CONTACT TRANSMISSION
Part 1: The Role of Surfaces in Healthcare-Associated Infections (HAIs)
An Issue Brief on Infection Control

INSIDE YOU WILL LEARN ABOUT:
The role of surfaces in the chain of transmission and the epidemiology of infections.
Environmental conditions that affect the growth and transmission of pathogens.
Cleaning and disinfecting strategies.

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Contact Transmission, Part 1: The Role of Surfaces in Healthcare-Associated Infections

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Executive Summary

The spread of infections through contact is linked to a range of environmental conditions that affect the growth and transmission of pathogens. Many pathogens have been found to persist in the environment and remain for days or even months (Dancer, 2014; McQueen & Ehnes, 2018; Mitchell, Spencer, & Edmiston, 2015; Schettler, 2016). Though the transmission of infection (direct or indirect) is most likely to occur via person-to-person contact, the role of
surfaces in contact transmission should not be ignored (Fijan & Turk, 2012; Yeargin, Buckley, Fraser, & Jiang, 2016).

Surfaces are generally classified as either hard surfaces (e.g., window sills, charting stations and workstations, floors, walls, ceilings) or soft surfaces (e.g., bed linen, upholstery, privacy curtains, apparel). Hand hygiene has been the primary focus of infection prevention efforts; however, the design and selection of built environment surfaces (especially those identified as “high-touch surfaces”) are also important considerations in interrupting the transmission chain.

Along with surfaces, ambient environmental factors like temperature, relative humidity, air change rate, ventilation, and pressure differentials to adjacent spaces have been found to affect the growth and transmission of microorganisms (Campoccia, Montanaro, & Arciola, 2013; Lopez et al., 2013; Ramos, Dedesko, Siegel, Gilbert, & Stephens, 2015; Şimşek, Grassie, Emre, & Gevrek, 2017; Tang, 2009; Verdier, Coutand, Bertron, & Roques, 2014; Yau, Chandrasegaran, & Badarudin, 2011). The design and selection of surfaces, materials, and finishes must also be considered in light of organizational policies and cleaning procedures (as summarized in the accompanying issue brief, Contact Transmission, Part 2: The Role of Materials, Design, and Cleaning in HAIs). Solutions include manual cleaning with disinfectants, no-touch automated disinfection technologies, and self-disinfecting surfaces (Rutala & Weber, 2013).

In order to reduce the transmission of HAIs through contact using design methods, the design process must take into account both surface selection and appropriate cleaning strategies. The literature reveals that operations, people, and built environmental factors can all play a role in infection prevention (Figure 1). For each element within the organization, it is necessary to pay close attention to the hosts, reservoirs, and carriers of infections, including inanimate surfaces that may be potential routes of transmission. In other words, stakeholders must take a systems approach that considers all the elements and interactions of the system holistically in order to optimize design for infection control.
Introduction

Healthcare-associated infections (HAIs) are infections that are contracted over the course of receiving medical care. One in 31 hospitalized patients in the United States has HAIs (Centers for Disease Control and Prevention, 2018). Increased awareness has led to a better understanding of how inanimate objects (fomites) contribute to the transmission of healthcare-associated pathogens (Beggs, Knibbs, Johnson, & Morawska, 2015; Boyce, 2007; Carling, 2016; Dancer, 2014).

As discussed in the Hand Hygiene issue brief, the economic burden associated with HAIs is significant. Some preventable infections, such as central line-associated bloodstream infections (CLABSIs), catheter-associated urinary tract infections (CAUTIs), surgical site infections (SSIs), hospital-acquired pneumonia (HAP) (including ventilator-associated pneumonia (VAP)), Methicillin-resistant *Staphylococcus aureus* (MRSA), and *Clostridium difficile* (C. diff or CDI), are tracked and reported as part of CMS reimbursement programs (Diekema, 2017; Schmier et al., 2016).

The threat of infections resulting from multidrug-resistant organisms (MDRO) has been another area of focus, with MRSA attracting the most attention (Sandora & Goldmann, 2012). Antimicrobial stewardship programs are often established to optimize antimicrobial use, decrease the incidence of MDRO-related infections, and reduce the risk of drug resistance (Moehring & Anderson, 2012). Though they are most often addressed in the context of antibiotics, Donskey (2013) states that environmental disinfection interventions “are analogous to antimicrobial stewardship interventions.”

Common terms used in these discussions include antimicrobial agents (those that kill or inhibit the growth of organisms), antibacterial agents (a subset of antimicrobial agents specific to bacteria), bactericidal agents (also a subset of antimicrobial agents specific to bacteria), biocidal agents (substances or chemicals used for sterilization and disinfection), and biocidal/antimicrobial activity (destruction of or damage to microorganisms at the cellular level). Distinctions can be further drawn according to whether a treatment is applied as a coating, impregnated into the surface, or exists as an inherent material characteristic (further discussed in Part 2).
In scientific terms, “bactericidal” refers to an agent that kills bacteria (>99.9% of an inoculum within 24 hours), while “bacteriostatic” refers to an agent that prevents the growth of bacteria (Pankey & Sabath, 2004). However, it’s worth noting that bactericidal agents usually fail to kill every organism within 24 hours of testing, and most bacteriostatic agents kill some bacteria within the same timeframe (though not enough to be called bactericidal).

**Epidemiology of Infections**

Healthcare workers, patients, and care partners can be exposed to multiple pathogens throughout the care process (McQueen & Ehnes, 2018; Mitchell et al., 2015; Schettler, 2016). The most common pathogens are shown in Table 1; these pathogens are found to persist in the environment and remain for days or even months (Dancer, 2014; McQueen & Ehnes, 2018; Mitchell et al., 2015; Schettler, 2016). Pathogen characteristics including type, shape, dimensions, structural variation and complexity, and adherence to a surface impact the retention and transfer of infection (Campoccia et al., 2013; Lichter, Van Vliet, & Rubner, 2009).

Biofilms (architectural colonies of microorganisms, a prevalent source of infection) result when bacteria attach to static surfaces and self-produce a matrix of extracellular polymeric substance that becomes resistant to antimicrobial agents (Costerton, Stewart, & Greenberg, 1999; Jamal et al., 2018). Disinfectants may only kill the bacteria on the top layer of the biofilm and have little to no effect on the bacteria located deeper within the microcolony (Tripathy, Sen, Su, & Briscoe, 2017). While biofilm investigations have typically focused on wet areas (e.g., faucets, sink drains) and medical devices (e.g., implants), recent research has found that dry surface bacteria are nearly universal on hospital surfaces (Ledwoch et al., 2018; Otter et al., 2015) and can be transferred from hands to fomites, highlighting the biofilm’s role as a persistent environmental source of pathogens (Chowdhury et al., 2018). It has also been suggested that since biofilms on dry hospital surfaces may interfere with traditional environmental sampling, the conditions of environmental surfaces as reservoirs may be underestimated (Yezli & Otter, 2012).

Microbes can be studied under various morphologies, one descriptor being shape (i.e., sphere, rod, or spiral). Verran et al., (2009) found that rod-shaped
cells were retained in higher numbers on surfaces with small width features due to alignments of certain shapes with the surface topography. Other characteristics include the composition of the outermost cell envelope (e.g., Gram-positive and Gram-negative bacteria) and the presence of protein fibers that can extend from the cell wall and bond to surfaces. It is necessary to document the structural characteristics of pathogens to understand their mechanisms of existence and survival.

Table 1: Epidemiology of Infections

<table>
<thead>
<tr>
<th>Pathogen</th>
<th>Indications/ Symptoms</th>
<th>Impact</th>
<th>Persistence in environment</th>
<th>Transmission/Common surfaces</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Clostridium difficile</em> (C. diff or CDI)</td>
<td>Healthcare-associated diarrhea (even death)</td>
<td>Most frequent infection type (CDC, 2003). 12.1% of all HAIs (Magill et al., 2014).</td>
<td>&gt;5 months</td>
<td>Contact with transient hand colonization (e.g., nurse), another CDI patient, or a contaminated environment (Loo, 2015).</td>
</tr>
<tr>
<td>Methicillin-resistant <em>Staphylococcus aureus</em> (MRSA)</td>
<td>Skin infections, fever, chest pain, fatigue, muscle aches</td>
<td>Contributes to 50% of all hospital-acquired <em>Staphylococcus aureus</em> (Siegel, Rhinehart, Jackson, &amp; Chiarello, 2007). Proportion of hospital surfaces contaminated with MRSA varies between 1–27% (Boyce, 2007).</td>
<td>7 days to &gt;12 months</td>
<td>People represent the primary reservoir of <em>S. aureus</em> (L.M. Sehulster et al., 2004). 65% of nurses who performed patient care activities on patients with MRSA in a wound or urine contaminated their nursing uniforms or gowns (Boyce, 2007). Most likely on surfaces in the patient zone (Dancer, 2014). High-touch surfaces where MRSA was recovered: bedside tables and rails, blood pressure cuffs, TV remote controls, toilet seats and rails, dressers, door handles, IV pumps (Otter, Yezli, &amp; French, 2014).</td>
</tr>
<tr>
<td>Vancomycin-resistant Enterococci (VRE)</td>
<td>Opportunistic: Symptoms from other infections that VRE triggers — urinary tract, bloodstream, wound infection, etc.</td>
<td>7–29% of environmental sites house VRE (Weber, Anderson, &amp; Rutala, 2013). Environmental contamination by VRE occurs as often or more often than MRSA (Boyce, 2007).</td>
<td>5 days to &gt;4 months</td>
<td>Most commonly contaminated hospital items: chairs and couches, bedside tables and rails, blood pressure cuffs, floors (Grabsch et al., 2006).</td>
</tr>
<tr>
<td>Acinetobacter spp.</td>
<td>Opportunistic: Symptoms from other diseases caused by Acinetobacter — pneumonia, ventilator-associated pneumonia, UTI, and wound infection</td>
<td>Accounts for almost 80% of infection in hospitals (CDC, 2016a). Associated mortality rates are between 17–52%. Environmental contamination ranges from 3–50% (Kotsanas et al., 2013).</td>
<td>3 days to 11 months</td>
<td>Isolated from the hands of 4–33% of healthcare workers (L.M. Sehulster et al., 2004). Commonly cultured from patients, air, and medical equipment (e.g., room air conditioners, ventilators, and vaporizers); also detected on dry environmental surfaces (L.M. Sehulster et al., 2004). Found in samples from hand washing sinks (Kotsanas et al., 2013), mattresses, vital signs monitors, horizontal surfaces in patient zone, computers, and glucometers (Doidge et al., 2010).</td>
</tr>
</tbody>
</table>
Chain of Contact Transmission

As described in an analysis report of 1,022 published HAI outbreaks, the most common pathogen reservoirs were patients, followed by medical equipment or devices, the environment, and staff members (Gastmeier et al., 2005). Though the transmission of infection (direct or indirect) is most likely to occur through person-to-person contact, air, water, or droplets, the role of fomites in contact transmission should not be ignored (Fijan & Turk, 2012; Yeargin et al., 2016).

Surfaces can be classified as either hard surfaces (e.g., window sills, charting stations and workstations, floors, walls, ceilings) or soft surfaces (e.g., bed linen, upholstery, privacy curtains, apparel). Multiple studies have reported that these surfaces are constantly touched by healthcare workers during patient care, thus becoming potential reservoirs of microbes and spores (CDC, 2003; Cohen et al., 2018; Dancer, 2014; Rutala & Weber, 2013; Sehulster, 2017; Siani & Maillard, 2015; Zimring, 2013). As shown in Figure 2, this indirect chain of transmission might include the organism or agent (i.e., a pathogen), a reservoir (e.g., a surface), objects or materials in and around the patient zone that can carry the pathogen, and the host (i.e., the patient or susceptible individual).
infection (i.e., fomites), a susceptible host carrier (e.g., a caregiver’s hands), and a susceptible host reservoir (e.g., the patient).

(Steinberg et al., 2013) conceptualized the role of healthcare facility design in breaking the chain of contact transmission through environmental interventions. Solutions include hand hygiene, physical barriers, touchless systems, private rooms, isolation, surface selection, and cleaning strategies. Hand hygiene has been the primary focus of infection prevention efforts; however, the design and selection of built environment surfaces (especially those identified as “high-touch surfaces”) are also important considerations in interrupting the transmission chain. Individual surfaces must be evaluated in the context of affordable and applicable cleaning strategies and technologies.

**Environmental Conditions**

Several studies showing reduced infection rates have tested built environment and organizational factors such as the number of patients in a room, prior room occupancy, and activity level (Cohen et al., 2018; Datta et al., 2011; Ramos et al., 2015; Stiller et al., 2016; Vaisman et al., 2017). Ambient environmental factors like temperature, relative humidity, air change rate, ventilation, and pressure differentials to adjacent rooms have been found to affect the growth and transmission of microorganisms (Campoccia et al., 2013; Lopez et al., 2013; Ramos et al., 2015; Şimşek et al., 2017; Tang, 2009; Verdier et al., 2014; Yau et al., 2011). Figure 3 shows the range of environmental conditions recommended by ASHRAE 170 in the 2018 FGI Guidelines.

<table>
<thead>
<tr>
<th>Ambient conditions</th>
<th>Temperature</th>
<th>Relative humidity</th>
<th>Air change rate</th>
<th>Pressurization</th>
<th>Ventilation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recommended range</td>
<td>68-75°F</td>
<td>30-60%</td>
<td>6-15 ACH</td>
<td>Neutral</td>
<td>Not specified</td>
</tr>
</tbody>
</table>

Figure 3: ASHRAE recommended range of environmental conditions (Facility Guidelines Institute, 2018)
Though there has been no conclusive research, temperatures between 20 and 25°C, humidity under 68%, and 6 to 15 air changes per hour (ACH) have been recommended in the Guidelines for Environmental Infection Control by the CDC and Healthcare Infection Control Practices Advisory Committee (HICPAC) (L. M. Sehulster et al., 2004). Patient comfort and environmental preferences should also be taken into account.

In a study by Lopez et al., (2013), transfer efficiency from fomite-to-finger was determined under low and high relative humidity conditions. Though most organisms had greater transfer efficiencies under high relative humidity, every microorganism reacted differently to different environmental conditions. Variations in pathogen behavior on a range of surfaces relative to temperature and humidity are summarized in Table 2.

### Table 2: Variations in pathogen behavior on different surfaces relative to temperature and humidity

<table>
<thead>
<tr>
<th>Surface finish/material</th>
<th>Environmental conditions (temperature and humidity)</th>
<th>Impact on pathogen retention, survival, and transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass (Lopez et al., 2013)</td>
<td>Low humidity</td>
<td>High transfer of <em>S. aureus</em></td>
</tr>
<tr>
<td></td>
<td>High humidity</td>
<td>High transfer of <em>E. coli</em></td>
</tr>
<tr>
<td>Laminate (Lopez et al., 2013)</td>
<td>High humidity</td>
<td>High transfer of <em>S. aureus</em></td>
</tr>
<tr>
<td>Acrylic (Lopez et al., 2013)</td>
<td>Low humidity</td>
<td>High transfer of <em>E. coli</em></td>
</tr>
<tr>
<td>Copper (Michels et al., 2009)</td>
<td>High humidity (&gt;90% RH) and typical temperature (20°C)</td>
<td>Less contamination compared with silver ion materials</td>
</tr>
<tr>
<td>Fabric (wool, cotton) (Yeargin et al., 2016)</td>
<td>High humidity (78%) and typical temperature (25°C)</td>
<td>Enteric virus survived 84 days on wool, 42 days on cotton</td>
</tr>
<tr>
<td></td>
<td>Low humidity (35%) and typical temperature (25°C)</td>
<td>Enteric virus survived 140 days on wool, 84 days on cotton</td>
</tr>
</tbody>
</table>

### Cleaning and Disinfecting Environmental Surfaces

The benefits of cleaning soiled surfaces have been acknowledged for over 150 years (Smith, Watkins, & Hewlett, 2012). Several design factors affecting cleanliness, including room type, configuration, and occupancy, have been discussed in other issue briefs. In addition to the ambient environmental conditions mentioned in the previous section, the design and selection of surfaces, materials, and finishes must be considered in light of organizational policies and cleaning procedures (as summarized in Part 2).
It is counterproductive to specify materials that cannot be effectively maintained. With this in mind, the choice of strategies for cleaning environmental surfaces should be determined by factors such as the nature of the items to be cleaned (i.e., critical, semi-critical, or noncritical surfaces), the amount of microorganisms present, their potential for resistance, the level of disinfection required (i.e., high, intermediate, low), and any limitations or specifications of the available products (Quan, Taylor & Zborowsky, 2015; CDC, 2003). As illustrated in Figure 4, disinfection solutions from the literature have been broadly classified (Rutala & Weber, 2013) into three categories:

- Manual cleaning with disinfectants,
- No-touch automated disinfection technologies, and
- Self-disinfecting surfaces.

**Figure 4: Strategies for cleaning environmental surfaces**

Spraying disinfectants (e.g., chlorines, phenols, hypochlorites, quaternary ammonium compounds, accelerated hydrogen peroxide) and wiping surfaces with microfiber/cotton wipes or mops are the first steps of the cleaning process. The concentration of the disinfectant, the choice of applicator, the application process, the ratio of volume to surface area, and the overall contact time can enhance or undermine surface decontamination. In some instances, pathogens can build up on surfaces following cumulative soiling and cleaning cycles (Airey & Verran, 2007). Researchers have observed that after these initial cleaning
operations, no viable cells were found on mirror finishes made of steel or copper. However, after repeated soiling/cleaning cycles over the course of five days, cell buildup was observed (more so on the copper surface).

While regular cleaning is necessary to eliminate pathogens and maintain hygiene, it is not the only mechanism available. Several strategies, such as newer cleaning technologies and self-disinfecting materials, have been outlined in Part 2.

Contrary to expectations of cleanliness, studies have shown that less than 50% of hard surfaces are adequately cleaned when chemical germicides are used (Weber & Rutala, 2013). Moreover, studies show that some lesser known high-touch reservoirs of pathogens (e.g., privacy curtains) are not cleaned or sanitized unless visibly soiled (Bloomfield et al., 2015; Kukla, 2013; McQueen & Ehnes, 2018). The cleanliness of high-touch surfaces in healthcare settings has usually been assessed by visual inspection. But when ATP (adenosine triphosphate) bioluminescence and microbiological screenings (e.g., aerobic colony count) were employed, surfaces that seemed clean did not meet benchmark requirements (Mulvey et al., 2011). Malik et al. (2003) found that 90% of tested surfaces did not meet the required standards.

As a result, a systems approach that takes into account the organization, the people, and the environment is required. Table 3 summarizes the systems approach that could improve design to reduce HAIs via contact transmission.

Table 3: Systems approach to reduce contact transmission HAIs

<table>
<thead>
<tr>
<th>Operational/Organizational factors</th>
<th>People/Behavior</th>
<th>Environmental/Design considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Monitoring mechanisms</td>
<td>• Cleaning responsibility</td>
<td>• Surface and pathogen characteristics for selection of materials/finishes</td>
</tr>
<tr>
<td>• Choice of cleaning method</td>
<td>• Surveillance, monitoring, and feedback</td>
<td>• Facility design (e.g., room layout, configuration)</td>
</tr>
<tr>
<td>• Staff training and knowledge</td>
<td>• Compliance</td>
<td>• Ambient environment (e.g., temperature, humidity, pressurization)</td>
</tr>
<tr>
<td>• Infection prevention stewardship programs involving multiple disciplines</td>
<td></td>
<td>• Equipment, based on cleaning method</td>
</tr>
</tbody>
</table>

Regulatory Oversight

In the United States, chemical sanitizers, disinfectants, and sterilants are regulated by the Antimicrobials Division of the Environmental Protection Agency (EPA). Any substance intended to prevent, destroy, repel, or mitigate
microorganism growth (not including those in or on living humans or animals) must be registered (CDC, 2016b). Treated products are defined as “items that are treated with an antimicrobial pesticide to protect the item itself” (EPA, 2015). The treatment (i.e., pesticide) is usually added to the product during or after manufacture, but prior to usage.

Manufacturers of treated products often claim that they protect against harmful microorganisms, placing them in a regulatory category of implied or explicit public health pesticidal claims. There is, however, a “treated articles exemption” that covers substances claiming to protect the article or substance itself, but not those bearing public health claims against human pathogens (EPA, 2014). In Europe, similar regulations and exemptions are included in the EU Biocides Regulation (Health Safety Executive, 2012).

According to the EPA exemption clause, some examples of language requiring registration as a pesticide include:

- Antibacterial, bactericidal, germicidal
- Kills pathogenic bacteria
- Effective against E. coli and Staphylococcus aureus
- Provides a germ/bacteria-resistant surface
- Kills/controls/minimizes the growth of common Gram-positive and Gram-negative bacteria

Furthermore, the EPA has established some protocols for antimicrobial product testing and labeling. These include testing products against biofilms (EPA, 2017) or Clostridium difficile spores on hard, non-porous surfaces (EPA, 2018), as well as evaluating the bactericidal activity of hard, non-porous copper-containing surface products (e.g., door knobs) (EPA, 2016). All of this speaks to the importance of thoroughly researching any product claims before use.

**Conclusion**

This issue brief has provided an overview of a systems model that can help design teams to understand the epidemiology of infections and their interaction with the healthcare environment. The current and emerging technologies introduced here are discussed in greater depth in Part 2. If and when changes are made to enhance infection control efforts based on these findings, it is
important for design teams to consider the impact of both methods and materials on cleanability and the cleaning process.

Despite research efforts toward improving surface cleanability, as well as guidance from the CDC, EPA, and other government agencies, HAIs continue to be transmitted through fomites in the healthcare environment. There is no single solution to the problem, and no one way to achieve benchmark cleanliness. Every organization must base its design decisions, cleaning procedures, and monitoring methods on the individual environment, organizational values, policies, objectives, and people involved.

For more information, refer to Contact Transmission, Part 2: The Role of Materials, Design, and Cleaning in HAIs.
References


