Evidence that contaminated surfaces contribute to the transmission of hospital pathogens and an overview of strategies to address contaminated surfaces in hospital settings

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Evidence that contaminated surfaces contribute to the transmission of hospital pathogens comes from studies modeling transmission routes, microbiologic studies, observational epidemiologic studies, intervention studies, and outbreak reports. This review presents evidence that contaminated surfaces contribute to transmission and discusses the various strategies currently available to address environmental contamination in hospitals.

Environmental surfaces were once thought to play a negligible role in the endemic transmission of nosocomial pathogens. However, recent data indicate that contaminated surfaces play an important role in the endemic and epidemic transmission of certain pathogens that cause health care-associated infections. Clostridium difficile, methicillin-resistant Staphylococcus aureus (MRSA), vancomycin-resistant enterococci (VRE), norovirus, and multidrug-resistant (MDR) gram-negative rods including Acinetobacter baumannii share the ability to be shed from infected or colonized patients, survive on dry surfaces for extended periods, and are difficult to eradicate by cleaning and disinfection. Whereas the role of contaminated surfaces in the transmission of some pathogens such as the spore-forming C difficile has been recognized for some time, the importance of contaminated surfaces in the transmission of other pathogens such as MDR Acinetobacter baumannii has come to light only in recent years. The continued emergence of antimicrobial resistance in gram-negative bacteria in particular means that effective prevention and control strategies are required urgently.

The transmission routes of pathogens are complicated and difficult to investigate, so studies focused on the role of surfaces in transmission have been rare until relatively recently. Data suggesting that contaminated surfaces play a role in transmission come from studies modeling transmission in vitro and in situ, observational epidemiologic studies, and intervention studies aimed at improving the efficacy of cleaning and disinfection.

EVIDENCE THAT CONTAMINATED SURFACES CONTRIBUTE TO TRANSMISSION

Modeling transmission

Modeling transmission routes can provide “proof of principle” that contaminated surfaces are involved in transmission: for example, monitoring the spread of nonmicrobial markers, the use of animal models, and mathematical modeling. One study evaluated the spread of a nonmicrobial marker (plant DNA) designed to model the spread of pathogens from hospitals surfaces. The marker was inoculated onto a single telephone handle in one of six 8-cot “pods” in a neonatal intensive care unit (ICU). The spread of the marker was remarkable: within 4 hours, it was identified from environmental surfaces and staff hands across the unit including all 6 pods. Whereas the spread of plant DNA does not necessarily

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accurately represent the spread of a pathogenic micro-organism, it
does present a picture of dynamic and rapid transmission involving
both environmental surfaces and staff hands.

Another approach to modeling transmission is the use of animal
models. For example, Lawley et al used a murine model to evaluate
the transmission of C difficile. The model established that C difficile
could be spread through experimentally contaminated cages in
a dose-dependent manner. Furthermore, the model also demon-
strated that disinfection of the cages using a range of disinfectants
interrupted transmission proportionally to the level of spore redu-
tion achieved.

Mathematical modeling can also provide some insight into
transmission routes. Mathematical models including the role of
contaminated surfaces are rare, but one study evaluated the likely
economic impact of various control strategies for norovirus
including improved disinfection. The model found that increased
disinfection alone or in combination with increased hand hygiene
and using protective apparel were most useful for the control and
containment of norovirus outbreaks.

**Microbiologic studies**

Environmental sampling of the surfaces surrounding patients
in hospitals has established that certain pathogens are shed into
the hospital environment. Wide variation in the reported
frequency of environmental contamination can be explained by
several factors, including the culturability of the organism, the
degree of shedding by the patient, the sampling methodology, the
ease of contamination (or difficulty of cleaning) of the particular
environment, and whether there is an ongoing outbreak at the
time of sampling.

Surfaces in the vicinity of patients have a higher frequency of
contamination than other sites. Infected patients shed more
pathogens than those who are only colonized, and diarrhea results
in widespread contamination.

Although the presence of a pathogen on a surface does not
necessarily represent a risk for transmission, studies have
demonstrated that the infectious dose of some pathogens is low.
For example, a small number of C difficile spores or norovirus
particles are sufficient to initiate an infection.

Microbiologic studies have established that certain hospital
pathogens can survive on dry hospital surfaces for extend periods
(Table 1). The survival of hospital pathogens on dry hospital
surfaces in vitro varies according to experimental conditions, but
some strains of vegetative bacteria have the capacity to survive for
months on dry hospital surfaces. VRE in particular seems to have
remarkable survival properties, with a recent study concluding
that VRE can remain viable on dry surfaces for such
fi...

### Table 1

<table>
<thead>
<tr>
<th>Organism</th>
<th>Survival time</th>
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<tbody>
<tr>
<td>Clostridium difficile (spores)</td>
<td>&gt;5 Months</td>
</tr>
<tr>
<td>Acinetobacter spp</td>
<td>3 Days to 11 months</td>
</tr>
<tr>
<td>Enterococcus spp including VRE</td>
<td>5 Days to &gt;46 months</td>
</tr>
<tr>
<td>Pseudomonas aeruginosa</td>
<td>6 Hours to 16 months</td>
</tr>
<tr>
<td>Klebsiella spp</td>
<td>2 Hours to &gt;30 months</td>
</tr>
<tr>
<td>Staphylococcus aureus, including MRSA</td>
<td>7 Days to &gt;12 months</td>
</tr>
<tr>
<td>Norovirus (and feline calicivirus)</td>
<td>8 Hours to &gt;2 weeks</td>
</tr>
</tbody>
</table>

**NOTE. Adapted from Kramer et al.**

### Table 2

<table>
<thead>
<tr>
<th>Direct patient contact</th>
<th>Contact with environmental surfaces only</th>
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<tr>
<td>45% of 50 HCP acquired MRSA on their gloved hands</td>
<td>52% of 44 HCP acquired VRE on their hands or gloves</td>
</tr>
<tr>
<td>50% of 30 HCP acquired Clostridium difficile on their gloved hands</td>
<td>40% of 50 HCP acquired MRSA</td>
</tr>
</tbody>
</table>
| Compliance with hand hygiene: 80% | Compliance with hand hygiene: 50%

HCP, Health care personnel.

more likely following direct patient contact compared with contact
with the patient environment, meaning that contamination acquired
from the environment is likely to persist for longer and hence could
be relatively more important for onward transmission.

Cleaning and/or disinfection is usually performed daily (or
several times daily) to reduce the environmental burden and
ensure that the patient environment remains visibly clean. More
stringent cleaning and/or disinfection is performed at patient
discharge (sometimes called “terminal” cleaning/disinfection) to
ensure that the clinical area is properly disinfected and safe for
the next occupant. Many studies have been performed to investigate
the efficacy of cleaning and disinfection, and most focus on the
efficacy of terminal cleaning/disinfection. Environmental sampling
performed after terminal disinfection often identifies surfaces
contaminated with the pathogen that the process is aiming to
eliminate. Even multiple “rounds” of bleach disinfection may not
be sufficient to eliminate some pathogens. For example, a recent study found that 27% of rooms remained contaminated with A baumannii or MRSA following 4 rounds of bleach disinfection.

Similarly, 43% of surfaces were contaminated with norovirus
RNA after 1 round of bleach disinfection, and 16% of surfaces were
contaminated after 2 rounds of bleach disinfection. Bleach and
other disinfectants are effective against these and other pathogens
in vitro, and, in theory, cleaning using a detergent alone would
remove contamination with these pathogens. Thus, the failure of
cleaning and disinfection to consistently eliminate surface
contamination with pathogens is most likely explained by the
challenge of repeatedly achieving adequate distribution and con-
tact time of the agent.

**Observational epidemiologic studies**

Carefully performed observational epidemiologic studies have
established that contaminated surfaces are involved in the trans-
mision of certain pathogens. For example, one study concluded
that at least 3 of 26 patients acquired MRSA directly from contami-
nated environmental surfaces. However, it is difficult to determine
the independent role of contaminated surfaces in these studies.

A useful way to elucidate the role of contaminated surfaces
in transmission is to evaluate the risk of acquiring certain
Fig 1. Chart showing the increased risk associated with the prior room occupant. The figures of difference in risk are unadjusted based on raw data. Several of the studies included adjusted measures of risk, but these were not included because of differences in study design. Any patient infected or colonized with VRE in the two weeks prior to admission. The immediate prior room occupant was known to be infected or colonized with VRE.

pathogens in patients admitted to rooms where the prior occupant was known to be infected or colonized with the pathogen. If environmental surfaces are an important factor in transmission because of inadequate disinfection after discharge of an infected or colonized patient, there will be an increased risk of acquisition of the same pathogen in the subsequent room occupant. This has been shown to be the case for a range of organisms, including C difficile, MRSA, VRE, and MDR gram-negative rods, including A baumannii (Fig 1). For example, during a 14-month study performed on 2 ICUs in the United States, all patients were screened for VRE on admission and twice weekly, and the environment was screened weekly; the 50 patients who acquired VRE were compared with the 588 who did not. Admission to a room from which a previous positive VRE culture had been obtained had the greatest increased risk of acquisition (hazard ratio [HR], 4.3); admission to a room where the immediate room occupant was infected or colonized with VRE had intermediate increased risk (HR, 3.8); and admission to a room that had been occupied by a VRE-infected or -colonized patient in the prior 2 weeks had the lowest increased risk (HR, 2.7).

The fact that terminal cleaning and disinfection does not reliably eliminate pathogens supports the findings of these “prior room occupancy” studies. Inadequate terminal disinfection may also result in a room becoming contaminated with more than 1 strain of a particular pathogen because of a “build up” over time. For example, MRSA with an average of 2.3 antibiograms were found in each patient room in one study where there was suboptimal terminal cleaning.

Similarly, in other studies, approximately 30% of MRSA environmental types were not closely related to the MRSA type affecting the patient in the room. Also, pathogens can be identified in empty rooms and can be transferred to the hands of health care personnel from surfaces in empty rooms.

These “prior room occupancy” studies allow the assessment of the risks associated with environmental contamination independent of common confounding variables of hospital infection, such as patient age, comorbidities, and length of stay. In addition, because the source patients were already discharged, in these studies patient acquisition directly from surfaces or via hand transfer from health care personnel is most likely to have come from contaminated surfaces.

**Intervention studies**

The findings of the prior room occupancy studies are supported by evidence that improved terminal cleaning and disinfection can reduce the risk of infection for the next occupant. Datta et al performed a retrospective cohort intervention study on 10 ICUs at a US hospital to evaluate the impact of improved cleaning and disinfection. The intervention consisted of targeted feedback using a black-light marker, the introduction of a “bucket method” for wetting cleaning cloths, and increased education of housekeeping staff. Patient acquisition was compared during 20-month baseline and intervention periods separated by 16 months. The acquisition of both MRSA and VRE fell significantly during the intervention periods, by 50% and 27%, respectively. The risk associated with the prior room occupant was successfully mitigated for MRSA but not for VRE.

Passaretti et al performed a prospective 30-month cohort intervention study on 6 high-risk units in a US hospital to evaluate the impact of introducing hydrogen peroxide vapor (HPV) for the terminal disinfection of select patient rooms. HPV was introduced to disinfect the rooms of patients known to be infected or colonized with multidrug-resistant organisms (MDROs) on 3 units following a 12-month preintervention phase. Patients admitted to rooms decontaminated using HPV were significantly less likely to acquire any MDRO (64% reduction) and VRE (80% reduction). HPV decontamination significantly reduced the proportion of rooms environmentally contaminated with MDROs by 35%. In particular, rooms contaminated with multiple MDROs, MDROs cultured from a room that differed from the room occupant’s known MDRO, and MDROs cultured from empty rooms were less frequent on HPV units during the intervention phase. These environmental findings can be explained by the improved terminal disinfection by HPV.

Several prospective studies have demonstrated that interventions aimed at reducing surface contamination reduce the transmission of hospital pathogens. These can be broadly divided into studies of a change in disinfection agent or educational improvements using existing agents.

**Outbreak reports**

Findings derived from outbreaks are often limited by lack of controls, multiple interventions and the potential for regression to the mean. However, many outbreak reports implicate contaminated surfaces in the transmission of C difficile, MRSA, VRE, and norovirus. Data supporting the role of contaminated surfaces in the transmission of norovirus come from outbreak reports, mostly in community settings. For example, a recent study from New Zealand provides compelling data that environmental contamination contributes to the transmission of norovirus through a remarkable outbreak of norovirus affecting successive flights of the same plane with distinct crews and passengers, associated with an episode of vomiting. The attack rate among staff decreased sequentially with subsequent flights, presumably as the environmental reservoir diminished. The attack rate in passengers could
not be determined because follow-up of each passenger was not feasible. The outbreak only ceased once the plane was refitted with new carpet in the affected area. Health care facilities do not have epidemiologically distinct cohorts of patients and staff, so it is more difficult to establish the role of contaminated surfaces in the transmission of norovirus. However, the finding of norovirus RNA contamination on surfaces in the immediate vicinity of patients and the general association between improved disinfection and the containment of outbreaks provides convincing evidence that contaminated surfaces are an important factor in the transmission of norovirus.6,46,62

**STRATEGIES TO ADDRESS ENVIRONMENTAL CONTAMINATION**

It is now clear that contaminated surfaces contribute to the transmission of some pathogens in some settings. However, the importance of contaminated surfaces relative to other transmission routes is not well understood. Indeed, when 6 experts speaking at an environmental session at APIC 2012 were asked to estimate the “percentage of all C difficile transmission in hospitals that is mediated, directly or indirectly, by contamination of the inanimate environment,” the responses ranged from 25% to 75% (unpublished data). Modeling, prior room occupancy studies, and intervention studies give a general indication of the contribution of contaminated surfaces to transmission, but carefully designed studies are required to provide more definitive data.

Despite the limitations of the evidence base, more needs to be done to address environmental contamination in hospitals to deliver the safest possible health care. Strategies to address environmental contamination can be divided into reducing and containing the shedding of pathogens and improved cleaning and disinfection.

**Reducing and containing shedding**

Improving compliance with hand hygiene following contact with a patient’s surroundings will reduce the chances of indirect spread of pathogens acquired on the hands of health care personnel following contact with their surroundings (Table 2).45 Also, improved compliance with hand hygiene before and after direct contact with patients will reduce the spread of contamination into the health care environment on the hands of health care personnel.

The rapid identification and isolation of infected or colonized patients is crucial for containing contamination. There is uncertainty surrounding the length of time patients should be isolated, and further work is required on this. Whereas hospitals in the United States generally have a high proportion of single rooms, hospitals in other countries typically have a much lower proportion of single rooms.63 The lack of single rooms hampers effective isolation of patients known to be infected or colonized with pathogens. Where single rooms are not available, cohorting of patients affected with the same pathogen within a multioccupancy area is often practiced.64,65 However, increasing the number of single rooms has been associated with reduced transmission.66 Thus, hospitals and health care administrators should ensure the adequate provision of isolation facilities through building hospitals with a high proportion of single occupancy rooms or modifying existing facilities to increase the proportion of single occupancy rooms.63,65-67

“Source control” through daily bathing with chlorhexidine is another approach to reducing the shedding of pathogens, and this has been shown to reduce the transmission of MRSA and VRE.68,69 However, most studies of the effectiveness of this intervention have been performed in ICU settings, so studies are required outside of the ICU.

**Improved cleaning and disinfection**

Effective cleaning and disinfection relies on the operator to repeatedly ensure adequate selection, formulation, distribution, and contact time of the agents used. Educational improvements designed to modify human behavior can be attempted with the support of various tools including fluorescent markers or adenosine triphosphate assays, and monitoring and feedback can improve the frequency of surface cleaning.70 reduce the level of environmental contamination,44,47i and reduce the acquisition of pathogens.19,20 However, no studies have evaluated the sustainability of such systematic improvements. Indeed, recent evidence indicates that altering the location of fluorescent dye spots reduced the proportion of objects that were cleaned from 90% to approximately 60%.72

Improvements in hospital design and materials, novel disinfectants, and cleaning/disinfection technologies should be evaluated to determine their effectiveness in improving cleaning and disinfection. For example, there has been recent discussion on “no-touch” automated room disinfection (NTD) systems, which remove or reduce the reliance on the operator to achieve adequate distribution and contact time of the active agents.73,74 HPV, aerosolized hydrogen peroxide, ultraviolet C, and pulsed-xenon ultraviolet radiation NTD systems have all shown promise and improved efficacy when compared with conventional methods.75,76-78 HPV has been associated with reductions in patient acquisition and evaluations of other NTD systems with a clinical outcome are eagerly awaited.77,78 NTD systems are only appropriate for certain applications and should be introduced in parallel with an educational campaign to improve conventional methods.

Antimicrobial or “self-disinfecting” surfaces and air disinfection units have shown some promise in reducing the environmental bioburden, but further evaluations with clinical outcomes are required.77,78 The most appropriate strategies to address surface contamination will depend on the setting and on local epidemiology.

**CONCLUSION**

There is now compelling evidence from modeling of transmission routes, microbiologic studies, observational epidemiology studies, intervention studies, and outbreak reports that contaminated surfaces contribute to the transmission of hospital pathogens. The finding that admission to a room previously occupied by a patient with a hospital pathogen increases the risk of acquiring that pathogen, combined with intervention studies showing that this increased risk can be mitigated by improved environmental decontamination, provides the most powerful evidence that contaminated surfaces contribute to transmission and that more needs to be done to improve surface decontamination. Improvement strategies include interventions to reduce and contain the shedding of pathogens into the environment and interventions to improve the efficacy of cleaning and disinfection. The most appropriate strategies to address surface contamination will depend on the setting and on local epidemiology.

**References**


