Limiting the Spread of Infection in the Health Care Environment

Assessment of Materials Commonly Utilized in Healthcare: Implications for Bacterial Survival and Transmission

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COALITION FOR HEALTH ENVIRONMENTS RESEARCH

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Acknowledgements

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Abstract

Background: Contaminated environmental surfaces, equipment, and healthcare workers' hands have been linked to outbreaks of infection or colonization due to vancomycin-resistant enterococci (VRE) and *Pseudomonas aeruginosa* (PSAE). In addition, the composition of certain fibers in textiles and surface structures of building materials such as upholstery, walls, and floors may actually enhance survival of bacteria, therefore providing infectious reservoirs.

Objectives: To investigate the ability of various surfaces to harbor VRE and PSAE; determine recovery of organisms on environmental surfaces after cleaning; and evaluate possible healthcare provider transmission.

Methods: Fourteen environmental surfaces used for upholstery, flooring, and wallcoverings were inoculated with VRE and PSAE and assessed for microbial recovery at 24 hours, 72 hours, and 7 days. Following inoculation, surfaces were cleaned according to manufacturers' recommendations and samples were obtained. To assess surfaces' potential for transmission, healthy human volunteers touched VRE-inoculated surfaces with the palmar surfaces of their hands and imprinted them onto contact impression plates.

Results: Twenty-four hours following inoculation, all (100%) surfaces had recovery of VRE and 13 (92.9%) of 14 surfaces had persistent growth of PSAE. After cleaning, VRE was recovered from 5 (35.5%) surfaces and PSAE from 4 (28.6%) surfaces. Cleaning methods were the least effective in removing bacteria from painted walls eliminating 3 $\log_{10}$ of VRE and PSAE. After inoculation followed by palmar contact, VRE was recovered from all 14 surfaces touched.

Conclusion: Many bacteria commonly encountered in hospitals are capable of prolonged survival on environmental surfaces and may promote cross-transmission. Product application and complexity of manufacturers' recommendations for surface disinfection should be considered when selecting materials for healthcare environments. The recovery of organisms on environmental surfaces, as well as the hands of volunteers, emphasizes the importance of compliance with hand hygiene prior to patient contact.

Executive Summary

Many factors impact decisions for the selection of optimal materials in healthcare environments. Recommendations can be offered based on the results of clinical research, information obtained from outbreak investigations, and *in vitro* environmental studies. The CDC and the American Institute of Architects (AIA) Academy of Architecture for Health have guidelines that provide basic standards for the industry.[1, 2] Additionally, previous reports have addressed surface design specific to the construction or renovation of facilities.[3]

The Guidelines for Design and Construction of Hospital and Healthcare Facilities offer recommendations for selecting upholstery materials, flooring surfaces, and wall finishes.[2] Fire-resistant qualities and materials that limit the production of noxious gases are advised. Optimal hard flooring surfaces are suggested to support ease of cleaning, water and wear-resistance, and resilience against the corrosive properties of germicides or food acids. As carpeted surfaces are potential reservoirs for microorganisms, it is recommended they not be utilized in high traffic areas, areas prone to spills, or in protective isolation rooms. The guidelines propose walls should be constructed with smooth surfaces free of spaces or crevices that could harbor bacteria, dirt, dust, or moisture. Additionally, wall coverings have the potential to trap moisture-promoting fungal growth on substrate materials.[2]

There are many confounding issues that have previously been discussed in the literature, which may affect transmission of infection. While this limited study cannot provide specific recommendations to suggest that any of the surfaces studied are superior in their ability to prevent nosocomial transmission, perform significantly better with cleaning, or prohibit cross-transmission of infection with VRE, it offers information to confirm previous findings that certain resistant organisms are capable of prolonged survival; selection and proper use of cleaning materials are important for disinfection; and adequate hand hygiene is necessary to avoid cross-transmission of organisms. This investigation raises questions about the feasibility of current manufacturers' recommended cleaning protocols for various surfaces in the healthcare environment.

The following are suggested:

- A thorough assessment of products and surfaces prior to installation.
- Planned application for product use within healthcare settings recognizing patient safety and infection control priorities for the various patient populations served. For example, an acute facility providing care for immunocompromised patients with susceptibility to healthcare-acquired infections due to treatments, medications or preexisting disease would prioritize a protective environment. In contrast, a long-term care or rehabilitation center may focus environmental initiatives on fall and accident prevention.
- Attention to appropriate maintenance of environmental surfaces, adequate cleaning protocols and education for staff.

- Future research efforts should consider:
  - Assessing the efficacy of manufacturers' recommendations for cleaning where EPA-approved disinfectants are not included. CDC guidelines indicate that noncritical medical equipment surfaces should be disinfected using a detergent/disinfectant followed by an application of an EPA-regulated hospital disinfectant.
  - Simulating the repeated cleaning of various surface materials
  - Examining the effects of other pathogenic organisms on surfaces
  - Evaluating the innate antibacterial action of specific surface applications
  - Assessing disinfectant technology addressing residual antimicrobial activity

Clearly, collaboration among various specialties, including infection control personnel, infectious disease specialists, microbiologists, environmental microbiologists, chemical engineers, product designers, interior designers, and architects is important for future research, communication, and dissemination of results.

Background

Acquisition of infections from nosocomial pathogens may cause as many as 90,000 deaths annually.[4] The prolonged survival of organisms, pathogen cross-contamination and transmission from the hands of healthcare workers to environmental surfaces and inanimate objects have the potential to affect patients, particularly those at high risk for infections secondary to compromised immune systems. Appropriate disinfection of healthcare workers' hands, medical equipment, and contaminated healthcare surfaces continues to be important in prevention of the transmission of microorganisms.[2, 5]

The viability of gram-positive and some gram-negative organisms under various environmental conditions has been previously described.[2, 6-8] The ability of enterococci to survive under dry conditions and on various fabrics utilized in the healthcare environment has also been examined. [6-8] Additionally, upholstery materials have been examined for their ability to harbor organisms.[9]

Contaminated environmental surfaces, equipment, and healthcare workers' hands have been linked to outbreaks of vancomycin-resistant enterococci (VRE) and *Pseudomonas aeruginosa* (PSAE) infection.[10-25] Previous studies have focused on the survival of these organisms on polyvinyl chloride, countertops, bedrails, and healthcare equipment.[6, 19, 24] Additionally, the composition of certain fibers in textiles and surface structures of building materials such as walls and floors may enhance survival or growth of bacteria, providing infectious reservoirs.[9, 23]

Modes of Transmission

While it is recognized that the healthcare environment is abundant with potentially dangerous microorganisms, they do not consistently cause healthcare-associated infections. Transmission of an illness-producing organism is a complex process. It is dependent upon a significant quantity of organism, viability or survival of the offending pathogen, an appropriate method of entry into a patient, and enhanced patient susceptibility.

Healthcare providers' hands may become transiently colonized with bacteria after patient or equipment contact. Pathogens may then be transmitted from patient to patient through the failure to perform hand hygiene or by inadequate handwashing technique.[25, 26] Once an organism has reached the patient it may grow and multiply causing either active infection or colonization without apparent illness of its host. Patients are a recognized "reservoir" for the transmission of antibiotic-resistant organisms causing infection.

Cleaning Rationale and Disinfectant Agents

Environmental contamination is affected by the amount of activity and individuals in the area, moisture, organic materials that support microorganism growth, and the type of surface. Environmental cleaning necessary for safety requires a thorough evaluation of the extent of contamination, potential infection risk, and the application for surface use. As the healthcare environment is rapidly re-contaminated after cleaning, there is no expectation for the total absence of microorganisms

following disinfection in general patient care areas. Among patients positive with VRE colonization, in particular those having fecal incontinence or diarrhea, pathogens may be dispersed into the surrounding patient care area and contaminate the environment.[27]

Low-level cleaning strategies are recommended for patient care equipment having physical contact with intact skin as well as environmental surfaces not touching patients.[2] While there is not a defined level of disinfection that is considered optimum for the healthcare environment, the "Guidelines for Environmental Infection Control in Health-Care Facilities" suggest cleaning of surfaces that is adequate to remove dust and soil to prevent gram-positive cocci, gram-negative-bacilli, and fungus. Decisions regarding the proper selection of cleaning agents such as soap and water, detergents, or disinfectants require information about the surface type and degree of contamination.[1] Previous studies have documented the efficacy of routine cleaning methods against both susceptible and resistant organisms.[28] Stronger cleaning methods have not been advocated due to concerns of creating antibiotic resistance.[29]

The purpose of this study was to investigate the ability of various surfaces to harbor bacteria, to determine recovery of organisms on environmental surfaces after cleaning, and to evaluate the potential for healthcare worker transmission.

Materials and Methods

Surfaces

As described in Table 1, we evaluated three types of surface applications, upholstery, flooring, and wall finishes. Of these, a total of fourteen materials were tested. These included woven solution dyed fabric upholstery (Designtex, Los Angeles, CA), woven Crypton® upholstery (Interspec, Allenwood, NJ), Endurion® upholstery (Omnova Solutions, Inc, Fairlawn, OH), vinyl upholstery (Fantagraph, Standard Textile, Cincinnati, OH), tufted solution dyed carpet with woven synthetic backing (Mannington Commercial, Calhoun, GA), tufted solution dyed carpet with vinyl backing (Collins & Aikman Floorcoverings, Dalton, GA), vinyl composition tile (Armstrong, World Industries, Inc., Lancaster, PA), linoleum with heat welded seams (Forbo Linoleum, Inc. Hazleton, PA), vinyl sheet goods flooring with heat welded seams (Armstrong World Industries, Inc., Lancaster, PA), rubber tile flooring with heat welded seams (Freudenberg Building Systems, Inc., Lawrence, MA), Proprietary Latex paint with eggshell finish (Benjamin Moore & Co., Montvale, NJ), Type II vinyl wallcovering with nonwoven backing, (Wolf Gordon Inc., Long Island City, NY), Genon® Type II Microvented/perforated vinyl wallcovering (Hirschfield, Minneapolis, MN), and Xorel® Two wallcovering with paper-backing (Carnegie, Rockville, NY). Samples (25.4 cm x 25.4 cm) were constructed using manufacturers' installation and construction specifications prior to testing. All substrate materials had documented volatile organic compounds (VOC) levels for each product. Wall covering and flooring seams were incorporated into the surfaces' construction. All materials tested were newly installed in good condition without noticeable surface damage. During testing investigators were blinded to manufacturing information and material content, as all surfaces were visually identifiable only.

Microbiologic Methods

Clinical isolates of vancomycin-resistant *Enterococcus faecium* (VRE) and *Pseudomonas aeruginosa* (PSAE) were used for inoculation studies. The most common genotype of each bacterium identified at our medical center was selected for the inoculation experiments. The VRE isolate chosen possessed high-level resistance to vancomycin (minimum inhibitory concentration [MIC] >256mg/mL), gentamicin (MIC>500mg/mL), and ampicillin (MIC>128mg/mL). The *Pseudomonas aeruginosa* isolate was a multidrug-resistant strain.

Inoculation of Environmental Surfaces

We inoculated 10^5 CFU/mL of vancomycin-resistant *Enterococcus faecium* and *Pseudomonas aeruginosa* onto each of the fourteen surfaces studied. This concentration simulates the bacterial content of urine in the setting of bacteriuria.[30] An initial suspension equivalent to 10^8 CFU/mL was prepared and diluted to 10^5 upon transfer to a larger test area. A preparation of a suspension of organisms, a small quantity of a few drops in sterile saline was inoculated onto the different fabrics and solid surfaces. Application was accomplished by dripping the prepared inoculate onto test surfaces. This was done to avoid a broth (nutrient) effect, and simulate soiling of surfaces by contami-

nated body fluids. After inoculating the surfaces, cultures were obtained at 5 minutes, 24 hours, 72 hours, and 1 week post-inoculation.

The cultures for VRE and PSAE were performed using culture impression plates (Remel, Lenexa, KS) containing tryptic soy agar plus 5% sheep blood. All plates were incubated at 35°C in ambient air and evaluated at 48 hours to determine the presence of VRE or PSAE. Bacterial growth on culture impression plates was quantified and organisms identified to the species level to confirm that the bacteria that were inoculated onto the surfaces were the bacteria recovered. No anaerobic cultures were performed.

Each surface was initially cultured prior to inoculation to serve as a negative control. All experiments compared the percent recovery of the initial inoculum (obtained 5 minutes following inoculation) to the amount of bacteria inoculated. Additionally, the results of the different surfaces within the same category were compared for each of the series of experiments.

Potential for surface decontamination

To test for surface decontamination, an impression plate culture was obtained 5 minutes following inoculation of each of the surfaces. Surfaces were then cleaned using materials and concentrations recommended by the manufacturers. Following cleaning, an impression plate culture was obtained for each surface.

Ability to transmit organisms

In the final phase of the study, hands of three participants were inspected to insure that they were free of cuts, scratches, or any other surface damage. Participants were all healthy and not providing any direct patient care during the study period. Nails were worn not more than 1/4 inch in length, without polish, nail extenders, or wraps. Participants removed all jewelry for the experiment. Hand hygiene was performed using 3 mL of a non-medicated liquid soap (Ivory, Procter and Gamble, Toronto, Ontario) and warm water. Unbleached sheets of paper towels were used by each of the participants to thoroughly dry their hands. After completing the handwashing procedure, each inoculated surface was touched with the palmar surface of the clean hand by each participant for five seconds, five minutes after inoculation of the surface. Following contact with each of the contaminated surfaces, hands were imprinted onto culture impression plates. Colony counts were performed at the following intervals: pre-inoculation, 5 minutes after inoculation, and following palmar contact with contaminated surfaces.

Data Analysis

Data were collected on a standardized data collection form and entered into a database using Microsoft Excel® version 97 (Microsoft Corporation, Redmond, WA).

Study results, bacterial colony forming units (CFUs) were converted to a [log.sub.10] scale. This scale allows data to be expressed in a power of 10. To illustrate computations, 10^2 can be

exponentially described as10 multiplied by 10 or 100. The log value or [log.sub.10] of 100 is 2. Results were reported as logs.

A reduction factor (RF) was used to determine a decrease in bacteria when applicable. To perform this measure, the baseline bacteria in logs, the study's baseline of 5 $\log_{10}$, was subtracted from the calculated logs after various times, and after cleaning. Of note, a smaller number (logs) would indicate less of a reduction of bacteria, a larger number (logs) would mean a greater reduction of bacteria. A decrease of 5 $\log_{10}$ CFU/mL has previously been described as effective against bacteria.[31]

Results

Table 1 describes products, applications, specifications, and substrate composition. Tables 2-7 and Figures 1-4 summarize cleaning methods and results of investigations. Overall, a total of 266 samples were obtained for the three experiments. Of these, 140 (52.6%) samples evaluated the ability for surfaces to harbor organisms, 84 (31.6%) samples assessed the ability for surfaces to be cleaned, and 42 (15.8%) samples evaluated the potential for transmission. Prior to inoculation, there was no measurable bacterial growth noted on any of the surfaces tested for any of the three experiments.

Upholstery

ABILITY TO HARBOR ORGANISMS

(Tables 2, 3 and Figures 1, 2)

- Within 24 hours, upholstery surfaces had reductions of VRE. All of the upholstery surfaces however, continued to have some level of persistent VRE contamination after 1 week.
- Endurion® upholstery performed similarly to woven solution dyed fabric upholstery and woven Crypton® upholstery surfaces after 24 hours.
- Overall, vinyl upholstery performed the best of all surfaces inoculated with VRE, with a 3.6 $\log_{10}$ reduction after 24 hours and 4.4 $\log_{10}$ reduction after one week.
- All of the upholstery surfaces had >4 $\log_{10}$ reduction in PSAE after 24 hours. This was observed to continue after 1 week.

DISINFECTION

(Tables 4, 5, 6 and Figure 3)

- All of the upholstery surfaces had >4 $\log_{10}$ reduction in VRE and PSAE after cleaning.

TRANSMISSION

(Table 7 and Figure 4)

- All upholstery surfaces had the ability to transmit VRE to volunteers' hands following surface contact.

Flooring

ABILITY TO HARBOR ORGANISMS

(Tables 2, 3 and Figures 1, 2)

- Tufted solution dyed carpet with vinyl backing and tufted solution dyed carpet with woven synthetic backing had ≥ 3 $\log_{10}$ reductions in VRE after 24 hours.
- Rubber tile, linoleum, vinyl sheet goods, and vinyl composition tile had no reduction in VRE at 24 hours.
- Of the six flooring surfaces, only vinyl composition tile had no reduction in VRE after 7 days.
- Tufted solution dyed carpet with woven synthetic backing had an almost 4 $\log_{10}$ reduction in VRE after 1 week.
- All flooring surfaces had ≥ 4 $\log_{10}$ reduction in PSAE after 24 hours.
- At 1 week, tufted solution dyed carpet with vinyl backing, vinyl composition tile, and vinyl sheet goods with heat welded seams had 5 $\log_{10}$ reduction in PSAE.

DISINFECTION

(Tables 4, 5, 6 and Figure 3)

- All of the flooring surfaces had ≥ 4 $\log_{10}$ reduction in VRE and PSAE after cleaning

TRANSMISSION OF ORGANISMS

(Table 7, Figure 4)

- Tufted solution dyed carpet with woven synthetic backing, tufted solution dyed carpet with vinyl backing, and linoleum with heat welded seams performed better with the least amounts of recoverable VRE with simulated hand transmission testing.

Wall Finishes

ABILITY TO HARBOR ORGANISMS

(Tables 2, 3 and Figures 1, 2)

- No wall surfaces had reduction in the amount of VRE after 24 or 72 hours.
- Latex paint with eggshell finish and Type II vinyl wallcovering with nonwoven backing had close to 3 $\log_{10}$ reduction of VRE after 7 days.
- Type II microvented/perforated vinyl wallcovering and Xorel® wallcovering with paper backing had no reduction of VRE after 7 days.
- Type II vinyl wallcovering with nonwoven backing, Type II microvented/perforated vinyl wallcovering and Xorel® wall covering with paper backing had >4 $\log_{10}$ reduction of PSAE after 24 hours. At 1 week, these products had 5 $\log_{10}$ reduction.

DISINFECTION

(Tables 4, 5, 6 and Figure 3)

- Three of the four wall surfaces had 5 $\log_{10}$ reduction in VRE and PSAE after cleaning. Only the latex paint with eggshell finish did not perform as well, having approximately 3 $\log_{10}$ reduction in both VRE and PSAE after cleaning.

TRANSMISSION OF ORGANISMS

(Table 7, Figure 4)

- Wall surfaces had almost 2 $\log_{10}$ recovery of VRE after simulated hand transmission.

Summary of Results

PRODUCT APPLICATION PERFORMANCE RELATED TO ORGANISM INOCULATION

- Surfaces harbored less PSAE with 4 $\log_{10}$ reduction after 24 hours without cleaning.
- VRE is an environmentally hardy organism and persisted longer when applied to test surfaces.

DIFFERENCES BETWEEN PRODUCT APPLICATIONS

- Product performance was similar for all investigations.
- Upholstery harbored less VRE than floors and walls however further tests are warranted.
- Product applications had very similar cleaning capabilities despite various methods and manufacturers' recommendations.
- For simulated healthcare provider transmission, wall surfaces had higher amounts of VRE (range 1.3-1.9 $\log_{10}$, mean 1.9 $\log_{10}$) recovered for all product applications tested however, all surfaces evaluated resulted in the transmission of VRE to hands. It is important to note that any amount of transmission has the potential to spread the organism to other sources i.e. patients, equipment, or the environment. Further study is suggested.

DIFFERENCES BETWEEN PRODUCTS

- Vinyl upholstery harbored less VRE after 24 hours.
- Vinyl composition tile flooring, Type II microvented/perforated vinyl wallcovering, and Xorel® wallcovering with paper backing harbored more VRE after 7 days than other products.
- Latex paint with eggshell finish did not achieve optimal reduction of VRE and PSAE after cleaning.

Discussion

Our study evaluated various surface materials used in healthcare environments, as well as, the likelihood these surfaces could contaminate the hands of healthcare workers. We investigated samples' ability to harbor microorganisms and to be adequately disinfected based on manufacturers' recommended cleaning protocols. Results are consistent throughout the three experiments. We validated that VRE are environmentally hardy organisms capable of prolonged survival on surfaces commonly encountered in the healthcare setting.[5, 6, 24] Additionally, our study suggests there may be a difference in recovery of vancomycin-resistant *Enterococcus faecium* and *Pseudomonas aeruginosa* over time on these various surfaces. *Pseudomonas aeruginosa* had significantly less bacterial colony counts at 24 hours with a reduction relatively consistent over 72 hours. The significance of the difference, however, is unknown. A clinical trial to further evaluate this using human subjects would not be feasible for ethical reasons.

Of note, there were inherent differences between microorganisms used in the experiments. It has been demonstrated that enterococci can thrive in drier environments while *P. aeruginosa* proliferate in moist surroundings and have the ability to develop resistance to disinfectants. These characteristics, as well as obvious designs of the various smooth, porous, or nonporous surfaces may explain variations among the results obtained. We showed that cleaning could successfully eradicate organisms from many surfaces. Our results, however, suggest the selection of disinfectants is important for walls and floors. Quaternary ammonium compounds have previously been proven effective against VRE for low-level disinfection of walls and floors.[31, 32] Because repeated contamination of the patient environment occurs, appropriate hand hygiene is important to prevent cross-transmission. This is particularly true for VRE which has previously been shown to survive well on hands.[5, 9]

To determine bacterial growth on test surfaces, we reviewed various methods for efficacy, accuracy, and ease of use. These included the swab technique, bioluminescence evaluation and direct inoculation using an imprint technique methodology. The premoistened swab technique has the ability to directly isolate different microbial populations, however recovery may not be reproducible or quantitative. The surface rinse approach requires that an entire surface be evaluated. Membrane filtration is also essential to effectively enumerate growth. This methodology was impractical given the size and weight of surfaces tested. The bioluminescence method is not sensitive for low microbial levels and is suitable for microbial counts of 10^4 to 10^8. Therefore, direct inoculation by surface to agar contact using the imprint technique was chosen for its ease and limited required materials. This involved touching semi-solid media plates to test surfaces. Previous studies have shown this methodology to be effective for recovering VRE, *C. difficile,* and methicillin-resistant *Staphylococcus aureus* from the environment.[33-37] While optimal for smooth surfaces and low bacterial counts, Skoutelis et al. effectively utilized this approach to detect *C. difficile* in carpeted and noncarpeted patient care settings.[37]

Of the surface applications tested, flooring and wall finishes were found to have an increased potential for transmission; however, it is difficult to discern whether study results are related to the amount of palmar contact with the surface, testing methodology, or perhaps test surfaces' fiber or

construction materials. Many of the surfaces contain substances that may affect or inhibit bacterial growth. These include antimicrobial agents, permanent static control, or stain resistance. Of the specific products tested, the woven solution dyed fabric upholstery had a Teflon finish; the tufted solution dyed carpet with synthetic backing had antimicrobial-impregnated fibers and permanent static guard; the tufted solution dyed carpet with vinyl backing had permanent static control and a soil stain protection finish. Products having antimicrobial claims require General Services Administration (GSA) testing and EPA registration. The length of antibacterial protection, impact of installation or substrate materials, recommended cleaning methods, and affects of routine use on antimicrobial efficacy must also be considered.

The painted surface tested has a proprietary composition containing pigments of titanium dioxide, and 37% volume solids. Agents that inhibit bacterial and fungal growth may be present in paint composition or be supplemented prior to use. Titanium dioxide is a photocatalytic, activated by light and is a disinfective agent. In a previous study by Cooley et al, standard interior latex paint was found to have antibacterial effects against *E. coli, P. aeruginosa,* and *E. faecalis* after 24 to 48 hours.[38] Pigment volume concentrations affect a dried paint's ability to disperse moisture over a surface limiting mildew and fungus. Our study demonstrated a reduction in VRE of 2.7 $\log_{10}$ after 7 days for VRE and a 5 log reduction for *P. aeruginosa* after 72 hours for the painted surface.

The tested upholstery and carpet surfaces may have an advantage with added surface treatments for stain protection or water resistance. Some textiles possess antimicrobial properties occurring through treatments added to the surface finish to kill microorganisms on contact. It is important to note that antimicrobial action may diminish over time, with use and cleaning for certain surface applications. Additionally, polymer grafting is utilized to kill pathogens on contact by interacting with the bacteria cell walls.[39] Interestingly, recent studies have found that *P. aeruginosa* may adhere to fiber surfaces, specifically acrylic, polyester, and wool. This could not be confirmed on cloth surfaces.[40]

The potential for transmission from contaminated hard-surface floors and walls is small unless there is existing moisture or residual stickiness present.[41] The risk may be greater for carpeting due to the persistence of gram-negative bacteria and fungi even after disinfection. Unprotected vacuuming of these surfaces has the potential for propelling microorganisms into the air. While carpeting is not preferred in clinical areas having immunocompromised or immunosuppressed patients, there are no current recommendations by the CDC against utilizing it in other patient care areas.[2] A caveat to carpets' use in patient care areas is an OSHA standard that "once contaminated by blood or infectious materials, it cannot be fully decontaminated." The Guidelines for Environmental Infection Control in Health Care Facilities recommends the use of carpet tiles that can be easily replaced if contaminated by blood or other spills.[2] The potential for microbial contamination between carpet tiles is not discussed.

We cleaned samples according to the manufacturers' recommendations; however these instructions were often vague. Guidelines may have been more appropriate to cleaning and maintenance outside of the healthcare environment. They lacked accurate details on optimal disinfection, and appeared to focus on maintaining surface integrity not disinfection. Design guidelines for healthcare facilities are established based on infection control principles. Therefore, recommendations for surface

and finish selections reflect cost, ease of cleaning, and ability to withstand repetitive wear and frequent germicidal decontamination, as well as, concern for materials' moisture resistance.[1, 33, 41] The CDC recommends healthcare facilities utilize EPA-registered disinfectants according to manufacturer's instructions for cleaning and disinfection of noncritical equipment or surfaces (Category IC).[2] Further considerations include the type of surface, the degree and type of contamination (Category II), and possibility for direct patient contact.[2] The number of various cleaning materials suggested by the manufacturers for the samples studied would be very costly for healthcare institutions. Additionally, education for the care and maintenance with different products would be cumbersome for environmental services.

Our study had several limitations. First, our initial inoculum, while consistent with infected body fluids, may have been too large to accurately examine bacterial kinetics. While previous studies have utilized this method, preparing a smaller inoculum may have limited confluent bacterial growth. However, survival in previous studies had been affected by a higher inoculum. Neely and Maley determined the viability of enterococci on fabrics was longer than on other surfaces using an aliquot methodology with inoculum of 10^5 CFU/mL.[8] Second, we studied a variety of different surface finishes. Variations in basic product design, proprietary construction, cleaning products, and disinfection methodologies make results less generalizable. Adapting our methodology based on the type of surface under investigation might have provided more controlled results. For example, the inoculum quickly sank below carpet and upholstery surfaces or in the grooves of the wall covering finishes but pooled on flat smooth surfaces making retrieval and contact for hand transmission variable. Previous studies evaluating microbial contamination on carpeting have indicated that plug-sampling methods may provide more reproducible results.[42] Although not measured specifically, surfaces varied in the amount of moisture that was present after inoculation, cleaning, or transmission testing. Researchers have found that environmental conditions have influenced the survival of various organisms. For example, gram-negative bacilli have survived longer on drier surfaces. Finally, it is important to note only two organisms of clinical importance to our medical center were tested on the environmental surfaces provided. Products may have had different results if other organisms were utilized in testing. Published reports have identified prolonged survival of various organisms (enterococci, staphylococci, and *Acinetobacter calcoaceticus*) on plastic, formica, and fabrics.[6, 8, 43, 44]

While interesting, our results are preliminary and further investigation is necessary to confirm our findings. Next steps might compare specific hospital protocols to manufacturers' recommendations to evaluate effective disinfection and determine if manufacturers' cleaning protocols require revision. Additional studies simulating multiple episodes of cleaning with these solutions would be useful to measure the ability of various surfaces to withstand disinfection.

In summary, we demonstrated that prolonged bacterial contamination of environmental surfaces encountered in the healthcare setting is common especially with environmentally hardy organisms such as VRE. In addition, adherence to the cleaning methodologies described by the manufacturer may not be significantly adequate to completely disinfect surfaces contaminated with bacteria. Finally, once contaminated, environmental surfaces can serve as a reservoir to transmit bacteria to the hands of healthcare workers. This emphasizes the importance of complying with standard hand hygiene recommendations prior to and following patient contact.

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Glossary

Aliquot methodology. One part of a total amount of liquid that is divided into equal parts or samples for testing.

Antimicrobial. Acts to kill bacteria and fungi. Applications having long-acting protection are described by the Chemical Fabrics and Film Association as "dry film" protection. Dry film preservatives are utilized for vinyl and other polymer films.

Cleaning. Describes the elimination or removal of pathogens through physical or chemical means. Cleaning efficacy may occur at the cellular level through enzyme, structural protein, nucleic acid, cell wall alterations, or outside an organism by making a surface slippery and allowing a contaminant to be easily dispersed and rinsed away. The prescribed level of cleaning necessary for safety incorporates the risk of infection with required use.

Colony forming unit (CFU). An enumeration of the number of bacteria on a solid test medium such as an agar plate. Each cell or clump of cells represents a microorganism on a surface area that was sampled.

Confluent growth (CG). The growth noted on test medium where the individual bacterial colonies are not discrete and cannot be counted.

Disinfection. A cleaning method to remove potentially harmful organisms that are capable of causing an illness or infection. Various factors have been found to limit disinfectant agents' effectiveness. These include the type and number of microorganisms on a contaminated surface, the concentration, temperature, pH of the cleaning agent, duration of the disinfectant exposure to the surface prior to rinsing, and the presence of organic materials such as blood, feces, emesis, or pus. Gram-negative bacteria are generally more resistant to disinfectant agents. Agents are chosen for their optimal effects against microorganisms.

Impression plate. A solid medium used to artificially support bacterial growth. When performing environmental cultures, commercial media is carefully chosen with chemical neutralizers that protect against any residual disinfectant activity while facilitating the recovery of microorganisms.

Inoculation. Introduction of microorganisms onto a medium in order to test for growth.

Microorganism. An organism of microscopic size.

Nosocomial infection. Hospital-acquired or health care-associated infection.

Pathogen. A causative agent for illness, infection, or a disease state.

Quaternary ammonium compound. A cationic detergent agent that kills bacteria. Most effective at an alkaline level with a pH of 7-10. Easily neutralized by other detergents. More effective against Gram-positive microorganisms. Temperature dependent with better activity at 37° C. Hard water interferes with cleaning action.

Rating categories from CDC and Healthcare Infection Control Practices Advisory Committee (HICPAC) recommendations. "Category IA. Strongly recommended for implementation and strongly supported by well-designed experimental, clinical, or epidemiologic studies. Category IB. Strongly recommended for implementation and supported by certain experimental, clinical, or epidemiologic studies. and a strong theoretic rationale. Category IC. Required by state or federal regulation, or representing an established association standard. Recommendations from regulations adopted at state levels are also noted. Recommendations from AIA guidelines cite the appropriate sections of the standards. Category II. Suggested for implementation and supported by suggestive clinical or epidemiologic studies, or a theoretic rationale.Unresolved. No recommendation is offered. No consensus or insufficient evidence exists regarding efficacy."

Reservoir. A host that is infected or colonized but has no outward signs of infection. Colonized patients are frequently reservoirs for resistant organisms such as vancomycin-resistant *enterococcus or* VRE.

Sanitize. A method of cleaning that provides a reduction in microorganisms to a "safe level." It is recognized in healthcare environments that there is re-contamination of the patient environment rapidly after cleaning. (See transmission.)

Transmission. Methods by which microorganisms can be spread from one patient to another or contaminate the environment. Contaminated health care provider hands, clothing, medical equipment or the patient environment may contribute to transmission. Normal shedding of skin cells occurs causing frequent contamination of various organisms within the healthcare environment. Hand contamination with transmission however requires the survival of an organism on an inanimate surface, the absence or inadequacy of hand hygiene by a healthcare provider, followed by direct hand contact with a patient or his environment.

Vector. An organism or "carrier" that transmits a microorganism from one source to another.

Viability. The capacity for survival or growth.

Volatile Organic Compounds: Substances that may become air-borne or volatile at room temperature. Paints, glues, adhesives and certain cleaners may emit these.

Acronyms

CDC: United States Centers for Disease Control and Protection

CG: Confluent growth

CFU: Colony forming unit

EPA: United States Environmental Protection Agency

HICPAC: Healthcare Infection Control Practices Advisory Committee

MIC: Minimum inhibitory concentration

mL: Milliliter

PSAE: *Pseudomonas aeruginosa*

VOC: Volatile Organic Compounds

VRE: Vancomycin-resistant *enterococcus*

Table 1. Surface descriptions

Product	Product Application	Specification/Description	Substrate, Other
Woven solution dyed fabric	Upholstery	Designtex, 100% Zeftron, 200 Nylon fiber, acrylic backing, Teflon (DuPont) finish	Dense Polyurethane Foam, anti-micro bacterial
Woven Crypton®	Upholstery	Interspec, 52% Polyester, 48% Acrylic/ Crypton fiber	Dense Polyurethane Foam, anti-micro bacterial
Endurion®	Upholstery	Omnova, 100% polyester	Dense Polyurethane Foam, anti-micro bacterial
Vinyl upholstery	Upholstery	Fantagraph, 100% vinyl, 100% polyester backing	Polyurethane Foam, anti-micro bacterial
Tufted solution dyed carpet with woven synthetic backing	Flooring	Mannington; 100% DuPont Fiber, nylon, antimicrobial agent, permanent staticguard, 100% Woven Synthetic backing	Mounted on concrete, H_2O base adhesive, seam sealer
Tufted solution dyed carpet with vinyl backing	Flooring	Collins & Aikman, permanent static guard, soil/stain protection, recycled vinyl backing	Mounted on concrete, floor primer, seam weld
Vinyl composition tile	Flooring	Armstrong, polyvinyl chloride resin, plasticizers, stabilizers, fillers, and pigments	Mounted on concrete, H_2O based rubber resin adhesive, moisture and alkali-resistant
Linoleum with heat welded seams	Flooring	Forbo Industries, jute backing, bacteria resistant	Mounted on concrete, H_2O based adhesive, moisture, mildew resistant antimicrobial, non-flammable, EVA polymer weld
Vinyl sheet goods with heat welded seams	Flooring	Armstrong, heat welded seams	Mounted on concrete, H_2O based emulsion adhesive, vinyl weld rod
Rubber tile flooring with heat welded seams	Flooring	Freudenberg Building Systems, Inc. slightly textured surface, heat welded seams	Mounted on concrete, heat welded seams, H_2O based adhesive
Latex paint with eggshell finish	Wall Finish	Benjamin Moore, Paint, interior finish, proprietary, pigment type Titanium Dioxide, 37% volume solids	Dry wall, joint compound vinyl-type, acrylic latex primer
Type II vinyl wall covering with nonwoven backing	Wall Finish	Wolf Gordon York Contract Studio Source, 20 oz. Yorkguard® Protective coating (stain resistance)	Gypsum board, vinyl-type spackle, joint tape, H_20 based acrylic latex primer
Type II microvented/ perforated vinyl wall covering	Wall Finish	Genon® 20 oz.	Gypsum board, vinyl-type spackle, joint tape, H_20 based acrylic latex primer
Xorel® wall covering with paper backing	Wall Finish	Xorel® Two	Gypsum board, vinyl-type spackle, joint tape, H_20 based acrylic latex primer

Note: For all materials, products were installed per manufacturers' recommendations prior to testing. All of substrate materials were documented VOC levels for each product. All products represent a new installation of materials.

Table 2. Ability of surfaces to harbor vancomycin-resistant enterococci (VRE) organisms after 24 hours, 72 hours, and 7 days without cleaning, measured by log reduction.

Surface	Log_{10} reduction 24 hours	Log_{10} reduction 72 hours	Log_{10} reduction 7 days	Comments
Upholstery				
Vinyl upholstery	3.6	4.0	4.4	Vinyl upholstery is the best performer for reductions of bacterial growth of VRE after 1 week.
Woven Crypton®	2.5	2.9	3.2	
Woven solution dyed fabric	2.5	2.8	3.1	
Endurion®	2.4	NT*	NT*	
Flooring				
Tufted solution dyed carpet with woven synthetic backing	3.2	3.8	3.9	Both carpet surfaces have the best reduction of bacterial growth for VRE after 24 hours. Requires validation with another sampling methodology.
Tufted solution dyed carpet with vinyl backing	3.1	3.5	3.7	
Rubber tile flooring with heat welded seams	0	3.1	3.2	Rubber, linoleum, and vinyl sheet goods have no reduction in bacterial growth of VRE at 24 hours. Vinyl composition tile continues to have contamination after 1 week.
Linoleum with heat welded seams	0	2.9	3.0	
Vinyl sheet goods with heat welded seams	0	2.8	2.9	
Vinyl composition tile	0	0	0	
Wall Finish				
Latex paint with eggshell finish	0	0	2.7	None of the wall finishes have reductions in growth after 72 hours.
Type II vinyl wall covering with nonwoven backing	0	0	2.5	
Type II microvented/perforated, vinyl wallcovering	0	0	0	Type II microvented/ perforated, vinyl wall covering and Xorel®
Xorel® wallcovering with paper backing	0	0	0	Wallcoverings with paper backing have no reduction in the growth of VRE after 1 week.

Common logarithms to base 10 were used. For example, $10^0=1$, $10^1=10$, $10^2=100$, $10^3=1000$. A log reduction of 5 was considered optimal. This was the initial amount of organism that was inoculated onto each of the surfaces.

*NT Not tested.

Table 3. Ability of surfaces to harbor *Pseudomonas aeruginosa* (PSAE) organisms after 24 hours, 72 hours, and 7 days without cleaning, measured by reduction in logs.

Surface	Log_{10} reduction 24 hours	Log_{10} reduction 72 hours	Log_{10} reduction 7 days	Comments
Upholstery				
Woven Crypton®	5	5	5	All upholstery surfaces have reduction in PSAE at 24 hours and continue after 1 week.
Woven solution dyed fabric	4.7	5	5	
Vinyl upholstery	4.4	5	5	
Endurion®	4	4.2	4.7*	
Flooring				
Tufted solution dyed carpet with synthetic backing	4.7	4.7	5	All flooring surfaces have reductions in PSAE at 24 hours and continue after 1 week.
Vinyl composition tile	4.7	5	5	
Tufted solution dyed carpet with vinyl backing	4.5	5	5	
Rubber tile flooring with heat welded seams	4.4	5	4.7	
Vinyl sheet goods with heat welded seams	4.2	5	5	
Linoleum with heat welded seams	4	4.4	4.5	
Wall Finish				
Type II microvented/perforated vinyl wallcovering	4.7	5	5	All wall finishes have reduction in PSAE at 24 hours and continue after 1week
Latex paint with eggshell finish	4.3	5	5	
Xorel® wallcovering with paper backing	4.2	4.7	4.7	
Type II vinyl wall covering with nonwoven backing	4.1	5	5	

Common logarithms to base 10 were used. For example, $10^0=1$, $10^1=10$, $10^2=100$, $10^3=1000$. A log reduction of 5 was considered optimal. This was the initial amount of organism that was inoculated onto each of the surfaces.

Table 4. Recommended cleaning methods

Product	Cleaning Method
Woven solution dyed fabric	Mild detergent foam shampoo,* Woolite (Platex, Dover, DE) 10 min, material was not saturated, hot water extraction
Woven Crypton®	Crypton® upholstery cleaner pre-treatment (West Bloomfield, MI), 1:1 solution enzyme powder detergent, Tide®, (Procter & Gamble, Cincinnati, OH), and H_2O
Endurion®	70% Isopropyl alcohol, 5 min, hot water extraction, repeated in 24 hours
Vinyl upholstery	Energetic washing, mild soap†, no agent specified. Solution enzyme powder detergent, Tide®, (Procter & Gamble, Cincinnati, OH), and H_2O
Tufted solution dyed carpet with woven synthetic backing	Quaternary solution, (Virex II 256, Johnson Wax Professional, Sturtevant, WI), hot water extraction
Tufted solution dyed carpet with vinyl backing	Full Strength Sylon-5 (Collins & Aikman Floor coverings, Dalton GA), agitation
Vinyl composition tile	Armstrong S-485 Floor Cleaner, (Armstrong World Industries, Lancaster, PA), 3 oz/gal
Linoleum with heat welded seams	Neutral pH detergent, Quaternary solution, (Virex II 256, Johnson Wax Professional, Sturtevant, WI)
Vinyl sheet goods with heat welded seams	Armstrong S-485® Floor Cleaner, (Armstrong World Industries, Lancaster, PA), 3 oz/gal
Rubber tile flooring with heat welded seams	Neutral pH cleaner,‡ Quaternary solution, (Virex II 256, Johnson Wax Professional, Sturtevant, WI)
Latex paint with eggshell finish	Mild detergent and H2O solution with a soft cellulose brush, 1:1 solution enzyme powder detergent, Tide®, (Procter & Gamble, Cincinnati, OH), and H_2O
Type II vinyl wall covering with nonwoven backing	Strong soap solution** Quaternary solution, (Virex II 256, Johnson Wax Professional, Sturtevant, WI)
Type II microvented/perforated vinyl wallcovering	70% Isopropyl alcohol, Formula 409®, (Clorox CO, Pleasanton, CA.)
Xorel® wallcovering with paper backing	Carbona® upholstery cleaner, Delta Carbona, (Fairfield NJ), followed by vinegar and rinsed with H_2O

* Water-based cleaning agent, upholstery shampoo (a pre-conditioning pre-spray and liquid emulsifying agent could not be used)

† Only manufacturer recommendation: "mild soap solution"

‡ neutral pH floor cleaner used

** Only manufacturer recommendation for feces, blood, or urine: "strong soap solution"

Table 5. Reduction in vancomycin-resistant enterococci (VRE) after cleaning using manufacturers' recommendations measured in log reduction.

Surface	Log_{10} Reduction	Comments
Upholstery		
Woven solution dyed fabric	5	All upholstery has reductions in VRE.
Vinyl upholstery	5	
Endurion®	5	
Woven Crypton®	4.5	
Flooring		
Tufted solution dyed carpet with synthetic backing	5	All flooring has reductions in VRE..
Tufted solution dyed carpet with vinyl backing	5	
Rubber tile with heat welded seams	5	
Vinyl composition tile	4.7	
Linoleum with heat welded seams	4.7	
Vinyl sheet goods with heat welded seams	4.4	
Wall Finish		
Type II vinyl wallcovering with nonwoven backing,	5	The Latex paint surface does not have the same reductions in VRE as the other wall finishes. Cleaning method, mild soap used may have affected results.
Type II microvented /perforated vinyl wallcovering	5	
Xorel® wallcovering with paper backing	5	
Latex paint with eggshell finish	2.9	

Common logarithms to base 10 were used. For example, $10^0 = 1$, $10^1 = 10$, $10^2 = 100$, $10^3 = 1000$. A log reduction of 5 was considered optimal. This was the initial amount of organism that was inoculated onto each of the surfaces.

Table 6. Reduction in *Pseudomonas aeruginosa* (PSAE) after cleaning using manufacturers' recommendations measured in log reduction.

Surface	Log_{10} Reduction	Comments
Upholstery		
Woven solution dyed fabric	5	All upholstery surfaces have reductions in PSAE.
Endurion®	5	
Vinyl upholstery	5	
Woven Crypton®	4.7	
Flooring		
Tufted solution dyed carpet with woven synthetic backing	5	All flooring has reductions in PSAE.
Tufted solution dyed carpet with vinyl backing	5	
Vinyl composition tile	5	
Linoleum with heat welded seams	5	
Rubber tile flooring with heat welded seams	4.7	
Vinyl sheet goods with heat welded seams	4.6	
Wall Finish		
Type II vinyl wallcovering with nonwoven backing	5	The Latex paint surface does not have the same reductions in PSAE as the other wall finishes. Results may be affected by the cleaning method used.
Type II microvented/perforated vinyl wallcovering	5	
Xorel® wallcovering with paper backing	5	
Latex paint with eggshell finish	3.1	

Common logarithms to base 10 were used. For example, $10^0=1$, $10^1=10$, $10^2=100$, $10^3=1000$. A log reduction of 5 was considered optimal. This was the initial amount of organism that was inoculated onto each of the surfaces.

Table 7. Simulated transmission of vancomycin-resistant enterococci (VRE) measured in log recovery of VRE from inoculated test surfaces

Surface	Log_{10} Reduction	Comments
Upholstery		
Woven solution dyed fabric	1.2	Upholstery surfaces perform similarly.
Vinyl upholstery	1.5	
Endurion®	1.6	
Crypton®	1.8	
Flooring		
Tufted solution dyed carpet with woven synthetic backing	0.8	Tufted solution dyed carpet with woven synthetic backing performs best. Vinyl sheet goods with heat welded seams is a poorer performer. May be related to testing methodology, however further testing specific for finishes should be considered.
Tufted solution dyed carpet with vinyl backing	0.9	
Linoleum with heat welded seams	0.9	
Vinyl composition tile	1.3	
Rubber tile flooring with heat welded seams	1.9	
Vinyl sheet goods with heat welded seams	2.1	
Wall Finish		
Xorel® wallcovering with paper backing	1.8	Wall finishes perform in a similar manner.
Latex paint with eggshell finish	1.9	
Type II vinyl wallcovering with nonwoven backing	1.9	
Type II microvented/perforated vinyl wallcovering	1.9	

Note: Smaller numbers of log recovery for VRE are desirable for transmission testing.

Figure 1. Ability of Surfaces to Harbor VRE

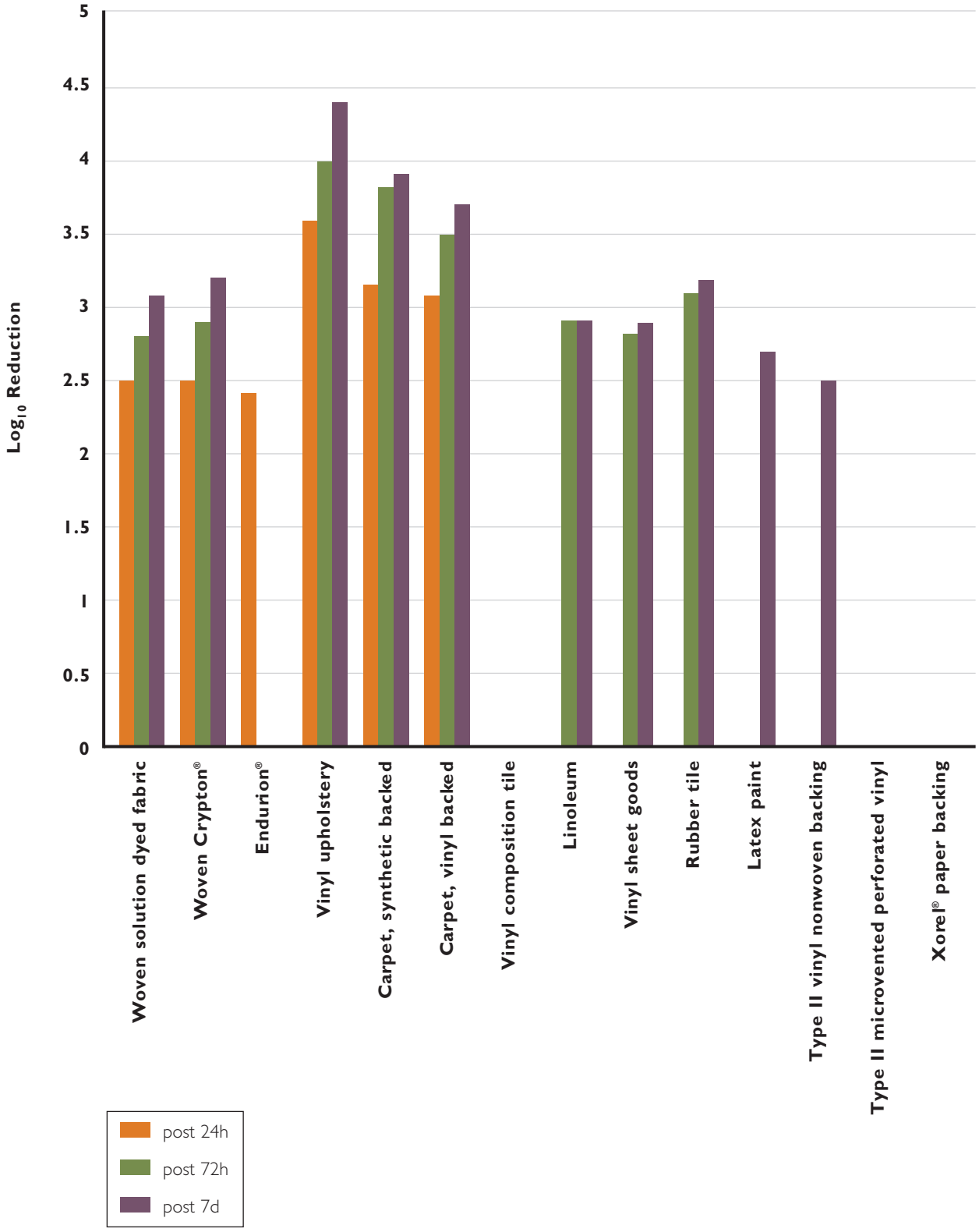


Figure 2. Ability of Surfaces to Harbor PSAE

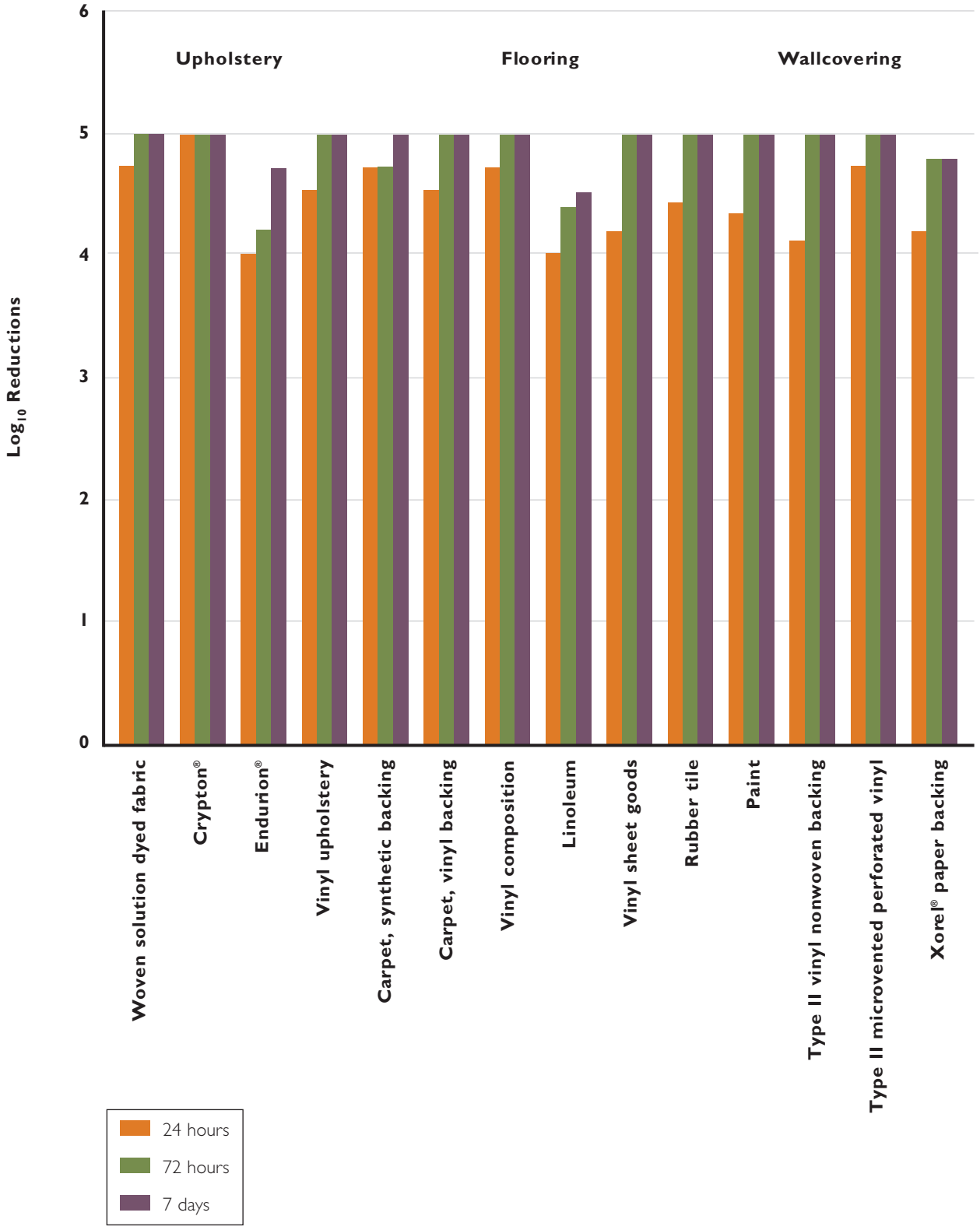


Figure 3. Reduction in VRE and PSAE After Cleaning

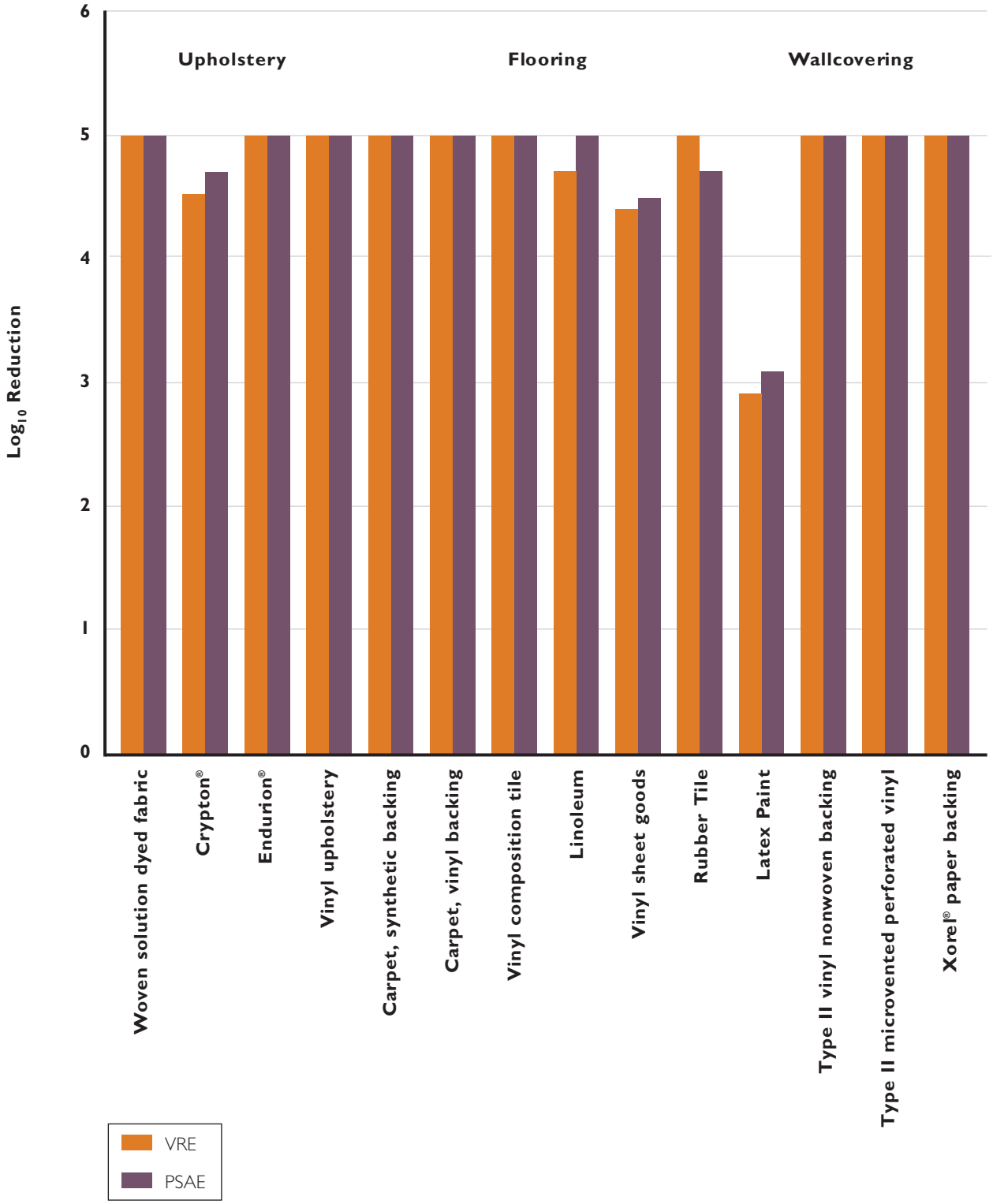
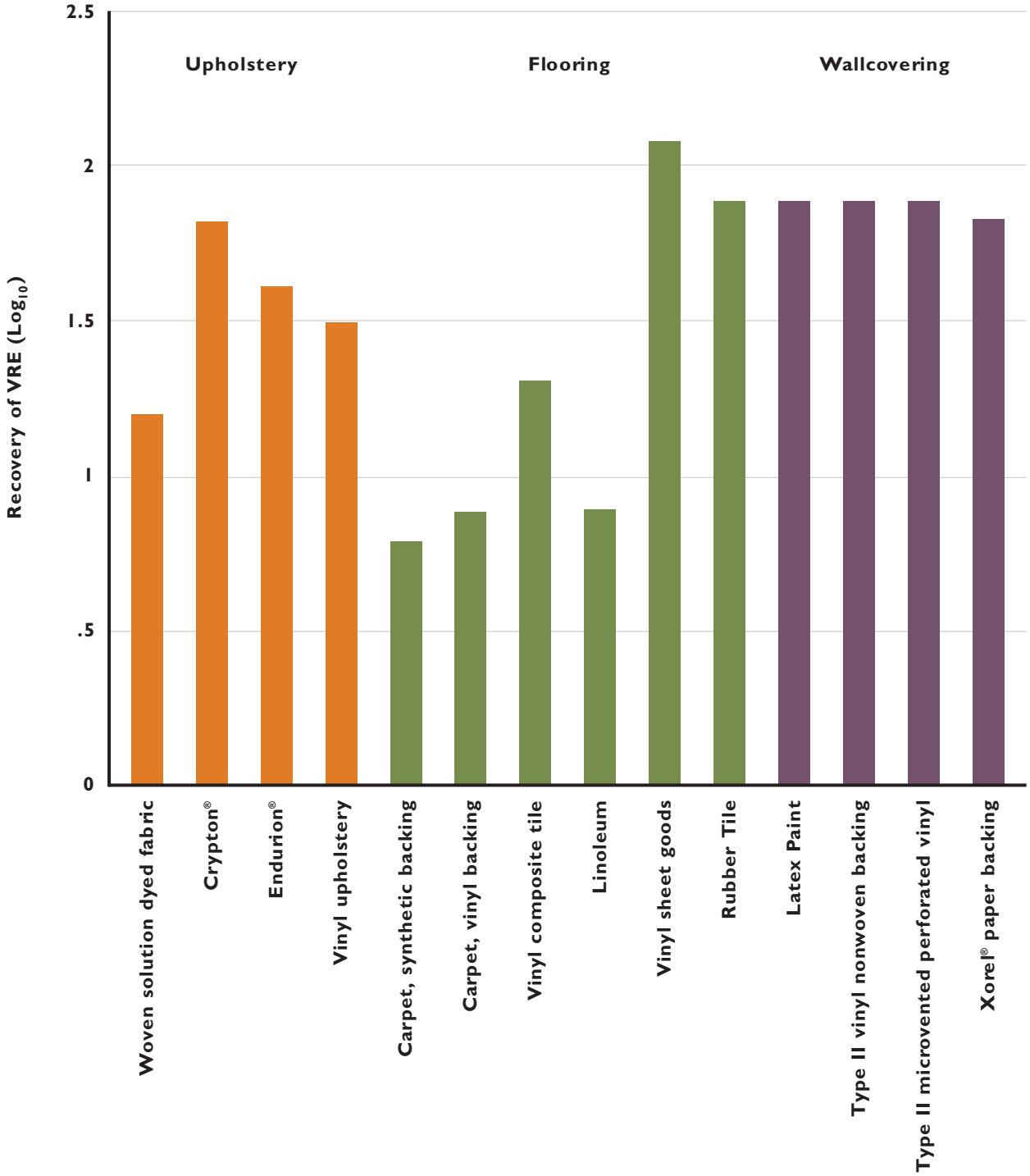


Figure 4. Simulated Transmission of VRE



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Appendices

Additional Resources

Persistent contamination of fabric-covered furniture by vancomycin-resistant enterococci: Implications for upholstery selection in hospitals

Materials Listing

Are those room finishes and cleaners safe?

By Roger Leib, AIA, ACHA, and Jane Rohde, AIA, ACHA, FIIDA, AAHID

Review Questions

Correct answers are at end.

1. In selecting finishes in relation to infection control for hospital environments, what would you ask of a product manufacturer?
    a. What color does your product come in?
    b. Have you tested your product with manufacturer cleaning recommendations?
    c. Have you tested your product utilizing CDC guidelines?
    d. Does your product contain antimicrobial?

2. Nosocomial Infection is:
    a. Material acquired infection
    b. Hospital acquired infection
    c. Initial diagnosis
    d. Complications of diagnosis

3. The most common transmission of nosocomial infection to a patient is from:
    a. Environmental surfaces
    b. Sinks
    c. Linens
    d. Staff hands

4. How many of the 14 surfaces tested positive for VRE after 24 hours after inoculation?
    a. 6
    b. 8
    c. 14
    d. 10

5. How many of the 14 surfaces tested positive for PSAE after cleaning?
    a. 4
    b. 14
    c. 9
    d. 11

6. Healthy human volunteers were utilized to test transmission of VRE from wallcovering, floor covering, and upholstery. How many of the 14 surfaces tested positive for VRE transmission by way of palmar contact?
    a. 7
    b. All
    c. None
    d. 10

7. The study reinforces the following:
    a. The importance of the location of sharps containers.
    b. The importance of specifying one material over another.
    c. The importance of washing linens daily.
    d. The importance of hand washing prior to patient contact.

8. What types of surfaces are easiest to disinfect?
    a. Woven
    b. Porous
    c. Nonporous
    d. Microvented

9. Manufacturer recommendations for cleaning are:
    a. Consistent and clear
    b. Vague and inconsistent
    c. Standardized and vague
    d. Inexpensive and cumbersome

10. The most important collaboration between manufacturers, design professionals, and infection control professionals is to:
    a. Improve products
    b. Improve anti-microbial additives
    c. Improve surface porosity
    d. Improve cleaning methods

Correct Answers

1. Correct Answer c
2. Correct Answer b
3. Correct Answer d
4. Correct Answer c
5. Correct Answer a
6. Correct Answer b
7. Correct Answer d
8. Correct Answer c
9. Correct Answer b
10. Correct Answer d

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