CONCISE COMMUNICATION

Evaluation of Hospital Floors as a Potential Source of Pathogen Dissemination Using a Nonpathogenic Virus as a Surrogate Marker

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Hospital floors are frequently contaminated with pathogens, but it is not known whether floors are a potential source of transmission. We demonstrated that a nonpathogenic virus inoculated onto floors in hospital rooms disseminated rapidly to the hands of patients and to high-touch surfaces inside and outside the room.

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Effective disinfection of contaminated surfaces is essential to prevent nosocomial transmission of pathogens such as *Clostridium difficile*, methicillin-resistant *Staphylococcus aureus*, and norovirus.[1] Efforts to improve disinfection usually focus primarily on surfaces that are frequently touched by the hands of healthcare workers or patients (eg, bed rails and call buttons). Notably, hospital floors are often heavily contaminated[2–4] but are not considered an important source for pathogen dissemination because they are rarely touched. However, floors are frequently contacted by objects that are subsequently touched by hands (eg, shoes, socks, slippers). In addition, it is not uncommon for high-touch objects such as call buttons and blood pressure cuffs to be in contact with the floor (authors' unpublished observations). Therefore, we hypothesized that floors might be an underappreciated reservoir for pathogen transmission.

Benign surrogate markers, such as viral DNA and nonpathogenic viruses, provide a powerful tool to study routes of pathogen transmission. In healthcare and community settings, inoculation of these markers onto high-touch surfaces (eg, door knobs, telephone handles) has been followed by widespread dissemination to environmental surfaces and hands.[5-6] In the current study, we used bacteriophage MS2, a nonpathogenic, nonenveloped RNA virus, to examine the potential for dissemination of microorganisms from floors of isolation rooms to the hands of patients and to high-touch surfaces inside and outside of rooms.

METHODS

The study protocol was approved by the Cleveland Veterans Affairs Medical Center's Institutional Review Board. Bacteriophage MS2 15597-B1 (American Type Culture Collection) was prepared as previously described.[7] Ten ambulatory patients in contact precautions for *C. difficile* infection or carriage of methicillin-resistant *S. aureus* were enrolled. For each patient, a 30×30 cm area of the wood laminate floor adjacent to the bed was inoculated with 2 mL of sterile water containing 1×10^8 plaque-forming units of MS2/mL and allowed to air dry. Patients were not aware of the precise area of inoculation. Hospital personnel were not aware of the study. The protocol for cleaning of contact precautions rooms included daily disinfection of high-touch surfaces with bleach wipes each morning but floors were cleaned only if visibly soiled; compliance with daily disinfection was monitored with fluorescent markers with more than 85% of sites demonstrating marker removal during the study. Preliminary experiments demonstrated that the MS2 inoculum persisted on wood laminate floors for at least 3 days, with a 1 to 2 log decrease in recovery attributed to desiccation.

On days 1, 2, and 3 after inoculation of MS2, sterile premoistened swabs (BBL CultureSwabs; Becton Dickinson) were used to sample environmental sites, patients' hands, and the soles of patients' footwear in the late afternoon. Environmental sites inside the inoculated room were categorized as being surfaces less than or equal to 3 feet (bed rails, bedside table, call button, telephone, bed linen) or more than 3 feet (night stand, sink, door knob, chair, light switch, pulse oximeter, and intravenous infusion pole) from the patient bed; or portable equipment; or personal items (wheelchairs, cell phones, books, clothing) (Figure 1). Environmental sites outside the inoculated room included adjacent rooms (bed rail, bedside table, call button, telephone, and floor) and the nursing station

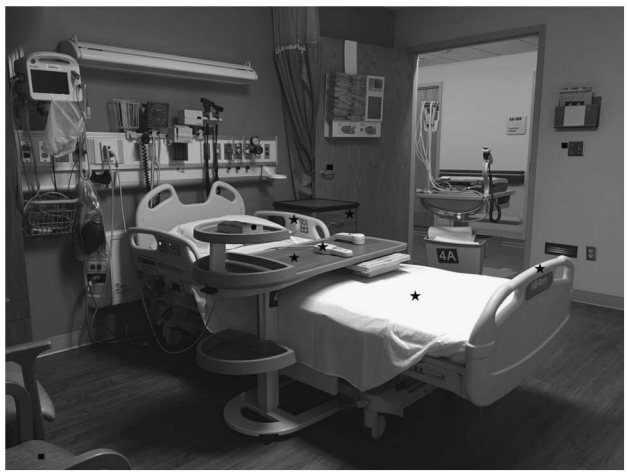

FIGURE 1. Illustration of high-touch surfaces sampled. Star, surfaces less than or equal to 3 feet from the center of the bed; square, surfaces more than 3 feet from the center of the bed; circle, personal items.

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TABLE 1. Recovery of Bacteriophage MS2 From Surfaces and Patients on Days 1, 2, and 3 After Inoculation of the Floor Adjacent to the Patient's Bed

	No. positive/ no. sampled (%), mean ± SEM $\log_{10}$ PFU recovered		
Variable	Day 1	Day 2	Day 3
Patients			
Hands	4/10 (40.0), 1.0 ± 0.4	5/8 (62.5), 1.5 ± 0.7	3/7 (42.9), 1.2 ± 0.3
Footwear	10/10 (100), 4.0 ± 0.6	8/8 (100), 3.9 ± 0.5	6/7 (85.7), 3.4 ± 0.9
High-touch surfaces			
≤3 feet from the bed			
Total surfaces	32/55 (58.2), 2.3 ± 0.2	28/45 (62.2), 1.8 ± 0.2	30/39 (76.9), 1.4 ± 0.2
Side bedrail	5/10 (50.0), 2.0 ± 0.3	5/8 (62.5), 1.9 ± 0.3	6/7 (85.7) 1.1 ± 0.2
Call button	5/10 (50.0), 1.2 ± 0.5	5/8 (62.5), 1.6 ± 0.7	5/7 (71.4), 1.6 ± 0.6
Phone	3/10 (30.0), 1.7 ± 0.3	4/8 (50.0), 1.1 ± 0.5	3/7 (42.9) 1.1 ± 0.1
Bed linens	9/10 (90.0) 3.0 ± 0.4	6/8 (75.0) 3.0 ± 0.6	7/7 (100), 1.9 ± 0.3
Foot board	4/5 (80.0), 3.3 ± 0.9	3/5 (60.0), 1.4 ± 0.6	4/4 (100), 1.6 ± 0.8
Tray table	6/10 (60.0), 2.2 ± 0.5	5/8 (62.5), 1.7 ± 0.3	5/7 (71.4), 0.7 ± 0.2
>3 feet from the bed			
Total surfaces	23/58 (39.7), 1.2 ± 0.2	34/50 (68.0), 1.4 ± 0.2	15/44 (34.1), 0.8 ± 0.2
Side table	4/8 (50.0), 1.0 ± 0.2	6/6 (100), 2.0 ± 0.5	5/5 (100), 0.7 ± 0.3
Pulse oximeter	3/7 (42.9), 0.7 ± 0.3	4/6 (66.7), 1.3 ± 0.3	1/7 (14.3), 0.7
IV pole	0/7 (0), 0	2/5 (40.0), 1.1 ± 0.02	1/6 (16.7), 0.3
Chair	5/8 (62.5), 1.3 ± 0.2	7/7 (100), 1.8 ± 0.4	3/5 (60.0), 0.4 ± 0.2
Door knob	4/10 (40.0), 2.0 ± 0.3	5/8 (62.5), 0.9 ± 0.2	2/7 (28.6), 1.2 ± 0.4
Light switch	1/10 (10.0), 0.78	3/8 (37.5), 0.1 ± 0.1	0/7 (0), 0
Sink	6/8 (75.0), 1.2 ± 0.4	7/8 (87.5), 1.4 ± 0.3	3/7 (42.9), 1.3 ± 0.4
Personal items[a]	6/12 (50.0), 1.5 ± 0.5	4/9 (44.4), 1.7 ± 0.3	4/8 (50.0), 1.2 ± 0.4
Portable equipment[b]	1/3 (33.3), 0.8	3/13 (23.1), 1.2 ± 0.5	3/3 (100), 0.7 ± 0.5
Adjacent rooms			
Floor	N/A	5/5 (100), 1.9 ± 0.1	8/10 (80.0), 1.4 ± 0.4
Environment[c]	N/A	2/5 (40.0), 0.9 ± 0.1	1/9 (11.1), 0.7
Nursing stations[d]	9/17 (52.9), 0.5 ± 0.1	15/32 (46.9), 0.2 ± 0.1	17/27 (63.0), 1.0 ± 0.2

NOTE. IV, intravenous; PFU, plaque-forming units; SEM, standard error of the mean.
[a]Personal items included wheelchairs, cell phones, books, and clothing.
[b]Portable equipment included medication cart, glucometer, and phlebotomy cart.
[c]Surfaces included bed rails, bedside table, call button, and telephone.
[d]Surfaces included computer keyboards, computer mouse, and telephones.

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(computer keyboards, computer mouse, telephones) on the same ward. For large surfaces, a 30 × 30 cm area was sampled; for smaller surfaces, such as telephones, the entire surface area was sampled. Swabs were vortexed for 1 minute in sterile water to elute the bacteriophage and serially diluted aliquots were cultured to quantify virus particles.[7] For each set of cultures, a negative control swab opened in the patient room but not placed in contact with surfaces was processed identically.

The Fisher exact test was used to compare the percentages of positive cultures on surfaces less than or equal to 3 feet vs more than 3 feet from the bed and on days 1, 2, and 3. Paired *t* tests were used to compare mean number of plaque-forming units recovered. Data were analyzed with SPSS statistical software, version 10.0 (IBM).

RESULTS

Of the 10 patients on 4 wards, 7 had samples collected for 3 days; 2 patients were discharged after 1 day and 1 was discharged after 2 days. Table 1 provides a summary of the culture results. MS2 was detected on multiple surfaces of all patient rooms by 1 day after inoculation. On days 1 and 3, the concentration of MS2 was higher for surfaces less than or equal to 3 feet vs more than 3 feet from the bed ($P < .02$ for both comparisons) and more sites were contaminated at less than or equal to 3 feet (day 1, $P < .06$; day 3, $P < .0001$). MS2 contamination was not significantly different at less than or equal to 3 feet vs more than 3 feet on day 2.

Contamination was common on high-touch surfaces in adjacent rooms, in the nursing station, and on portable equipment. Portable equipment included wheelchairs, medication carts, vital signs equipment, and pulse oximeters. All negative control swabs were negative for MS2.

DISCUSSION

We found that a nonpathogenic virus inoculated onto floors in hospital rooms disseminated rapidly to the footwear and hands of patients and to high-touch surfaces in the room. The virus was also frequently found on high-touch surfaces in adjacent rooms and at nursing stations. These results suggest that floors in hospital rooms could be an underappreciated source for dissemination of pathogens.

It is likely that both patients and healthcare personnel contributed to dissemination of the virus. MS2 virus present on patients' footwear was probably acquired during direct contact with the contaminated floor site adjacent to the bed. During removal of footwear, patients could easily acquire the virus on their hands, with subsequent transfer to touched surfaces and to other skin sites. The finding of contamination in adjacent rooms and in the nursing station clearly suggests that healthcare personnel contributed to dissemination after acquiring the virus during contact with contaminated surfaces or patients.

Our findings have important implications. Studies are needed to assess the potential for modes of dissemination from floors other than footwear. For example, wheelchairs and other wheeled equipment could disseminate pathogens.[8] If additional evidence demonstrates dissemination from floors, studies will be needed to assess the efficacy of current floor cleaning strategies and to evaluate other methods to interrupt dissemination. Because nonsporicidal disinfectants are often used on floors in rooms of patients with *C. difficile* infection, there is a particular need for data on how effectively the burden of spores is reduced on floors. Finally, studies in nonhospital settings are needed. For example, floors in community households have been shown to be frequently contaminated with *C. difficile* spores.[9]

Our study has some limitations. We studied dissemination of a virus. However, previous studies have demonstrated that transfer efficiency of MS2 and bacteria from fomites to fingers is comparable.[10] The concentration of virus applied to the floors was high, so our results are likely to reflect a worst-case scenario. We cannot exclude the possibility that results might vary with different types of floors. However, we demonstrated similar recovery of MS2 from different types of inoculated dry surfaces (authors' unpublished data).

In summary, we demonstrated that a nonpathogenic virus inoculated onto floors in hospital rooms disseminated rapidly to the hands of patients and to high-touch surfaces inside and outside the room. These findings provide further evidence that benign surrogate markers, such as nonpathogenic viruses, can provide a powerful tool to study routes of pathogen dissemination. Studies are needed to investigate the potential for contaminated hospital floors to contribute to pathogen transmission.

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