Contamination, Disinfection, and Cross-Colonization: Are Hospital Surfaces Reservoirs for Nosocomial Infection?

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Abstract

Although it is well-documented that hospital environments—such as surfaces and medical equipment—can become contaminated with nosocomial pathogens, the evidence linking contaminated fomites directly to hospital-acquired infections is mostly indirect. There is stronger evidence supporting the persistence of certain pathogens, including Clostridium difficile, vancomycin-resistant enterococci, and methicillin-resistant Staphylococcus aureus, in environmental reservoirs. Other pathogens, such as norovirus, influenza virus, the coronavirus associated with severe acute respiratory syndrome (SARS), and Candida species, are also believed to survive in these environments. To effectively reduce nosocomial infections caused by these organisms, infection control strategies should adhere to established guidelines, focusing particularly on thorough environmental cleaning and the use of EPA-approved detergent-disinfectants.

Background

The contribution of the inanimate hospital environment—such as surfaces and medical equipment—to the transmission of nosocomial infections remains a subject of debate. While the presence of microorganisms contaminating these environments has been acknowledged for some time, the extent to which this contamination influences infection rates is still uncertain. For instance, one medical facility reported that although environmental contamination significantly decreased after relocating to a new hospital, this reduction did not correspond with a decline in nosocomial infection rates [1]. This raises the question: are microbes found on inanimate surfaces merely passive contaminants, or do they actively contribute to patient colonization and infection? Variations in findings across different studies may be due to the complexity of infection transmission dynamics, inconsistencies in how contamination is measured, or differences in the effectiveness of cleaning practices—an often overlooked yet crucial factor. Moreover, the detection of pathogens on hospital surfaces, while necessary to establish potential risk, does not alone confirm a direct causal role in the development of infections. Additionally, reports from uncontrolled outbreak investigations suggesting that enhanced environmental cleaning ended transmission must be interpreted with caution, since simultaneous implementation of multiple infection-control strategies can mask the specific impact of cleaning. Evaluating the evidence regarding environmental contamination requires consideration of four key factors: (1) the extent to which the hospital environment is contaminated by specific pathogens; (2) whether studies examine temporality—that is, if contamination occurs before or after patient colonization; (3) assessment of confounding variables, such as hand hygiene practices and the thoroughness of surface cleaning; and (4) whether improvements in cleaning, when isolated from other interventions, lead to reduced patient infection risk. The most robust investigations use molecular epidemiology to track pathogen strains, systematically monitor environmental cleaning and hand hygiene quality over time, and establish spatial and temporal links between contaminated surfaces and patient cross-colonization events.

CONTAMINATION OF THE HOSPITAL ENVIRONMENT BY NOSOCOMIAL PATHOGENS

Viruses

Viruses can contaminate and persist on inanimate surfaces (see Table 1), making environmental cleaning a crucial component of infection control, particularly for influenza, parainfluenza, enteric viruses, hepatitis B virus (HBV), and severe acute respiratory syndrome (SARS) coronavirus. Influenza virus primarily spreads via large respiratory droplets and possibly through airborne droplet nuclei. Classic studies demonstrate that influenza can contaminate surfaces, survive drying, and become re-aerosolized during floor sweeping. The virus can remain viable for 24 to 48 hours on nonporous surfaces and can transfer to skin, indicating that contaminated environments may facilitate cross-infection through the hands of healthcare workers [3]. Similarly, parainfluenza virus resists drying and can survive for up to 10 hours on nonporous surfaces and 16 hours on clothing [5].

Human enteric viruses frequently contaminate inanimate surfaces and can cause outbreaks in institutional settings [38–40]. For example, rotavirus is a well-known source of infections in daycare centers and healthcare facilities; it extensively contaminates surfaces and may spread via contaminated toys shared by children [38]. Norovirus has caused outbreaks on cruise ships, hospitals, and hotels [7, 8, 39, 40]. In 2002 alone, nine outbreaks of norovirus were reported on cruise ships [40], some requiring suspension of services and intensive cleaning to halt transmission. Although direct proof of environment-to-person transmission is lacking, norovirus is often cultured from environmental samples during outbreaks [8, 39], and indirect evidence suggests aerosolization may occur during vomiting episodes [8].

Individuals lacking immunity to HBV are at risk of infection from contaminated environmental sources. Blood from actively replicating HBV-infected individuals can contain high viral loads, and even small, invisible amounts can be highly infectious. HBV can survive up to seven days at relative humidity around 42% [9]. Outbreaks linked to fomites have been traced to contaminated medical equipment such as electroencephalographic electrodes [10] and glucose-monitoring lancets [11].

SARS coronavirus is primarily transmitted through respiratory droplets, but fecal-oral and surface contamination routes may also contribute. Infection control in hospitals includes precautions against contact, droplet, and airborne transmission [14]. The virus can survive on plastered walls, plastic laminate (e.g., Formica), and other plastic surfaces for 24 to 72 hours and remains viable in feces and urine for one to two days at room temperature [13]. A notable outbreak in a Hong Kong apartment complex might have involved fecal-oral transmission combined with environmental contamination [15], although airborne spread was also suggested by modeling studies [41]. Environmental cleaning effectively reduces contamination; a Taiwan emergency department outbreak ceased after cleaning and patient isolation, with environmental samples turning culture-negative [12].

Fungi

Most Candida infections originate from the patient's own flora, but molecular typing indicates that fomites may play a role in spreading Candida species such as C. albicans, C. glabrata, and C. parapsilosis, especially among bone marrow transplant patients. However, the direction of transmission—patient to environment or vice versa—is not definitively proven [16]. Candida can survive on dry surfaces for several days: 3 days for C. albicans and up to 14 days for C. parapsilosis [17]. Epidemic outbreaks have implicated environmental sources like blood pressure transducers or irrigating solutions [16, 42]. Molecular typing supports the presence of endemic environmental reservoirs, with patient strains matching those found on hospital surfaces before infection [16].

Aspergillus and Zygomycetes species are known causes of nosocomial skin infections linked to contaminated fomites. These infections have been associated with arm boards, bandages in patients with intravascular catheters, surgical bandages, hospital construction, and postoperative wounds [43].

Bacteria

Clostridium difficile produces durable spores resistant to common cleaning methods. Environmental contamination near infected or colonized patients is frequent, with rates up to 58%. Contaminated surfaces include commodes, bedpans, blood pressure cuffs, walls, floors, washbasins, and furniture [18–20]. Low levels of spores have been found on shoes and stethoscopes [20]. Floors can remain contaminated for up to five months [19]. The contamination density increases in areas with colonized or diarrheal patients [18, 20]. Molecular evidence confirms transmission from contaminated surfaces to patients: health care workers' hands harbor C. difficile, contamination correlates with patient colonization, and dominant strains are more likely to contaminate environments [18, 44]. These findings suggest that surfaces serve as reservoirs enabling cross-colonization after contact with healthcare workers.

Enteric gram-negative bacilli generally do not survive long on dry surfaces (less than 7 hours), and infection usually results from endogenous sources or patient-to-patient transmission via healthcare workers' hands [22]. However, Pseudomonas aeruginosa and Acinetobacter baumannii are strongly associated with environmental contamination. Numerous studies report P. aeruginosa contamination in sinks and drains [21], though its environmental strain types do not always match clinical isolates [23]. Most P. aeruginosa infections stem from endogenous flora rather than environmental sources [21]. Similarly, A. baumannii—a commensal and opportunistic pathogen with increasing antibiotic resistance—has been isolated extensively from hospital environments, including beds, mattresses, floors, sinks, and humidifiers [24, 25]. Airborne spread has been suggested through air sampling [24]. This organism can survive up to three years in hospital environments [26]. Environmental strains include those causing patient infections as well as those without clinical association [27]. Some outbreak investigations found no environmental A. baumannii, complicating assessments of environmental roles [45, 46]. Hand hygiene and cleaning practices may influence these findings.

Gram-positive cocci, especially methicillin-resistant Staphylococcus aureus (MRSA), primarily colonize or infect patients and occasionally hospital staff, with transmission mostly via unwashed healthcare worker hands [47]. The environmental role in MRSA spread is debated; environmental contamination is variable, and strain types from environment and patients do not always match [31, 48]. Burn units show higher environmental contamination, with MRSA rates up to 64%, compared to 1–18% in nonburn wards [28]. Hydrotherapy rooms associated with burn units are especially contaminated [47]. Contamination also varies by infection site in patients: rooms of those with urine or wound infections show more environmental contamination than those with bacteremia alone [28]. Outbreaks have cultured MRSA from mattresses, where moist padding and damaged covers are common [49], as well as from mops, gowns, and gloves [28]. MRSA and methicillin-susceptible S. aureus can survive up to 9 weeks despite drying and remain viable for up to 2 days on plastic laminate surfaces under lab conditions [29, 30].

INTERVENTION STRATEGIES

Cleaning intensity is generally classified into two main categories: sterilization and disinfection. Sterilization aims to completely destroy all microbial life on surfaces or objects, and it can be achieved through heat, pressure, or chemical methods. Disinfection, on the other hand, reduces the number of microorganisms significantly but does not eliminate bacterial spores. The effectiveness of disinfection depends on how sensitive the microbes are to the chemicals used. High-level disinfection kills all microorganisms except large amounts of spores, intermediate-level disinfection destroys all microbes except spores, and low-level disinfection does not reliably kill mycobacteria or spores. “Cleaning” refers to the physical removal of dirt and organic matter from surfaces, often involving mechanical action and detergents with water. Cleaning alone can lower the number of organisms on a surface, and when combined with disinfection, it can significantly reduce microbial load more quickly [62].

There are three types of solutions commonly used for cleaning: detergents that remove organic matter and dissolve grease or oils; disinfectants that quickly kill or inactivate infectious agents; and detergent-disinfectants that perform both functions. However, there is no definitive evidence proving that routine disinfection of hospital surfaces is better than using detergent alone [63]. As a result, the regular use of detergent-disinfectants is mainly supported by expert consensus and practical considerations [4].

In 2003, the Healthcare Infection Control Practice Advisory Committee of the CDC (CDC/HICPAC; Atlanta, GA) updated guidelines on environmental infection control for healthcare facilities [4]. These guidelines recommend cleaning strategies for patient care areas, emphasizing that surfaces should be visibly clean, with high-touch areas disinfected more frequently than others, and spills cleaned promptly. Environmental services staff are advised to use EPA-registered detergent-disinfectants to clean inanimate surfaces in patient care settings. Although this recommendation has been debated [63], it accounts for uncertainty about contaminants, such as blood or bodily fluids versus normal dust or dirt, and the potential presence of multidrug-resistant organisms [4].

The guidelines do not specify how often cleaning should occur, only that it should be done regularly. In hospitals, patient rooms are usually cleaned daily and receive a thorough “terminal cleaning” after a patient is discharged. Terminal cleaning involves an intensive cleaning of noncritical surfaces, typically using disinfectants like quaternary ammonium compounds or phenolics (though phenolics are not recommended for nurseries or infant care areas). This thorough cleaning may be more effective at reducing environmental contamination due to its comprehensiveness.

Generally, changing cleaning products or procedures is not necessary to target specific pathogens. However, in areas with high rates of *Clostridioides difficile* infections, hypochlorite-based disinfectants may be preferred because of their reliable ability to kill spores. Most commercial disinfectants used in healthcare settings are effective against viruses; enveloped viruses are more susceptible to detergents than non-enveloped ones [9]. Viruses, including the SARS coronavirus, can typically be eliminated with EPA-approved disinfectants or detergent-disinfectants when used according to the manufacturer’s instructions [14].

In cases of norovirus outbreaks, decontamination should involve germicidal products such as a 10% sodium hypochlorite (bleach) solution, and closure of the affected facility may be required [6]. Intuitively, effective cleaning is important for controlling resistant organisms. One study showed that extending the exposure time of cleaning agents on surfaces effectively eliminated environmental *vancomycin-resistant Enterococcus* (VRE) [64]. Improving cleaning compliance also benefits hygiene: feedback to housekeeping staff resulted in better cleaning practices and a threefold reduction in VRE contamination, achieved with standard cleaning materials and methods [65]. However, it remains unclear whether such improvements directly lead to reduced rates of hospital-acquired infections.

DISCUSSION

Although much about the transmission of hospital-acquired (nosocomial) infections remains unclear, several key findings have emerged from current research: (1) inanimate surfaces within healthcare environments can become persistently contaminated after contact with colonized patients; (2) while certain organisms may be widespread within a facility, specific strains often dominate on these surfaces, as seen with *Clostridioides difficile* and vancomycin-resistant enterococci (VRE); and (3) contaminated patient rooms may increase the risk of infection for subsequent patients. Molecular epidemiology has enhanced our understanding by showing that environmental isolates often match those found in patients (as demonstrated for *C. difficile*, *Candida* species, and VRE), though differences exist for organisms like *Acinetobacter* species.

Interpreting existing outbreak reports and environmental studies is challenging because factors like hand hygiene and cleaning practices—important variables influencing transmission—are infrequently measured and may confound results. There is a clear need for rigorous studies that evaluate whether enhanced cleaning protocols actually reduce nosocomial infection rates. Future research on the environmental role in infections should include detailed timing of contamination and patient acquisition events, precise patient locations relative to contaminated areas, and assessments of hygiene and cleaning effectiveness.

Understanding the role of the inanimate environment is critical, especially given ongoing challenges in infection control compliance and hand hygiene adherence. The introduction of alcohol-based hand gels has improved compliance and may lessen transmission from contaminated surfaces like walls, bed rails, and medical equipment. Nevertheless, hospitals might benefit from adopting additional, cost-effective strategies such as more thorough and frequent environmental cleaning to lower the risk of cross-colonization.

Conclusions

Our results indicate that the primary factors associated with loneliness, after controlling for other variables, span sociocultural influences (such as experiences of discrimination), relational aspects (including couple satisfaction and time spent alone), and individual characteristics (notably neuroticism and personal self-esteem). Therefore, effective interventions must take a comprehensive approach that addresses these multiple dimensions. It is essential to tailor strategies to the diverse needs of individuals while also confronting broader issues of marginalization. Focusing solely on individual or relationship-level solutions, without tackling the underlying structural inequalities, is unlikely to reduce loneliness or its negative impacts on health and well-being, and may perpetuate disparities experienced by marginalized populations.

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