The role of the surface environment in healthcare-associated infections

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Purpose of review

This article reviews the evidence demonstrating the importance of contamination of hospital surfaces in the transmission of healthcare-associated pathogens and interventions scientifically demonstrated to reduce the levels of microbial contamination and decrease healthcare-associated infections.

Recent findings

The contaminated surface environment in hospitals plays an important role in the transmission of methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant *Enterococcus* spp. (VRE), *Clostridium difficile*, *Acinetobacter* spp., and norovirus. Improved surface cleaning and disinfection can reduce transmission of these pathogens. 'No-touch' methods of room disinfection (i.e., devices which produce ultraviolet light or hydrogen peroxide) and 'self-disinfecting' surfaces (e.g., copper) also show promise to decrease contamination and reduce healthcare-associated infections.

Summary

Hospital surfaces are frequently contaminated with important healthcare-associated pathogens. Contact with the contaminated environment by healthcare personnel is equally as likely as direct contact with a patient to lead to contamination of the healthcare provider's hands or gloves that may result in patient-to-patient transmission of nosocomial pathogens. Admission to a room previously occupied by a patient with MRSA, VRE, *Acinetobacter,* or *C. difficile* increases the risk for the subsequent patient admitted to the room to acquire the pathogen. Improved cleaning and disinfection of room surfaces decreases the risk of healthcare-associated infections.

Keywords

copper, environment, healthcare-associated infections, hospital surfaces, hydrogen peroxide systems, surface disinfection, ultraviolet light

INTRODUCTION

Healthcare-associated infections (HAI) remain a major cause of patient morbidity and mortality in the United States with approximately one out of every 20 hospitalized patients developing an HAI. Klevens *et al.* [1] estimated that in 2002 there were approximately 1.7 million healthcare-associated infections, which resulted in approximately 99 000 deaths. It has been estimated that the source of pathogens causing an HAI in the ICU was the patients' endogenous flora, 40–60%; cross-infection via the hands of personnel, 20–40%; antibiotic-driven changes in flora, 20–25%; and other (including contamination of the environment), 20% [2]. Over the past decade, substantial scientific evidence has accumulated that contamination of environmental surfaces in hospital rooms plays an important role in the transmission of several key healthcare-associated pathogens, including methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant *Enterococcus* spp. (VRE), *Clostridium difficile*, *Acinetobacter* spp., and norovirus [3–5,6■■,7■]. Evidence supporting the role of the contaminated surface environment in the transmission of several key healthcare-associated pathogens is summarized as follows:

(1) The surface environment in rooms of colonized or infected patients is frequently contaminated with the pathogen.

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Curr Opin Infect Dis 2013, 26:338–344

DOI:10.1097/QCO.0b013e3283630f04

KEY POINTS

- Hospital surfaces are frequently contaminated with important nosocomial pathogens including MRSA, VRE, *Clostridium difficile*, *Acinetobacter* spp., and norovirus.
- The contaminated hospital environment has been demonstrated to be important in the person-to-person transmission of these pathogens.
- Improved surface cleaning and disinfection can reduce the incidence of healthcare-associated infections.
- 'No-touch' methods of room disinfection (i.e., devices which produce ultraviolet light or hydrogen peroxide) and 'self-disinfecting' surfaces (e.g., copper) show promise to decrease contamination and reduce healthcare-associated infections.

(2) The pathogen is capable of surviving on hospital room surfaces and medical equipment for a prolonged period of time.
(3) Contact with hospital room surfaces or medical equipment by healthcare personnel frequently leads to contamination of hands and/or gloves.
(4) The frequency with which room surfaces are contaminated correlates with the frequency of hand and/or glove contamination of healthcare personnel.
(5) Clonal outbreaks of pathogens contaminating the room surfaces of colonized or infected patient are demonstrated to be due to person-to-person transmission or shared medical equipment.
(6) The patient admitted to a room previously occupied by a patient colonized or infected with a pathogen (e.g., MRSA, VRE, *C. difficile*, *Acinetobacter*) has an increased likelihood of developing colonization or infection with that pathogen.
(7) Improved terminal cleaning of rooms leads to a decreased rate of infections.
(8) Improved terminal disinfection (e.g., vaporized hydrogen peroxide) leads to a decreased rate of infection in patients subsequently admitted to the room where the prior occupant was colonized or infected.

Although pathogen transfer from a colonized or infected patient to a susceptible patient most commonly occurs via the hands of healthcare personnel, contaminated hospital surfaces and medical equipment (and less commonly water and air) can be directly or indirectly involved in the transmission pathways. These transmission pathways have been diagramed and these models provide the basis for the development of interventions to disrupt transmission [5,8]. This review will focus on recent literature that demonstrates the importance of surface contamination in hospitals for patient-to-patient transmission of pathogens and scientifically demonstrated interventions to reduce such transmission.

CONTAMINATION OF SURFACES IN THE HOSPITAL ENVIRONMENT

The survival of nosocomial pathogens on environmental surfaces has been reviewed [9,10]. MRSA, VRE, *Pseudomonas* spp., *Acinetobacter* spp., and norovirus are capable of surviving for days to weeks on dry inanimate surfaces. *C. difficile* spores may survive on environmental surfaces for months.

Multiple studies have demonstrated that surfaces in the rooms of patients colonized or infected with important healthcare-associated pathogens are frequently contaminated. The proportion of hospital surfaces contaminated with MRSA has varied in published reports from 1 to 27% of surfaces in patient rooms on regular hospital wards, and from a few percent to 64% of burn units with MRSA patients [3]. One review reported that 7–29% of environmental sites were positive in areas housing VRE patients [11]. More recent studies have reported that the frequency of environmental contamination reached 60–70% in the room of patients colonized with VRE at three or four body sites and that 36–58% of chairs and couches used by VRE patients were positive in areas housing VRE patients [3]. Many studies have demonstrated widespread environmental contamination with *C. difficile* in the rooms of patients with *C. difficile* infection (CDI), with a range of 2.9–75% [4]. Finally, the frequency of environmental contamination with *Acinetobacter* spp. in outbreak settings has been reported by investigators to range from 3 to 50% [4].

Although hospital room surfaces are frequently contaminated, the level of contamination is generally less than 10 organisms per cm^2. For example, Huslage *et al.* [12] reported that the number of colony forming units (CFU) was less than 100 bacteria per RODAC plate (25 cm^2). Importantly, there was no statistical difference in the level of contamination despite whether the surface was a high, medium or low touch surface. Similar findings have been reported by others [13]. Several studies have evaluated the level of microbial contamination of *C. difficile* on surfaces in the rooms of patients with CDI. Most of these studies reported that surfaces were contaminated with less than 1–2-$\log_{10}$ *C. difficile*, but one study that sampled a larger area using a sponge technique reported 1300 colonies [7▪].

ROLE OF THE CONTAMINATED ENVIRONMENT IN TRANSIENT HAND/GLOVE CONTAMINATION OF HEALTHCARE PERSONNEL

Healthcare personnel have frequent contact with environmental surfaces in patient's rooms, providing ample opportunity for contamination of gloves and/or hands [14]. Importantly, hand contamination with MRSA has been demonstrated to occur with equal frequency whether healthcare personnel (HCP) have direct contact with a colonized/infected patient or through touching only contaminated surfaces [15]. The most important risk factor for hand/glove contamination of HCP with multidrug-resistant pathogens has been demonstrated to be positive environmental cultures [16■■]. Importantly, the frequency that hand cultures of HCP grow *C. difficile* is correlated with the intensity of environmental contamination of *C. difficile*. Samore *et al.* [17] reported that hand contamination was 0% when environmental contamination was 0–25%, was 8% when environmental contamination was 26–50%, and was 26% when environmental contamination was greater than 50%.

SURFACE CONTAMINATION FOLLOWING DISINFECTION

Multiple studies have demonstrated that surfaces in hospital rooms are poorly cleaned during terminal cleaning. Although methods of assessing the adequacy of cleaning varied (i.e., visibly clean, ATPase, fluorescent dye, aerobic plate counts), several studies have demonstrated that less than 50% of room surfaces are clean [18–20]. Similar deficiencies have been reported for cleaning and disinfection of portable medical equipment between patients [21]. Given the deficiencies demonstrated in terminal cleaning, it is not surprising that many hospital surfaces remain contaminated with important nosocomial pathogens.

The most commonly used surface disinfectants in hospitals have been phenols and quaternary ammonium compounds. However, such compounds are not active against spore forming pathogens such as *C. difficile* and norovirus. For this reason, hypochlorites often have been used to disinfect surfaces in rooms of patients with CDI and/or norovirus, and have been included as part of multiple interventions to terminate outbreaks. Importantly, it has been shown that use of nonsporicidal wipes (e.g., containing a quaternary ammonium compound) or inappropriate use of sporidical wipes (e.g., wipe used on an excessively large surface) may result in efficient transfer of *C. difficile* spores from contaminated to clean surfaces [22]. Multiple surface disinfectants are now US Environmental Protection Agency (EPA)-registered as effective against *C. difficile*; most contain sodium hypochlorite but several other germicides have also been registered (ethaneperoxoic acid/hydrogen peroxide, silver, tetraacetylethylene-diamine) [23]. The EPA website also lists products registered effective against norovirus [23].

RISKS OF PATHOGEN ACQUISITION DUE TO INADEQUATE TERMINAL DISINFECTION

Hospitalization in a room in which the previous patient had been colonized or infected with MRSA [24], VRE [24,25], *C. difficile* [26], and multidrug-resistant *Acinetobacter* spp. or multidrug-resistant *Pseudomonas* [27] has been shown to be a risk factor for colonization or infection with the same pathogen for the next patient admitted to the room.

PREVENTING TRANSMISSION OF NOSOCOMIAL PATHOGENS DUE TO CONTAMINATED SURFACES

Three general methods may be utilized to decrease patient-to-patient transmission of healthcare-associated pathogens as a result of the contaminated surface environment. First is the improved cleaning and disinfection of room surfaces [28,29]. Second is 'no touch' methods for terminal room disinfection. The most commonly studied devices generate ultraviolet light (UV) or hydrogen peroxide [30,31,32■■,33■]. Finally, 'self-disinfecting' surfaces have been developed to reduce the bioburden on environmental surfaces [34■■]. 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.

Improving surface cleaning and disinfection

Multiple studies have demonstrated that less than 50% of hospital room surfaces are adequately cleaned and disinfected when chemical germicides are used [35,36]. Interventions including improved education of environmental service workers, checklists to assure that all surfaces (usually by environmental service workers) and medical devices/equipment (usually by nursing) are cleaned and disinfected, and assessment of the cleanliness of the environment (e.g., fluorescent dye, ATPase) with immediate feedback to the environmental service worker have been demonstrated to improve the frequency of adequate cleaning in the range of 71–77% [35,36].

Multiple methods of assessing the adequacy of cleaning have been developed but the two most practiced are the use of a fluorescent dye and ATP bioluminesence [37■]. The fluorescent dye is applied as a 'dot' to surfaces where it dries clear. If cleaning is adequate no fluorescence is detected when the dotted object is exposed to black light but a fluorescent dot appears if cleaning is inadequate. ATP bioluminescence systems measure the presence of ATP, which is a marker for microbial contamination. It is important to note that the presence of ATP does not necessarily indicate viable pathogens and its absence does not necessarily mean the surface is not contaminated. Importantly, it has been shown that the results from using the fluorescent dye correlated more closely with aerobic colony counts than did measurement of ATP bioluminescence [13].

Best practices for cleaning and disinfection of room surfaces have been reviewed [38,39■], and a toolkit for evaluating environmental cleaning is available from the US Centers for Disease Control and Prevention [40■]. Eliminating surface contamination as a source for patient-to-patient transmission of nosocomial pathogens will require multiple interventions aimed at cleaning/disinfecting the environment as well as improved adherence to hand hygiene guidelines. This was exemplified in an excellent recent study by Sitzlar *et al.* [41■], who demonstrated a dramatic reduction in the frequency of positive surface cultures of *C. difficile* by sequential terminal cleaning and disinfection interventions (i.e., monitoring of cleaning by fluorescent markers with feedback, use of a UV-C room disinfection device, and enhanced standard disinfection of *C. difficile* rooms including a dedicated daily disinfection team). To date, most studies demonstrating the impact of improved surface cleaning and disinfection have focused on terminal cleaning (i.e., after the patient has been discharged). Recently, Kundrapu *et al.* [42■] demonstrated in a randomized trial that daily disinfection of high-touch surfaces in rooms of patients with MRSA colonization or CDI reduced acquisition of the pathogens on hands after contacting high-touch surfaces and reduced contamination of hands of healthcare workers caring for the patients. In an excellent review, Donskey [43■■] concludes that 'a growing body of evidence has accumulated suggesting that improvements in environmental disinfection may prevent transmission of pathogens and reduce healthcare-associated infections'.

'No-touch' methods of surface disinfection

Although intervention to enhance terminal room cleaning and disinfection have been successful both at improving cleaning and reducing healthcare-associated infections, studies have shown that many room surfaces are still not adequately disinfected. For this reason, several manufacturers have developed room disinfection units that can decontaminate environmental surfaces and objects. These systems use one of two methods: either ultraviolet light (UV) or hydrogen peroxide. These technologies supplement, but do not replace, standard cleaning and disinfection because surfaces must be physically cleaned of dirt and debris. Additionally, these methods can only be used for terminal or discharge room decontamination (i.e., cannot be used for daily room decontamination) because the room must be emptied of people.

UV irradiation has been used for the control of pathogenic microorganisms in a variety of applications, such as control of legionellosis, as well as disinfection of air, surfaces, and instruments. At certain wavelengths, UV light will break the molecular bonds in DNA, thereby destroying the organism. The efficacy of UV irradiation is a function of many different parameters such as intensity, exposure time, lamp placement, and air movement patterns.

Most devices use UV-C radiation, at a wavelength of 200–270 nm (e.g., 254 nm), which lies in the germicidal active portion of the electromagnetic spectrum of 200–320 nm, although a device that uses pulsed xenon has also been developed. Three studies have demonstrated an automated mobile UV-C device is capable of reducing vegetative bacteria inoculated on a carrier by more than 3 to more than 4-$\log_{10}$ in 15–20 min and *C. difficile* by more than 1.7 to 4-$\log_{10}$ in 35–100 min. These studies demonstrated reduced effectiveness when surfaces were not in direct line of sight although more than 2-$\log_{10}$ reductions were demonstrated. To date there are no published studies that demonstrate a reduction in the incidence of healthcare-associated infections using a UV device for terminal room disinfection.

Several systems that mist or vaporize hydrogen peroxide (e.g., aerosolized dry mist hydrogen peroxide, hydrogen peroxide vapor) have been studied for their ability to decontaminate environmental surfaces and objects in hospital rooms. Studies have also demonstrated the ability of hydrogen peroxide systems to almost eliminate MRSA, VRE, *Mycobacterium tuberculosis*, spores, viruses, and multidrug-resistant Gram-negative bacilli. Using a before–after design, Boyce *et al.* [44] have previously shown that use of a hydrogen peroxide system was associated with a significant reduction in the incidence of *C. difficile* infection on five high-incidence wards. Using a similar design, Passaretti *et al.* [45] demonstrated that hydrogen peroxide vapor reduced environmental contamination and the risk of subsequent patients admitted to treated rooms for acquiring any multidrug-resistant organism by 64%.

The advantages and limitations of UV and hydrogen peroxide systems have been reviewed [33■,35]. A major disadvantage of the UV system is that it will not disinfect areas that do not have a direct or indirect line of sight (e.g., bathroom with closed door, drawers). A major disadvantage of hydrogen peroxide systems is that they require substantially more time for decontamination as compared to UV or conventional cleaning, resulting in prolonged bed turnover time.

'Self-disinfecting' surfaces

Self-disinfecting surfaces can be created by impregnating or coating surfaces with heavy metals (e.g., silver or copper), germicides (e.g., triclosan), or miscellaneous methods (e.g., light-activated antimicrobials). It has been known since antiquity that some heavy metals (e.g., silver, copper, gold, mercury, lead) possess antiinfective activity. Although the development of self-disinfecting surfaces impregnated or coated with copper are farthest advanced, the use of other heavy metals such as silver and titanium are also being studied.

Copper ions at increased levels are toxic to most microorganisms due to their ability to generate reactive oxygen species and act as a strong soft metal (e.g., leading to release of iron from Fe-S clusters) [34■■]. The copper generated radicals can damage lipids, nucleic acids, and proteins, leading to cell death. In healthcare, copper compounds (i.e., copper–silver ionization) are used for control of *Legionella* species in water supplies and *Aspergillus* on building materials (i.e., copper-8-quinolinolate). More recently, copper coated or impregnated surfaces have been evaluated in hospitals. Multiple studies of copper containing surfaces or devices have been conducted in the healthcare setting comparing the level and frequency of surface contamination to control surfaces [46–50]. Studies have either used concurrent noncopper containing control surfaces or a cross over design. In general, these studies have demonstrated that copper coated or impregnated surfaces reduced the levels of vegetative bacteria by approximately 1–2-$\log_{10}$ CFU. In an important study using a randomized trial, Salgado *et al.* [51■■] reported that the installation of multiple copper coated surfaces in hospital rooms reduced the rate of healthcare-associated infections by more than 50%. A limitation of this study was the failure to assess the frequency of hand hygiene by healthcare personnel and the effectiveness of routine and terminal room disinfection; an imbalance in each of these activities could have biased the study results.

Other potential methods of creating self-disinfecting surfaces include use of germicides such as triclosan, altered topography (i.e., Sharklet AF pattern), and light-activated antimicrobicides (e.g., cellulose acetate layer containing the photosensitizer with toluidine blue O).

CONCLUSION

Several key nosocomial pathogens (i.e., MRSA, VRE, *Acinetobacte*r spp., norovirus, and *C. difficile*) have been demonstrated to persist in the environment for hours to days (and in some cases months), to frequently contaminate the surface environment and medical equipment in the rooms of colonized or infected patients, to transiently colonize the hands of HCP, to be associated with person-to-person transmission via the hands of 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*, multidrug-resistant *Acinetobacter* spp., or multidrug-resistant *Pseudomonas* has been shown to be a risk factor for colonization or infection with the same pathogen for the next patient admitted to the room.

The implementation of enhanced education, checklists, and methods to measure the effectiveness of room cleaning (e.g., use of fluorescent dye) with immediate feedback to environmental service personnel has been found to improve cleaning and lead to a reduction in healthcare-associated infections. 'No-touch' methods (e.g., UV-C light, hydrogen peroxide vapor) have been developed to improve terminal room disinfection and show promise to reduce healthcare-associated infections. In addition, 'self-disinfecting' surfaces, especially copper coated surfaces, show promise for reducing the bioburden on hospital surfaces and decreasing healthcare-associated infections.

Acknowledgements

None.

Conflicts of interest

D.J.W. report consultation with Clorox, W.A.R. reports consultation with Clorox and A.S.P.

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