whether installing such surfaces reduces the incidence of healthcare-associated infections. Although high-touch surfaces have been defined,[31] the relative contribution of individual surfaces to the contamination of the hands of HCP and to the risk of cross-transmission is incompletely defined. Thus, it is unclear which environmental surfaces and medical devices in patient rooms should or could be coated with a self-disinfecting surface. Nevertheless, continued research in this area to discover means of reducing the impact of environmental contamination in the transmission of healthcare-associated pathogens is clearly warranted.

ACKNOWLEDGMENTS

Financial support. The University of North Carolina at Chapel Hill.

Potential conflicts of interest. The authors acknowledge having served as consultants for Clorox. All authors submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest, and the conflicts that the editors consider relevant to this article are disclosed here.

Address correspondence to David J. Weber, MD, MPH, 2163 Bioinformatics, CB #7030, Chapel Hill, NC 27599 (dweber@unch.unc.edu).

REFERENCES

1. Boyce J. Environmental contamination makes an important contribution to hospital infection. *J Hosp Infect* 2007;65(suppl 2):S50–S54.
2. 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–S33.
3. Otter JA, Yezli S, French GL. The role played by contaminated surfaces in the transmission of nosocomial pathogens. *Infect Control Hosp Epidemiol* 2011;32:687–699.
4. Rutala WA, Weber DJ. Cleaning, disinfection, and sterilization. In: *APIC Text of Infection Control and Epidemiology*. 3rd ed. Washington, DC: Association for Professionals in Infection Control and Epidemiology, 2009:21-1–21-18.
5. Rutala WA, Weber DJ; Healthcare Infection Control Practices Advisory Committee. *Guideline for Disinfection and Sterilization in Healthcare Facilities, 2008.* http://www.cdc.gov/hicpac/Disinfection_Sterilization/acknowledg.html. Published 2008. Accessed October 14, 2011.
6. Rutala WA, Weber DJ. Are room decontamination units needed to prevent transmission of environmental pathogens? *Infect Control Hosp Epidemiol* 2011;32:743–747.
7. Carling PC, Parry MF, von Beheren SM. Identifying opportu-

nities to enhance environmental cleaning in 23 acute care hospitals. *Infect Control Hosp Epidemiol* 2008;29:1–7.
8. 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;29:593–599.
9. Weber DJ, Rutala WA. Use of metals as microbicides in preventing infections in healthcare. In: Block SS, ed. *Disinfection, Sterilization, and Preservation.* 5th ed. Philadelphia: Lippincott Williams & Wilkins, 2001:415–430.
10. Grass G, Rensing C, Solioz M. Metallic copper as an antimicrobial surface. *Appl Environ Microbiol* 2011;77:1541–1547.
11. 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(1):3–9 (in this issue).
12. 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;87:1875–1879.
13. Santo CE, Morais PV, Grass G. Isolation and characterization of bacteria resistant to metallic copper surfaces. *Appl Environ Microbiol* 2010;76:1341–1348.
14. Wang H, Huang T, Jing J, et al. Effectiveness of different central venous catheters for catheter-related infections: a network meta-analysis. *J Hosp Infect* 2010;76:1–11.
15. Rutala WA, Weber DJ. New disinfection and sterilization methods. *Emerg Infect Dis* 2001;7:348–353.
16. Brady MJ, Lisay CM, Yurkovetskiy AV, Sawan SP. Persistent silver disinfectant for the environmental control of pathogenic bacteria. *Am J Infect Control* 2003;31:208–214.
17. Chaloupka K, Malam Y, Seifalian AM. Nanosilver as a new generation of nanoproduct in biomedical applications. *Trends Biotechnol* 2010;28:580–588.
18. Centers for Disease Control and Prevention. Guideline for hand hygiene in health-care settings. *MMWR Morb Mortal Wkly Rep* 2002;51(RR-16):1–45.
19. Weber DJ, Rutala WA. Use of germicides in the home and healthcare settings: is there a relationship between germicide use and antibiotic resistance? *Infect Control Hosp Epidemiol* 2006;27:1107–1119.
20. Moretro T, Hoiby-Pettersen GS, Habimana O, Heir E, Langsrud S. Assessment of the antibacterial activity of a triclosan-containing cutting board. *Int J Food Microbiol* 2011;146:157–162.
21. Smith K, Hunter IS. Efficacy of common hospital biocides with biofilms of multi-drug resistant clinical isolates. *J Med Microbiol* 2008;57:966–973.
22. Russell AD. Whither triclosan? *J Antimicrob Chemother* 2004;53:693–695.
23. Baxa D, Shetron-Rama L, Golembieski M, et al. In vitro evaluation of a novel process for reducing bacterial contamination of environmental surfaces. *Am J Infect Control* 2011;39:483–487.
24. 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.
25. Chung KK, Schumacher JF, Sampson EM, Burne RA, Antonelli PJ, Brennan AB. Impact of engineered surface microtopography on biofilm formation of *Staphylococcus aureus. Biointerphases* 2007;2:89–94.
26. Reddy ST, Chung KK, McDaniel CJ, Darouiche RO, Landman J, Brennan AB. Micropatterned surfaces for reducing the risk of catheter-associated urinary tract infection: an in vitro study on the effect of Sharklet micropatterned surfaces to inhibit bacterial colonization and migration of uropathogenic *Escherichia coli. J Endourol* 2011;25:1547–1552.
27. Decraene V, Pratten J, Wilson M. Novel light-activated antimicrobial coatings are effective against surface-deposited *Staphylococcus aureus. Curr Microbiol* 2008;57:269–273.
28. Decraene V, Pratten J, Wilson M. Cellulose acetate containing toluidine blue and rose bengal is an effective antimicrobial coating when exposed to white light. *Appl Environ Microbiol* 2006;72:4436–4439.
29. Decraene V, Pratten J, Wilson M. Assessment of the activity of a novel light-activated antimicrobial coating in a clinical environment. *Infect Control Hosp Environ* 2008;29:1181–1184.
30. Ismail S, Perni S, Pratten J, Parkin I, Wilson M. Efficacy of a novel light-activated antimicrobial coating for disinfecting hospital surfaces. *Infect Control Hosp Epidemiol* 2011;32:1130–1132.
31. 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.