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SPECIAL REPORT

Cross-Contamination Prevention:
Addressing Keyboards as Fomites

This report presents information on the the chain of infection, bacterial transfer and how to prevent cross-contamination relating to the use of keyboards and other computer equipment in the healthcare environment. It summarizes the medical literature and offers suggestions for best practices relating to keyboard disinfection.

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VIRGO
MEDICAL

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Addressing Keyboards as Fomites

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Cross-contamination may be defined as "the passing of bacteria, microorganisms or other harmful substances indirectly from one patient to another through improper or unsterile equipment, procedures or products." In order to prevent incidences of cross-contamination in the healthcare setting, it is important to review the concept of the chain of infection. According to the Centers for Disease Control and Prevention (CDC), the traditional epidemiologic triad model holds that infectious diseases result from the interaction of agent, host and environment. More specifically, transmission occurs when the agent leaves its reservoir or host through a portal of exit, is conveyed by some mode of transmission, and enters through an appropriate portal of entry to infect a susceptible host. This sequence is referred to as the chain of infection.

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Reservoir

The reservoir of an infectious agent is the habitat in which the agent normally lives, grows and multiplies.

Many common infectious diseases have human reservoirs. Diseases that are transmitted from person to person without intermediaries include the sexually transmitted diseases, measles, mumps, streptococcal infection, and many respiratory pathogens. Because humans were the only reservoir for the smallpox virus, naturally occurring smallpox was eradicated after the last human case was identified and isolated. Human reservoirs may or may not show the effects of illness. A carrier is a person with unapparent infection who is capable of transmitting the pathogen to others. Asymptomatic or passive or healthy carriers are those who never experience symptoms despite being infected. Incubatory carriers are those who can transmit the agent during the incubation period before clinical illness begins. Convalescent carriers are those who have recovered from their illness but remain capable of transmitting to others. Chronic carriers are those who continue to harbor a pathogen for months or even years after their initial infection. Carriers commonly transmit disease because they do not realize they are infected, and consequently take no special precautions to prevent transmission. Symptomatic persons who are aware of their illness, on the other hand, may be less likely to transmit infection because they are either too sick to be out and about, take precautions to reduce transmission, or receive treatment that limits the disease.

Portal of exit

Portal of exit is the path by which a pathogen leaves its host. The portal of exit usually corresponds to the site where the pathogen is localized. For example, influenza viruses and Mycobacterium tuberculosis exit the respiratory tract, schistosomes through urine, cholera vibrios in feces, Sarcoptes scabiei in scabies skin lesions, and enterovirus in conjunctival secretions. Some bloodborne agents can exit through cuts or needles in the skin (hepatitis B).

Modes of transmission

An infectious agent may be transmitted from its natural reservoir to a susceptible host in different ways. There are different classifications for modes of transmission. Here is one classification:

- **Direct**
  - Direct contact
  - Droplet spread
- **Indirect**
  - Airborne
  - Vehicleborne

In direct transmission, an infectious agent is transferred from a reservoir to a susceptible host by direct contact or droplet spread.

Direct contact occurs through skin-to-skin contact, kissing and sexual intercourse. Direct contact also refers to contact with soil or vegetation harboring infectious organisms.

Droplet spread refers to spray with relatively large, short-range aerosols produced by sneezing, coughing, or even talking. Droplet spread is classified as direct because transmission is by direct spray over a few feet, before the droplets fall to the ground. Pertussis and meningococcal infection are examples of diseases transmitted from an infectious patient to a susceptible host by droplet spread.

Indirect transmission refers to the transfer of an infectious agent from a reservoir to a host by suspended air particles, inanimate objects (vehicles), or animate intermediaries (vectors).

Airborne transmission occurs when infectious agents are carried by dust or droplet nuclei suspended in air. Airborne dust includes material that has settled on surfaces and become re-suspended by air currents as well as infectious particles blown from the soil by the wind. Droplet nuclei are dried residue of less than 5 microns in size. In contrast to droplets that fall to the ground within a few feet, droplet nuclei may remain suspended in the air for long periods of time and may be blown over great distances.

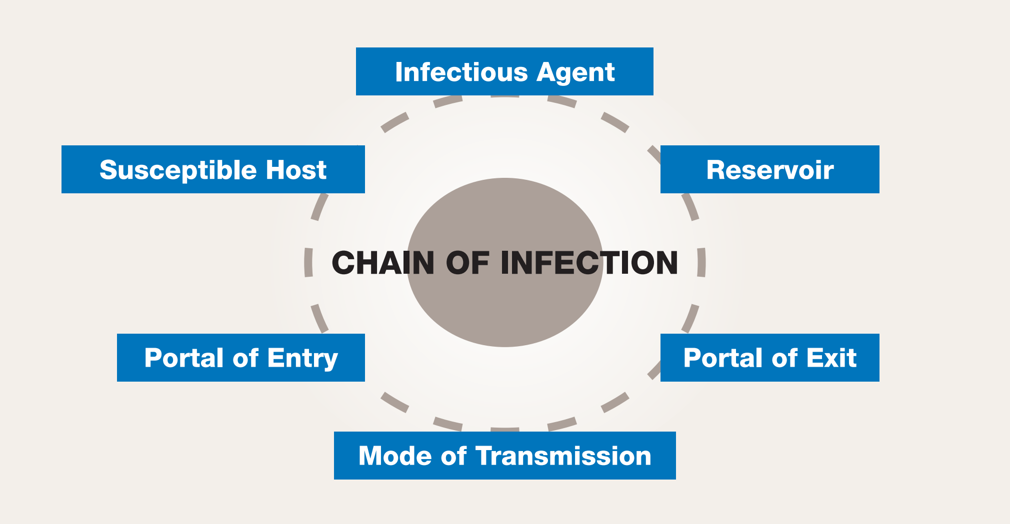
Vehicles that may indirectly transmit an infectious agent include food, water, biologic products (blood), and fomites (inanimate objects s). A vehicle may passively carry a pathogen — as food or water may carry hepatitis A virus. Alternatively, the vehicle may provide an environment in which the agent grows, multiplies, or produces toxin — as improperly canned foods provide an environment that supports production of botulinum toxin by Clostridium botulinum.

Portal of entry

The portal of entry refers to the manner in which a pathogen enters a susceptible host. The portal of entry must provide access to tissues in which the pathogen can multiply or a toxin can act. Often, infectious agents use the same portal to enter a new host that they used to exit the source host. For example, influenza virus exits the respiratory tract of the source host and enters the respiratory tract of the new host. In contrast, many pathogens that cause gastroenteritis follow a so-called "fecal-oral" route because they exit the source host in feces, are carried on inadequately washed hands to a vehicle such as food, water or utensil, and enter a new host through the mouth. Other portals of entry include the skin, mucous membranes, and blood.

Host

The final link in the chain of infection is a susceptible host. Susceptibility of a host depends on genetic or constitutional factors, specific immunity, and nonspecific factors that affect an individual's ability to resist infection or to limit pathogenicity. An individual's genetic makeup may either increase or decrease susceptibility.



Pathogen Persistence

Persistence of pathogenic organisms is a concern. As Kramer, et al. (2006) observe, "The longer a nosocomial pathogen persists on a surface, the longer it may be a source of transmission and thus endanger a susceptible patient or healthcare worker." They add, "The most common nosocomial pathogens may well survive or persist on surfaces for months and can thereby be a continuous source of transmission if no regular preventive surface disinfection is performed." The researchers' review of the literature revealed that most Gram-positive bacteria, such as Enterococcus spp. (including VRE), Staphylococcus aureus (including MRSA), and Streptococcus pyogenes, survive for months on dry surfaces, while many Gram-negative species, such as Acinetobacter spp., Escherichia coli, Klebsiella spp., Pseudomonas aeruginosa, Serratia marcescens, or Shigella spp., can also survive for weeks to months. Candida albicans, a significant nosocomial fungal pathogen, can survive up to four months on surfaces.

Researchers have cited some of the factors that affect pathogen persistence such as the genus, species and strain of the microorganism in question as well as the number of bacteria or viruses on the surface or fomite, as well as environmental factors such as light, temperature, humidity, medium in which the microbe is suspended and the surface on which the microbe is deposited.

As Neely and Sittig (2002) explain, "Humans are surrounded by a number of microorganisms, most of which are completely harmless and some of which are beneficial and even necessary for our existence. At times, however, our interaction with microbes can lead to an infection. In general, at least four factors, some microbial-associated and some host-associated, determine whether an infection will occur. Microbial factors of importance include the number of microorganisms present. The more microorganisms present, the greater the chance of an infection. Secondly, the particular armamentarium of virulence factors that the microbe has will influence its ability to cause an infection. For example, a bacterium that produces a particularly potent toxin can be more apt to cause an infection than one that does not. Third, the most critical factor that the host brings to the interaction is immunologic status. A person who is immunosuppressed or immunocompromised due to any number of circumstances will be more susceptible to an infection. Finally, in order for an infection to occur, the microorganism or its products must come in contact with the host. Contact can happen in a number of different ways. The microbe might directly contact the host, or it might contact the host via an indirect route involving inanimate objects, called fomites, and/or living organisms, called vectors. The fomite, such as a piece of computer hardware, or the vector, such as a healthcare worker, becomes contaminated with a microbe and then serves as a reservoir for transmitting the microorganism to the host by some form of contact. Once the microbe reaches the host, a number of different associations are possible. The presence of a microbe in or on a host with growth and multiplication of that microorganism, but without tissue damage, is termed colonization. Once tissue damage begins, the colonization becomes an infection. Not all colonizations become infections, but all infections are generally preceded by colonization."

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Keyboards and Computer Mice as Fomites

One of the most ubiquitous fomites in the healthcare setting is keyboards. As Neely and Sittig (2002) summarize, “Computer technology from the management of individual patient medical records to the tracking of epidemiologic trends has become an essential part of all aspects of modern medicine. Consequently, computers, including bedside components, point-of-care testing equipment, and handheld computer devices, are increasingly present in patients’ rooms." Neely and Sittig (2002) add, “Over the past 50 years, various forms of computer-based, information management applications have been developed and deployed in the clinical setting. During this time, many system developers have recognized the benefits associated with having computer hardware in the examination room[2] or at the patient’s bedside in the hospital. More specifically, the Institute of Medicine has recognized the importance of having clinicians directly involved in data entry activities at the point of care in order to ensure accuracy and timeliness of the data. Finally, over the past several years the use of portable computing devices by clinicians in the patient’s presence has expanded considerably.”

Only recently have investigators begun to examine the microbial contamination on computer hardware and to ask if these microorganisms might play a role in patient acquired infections.

Neely and Sittig (2002) say that “It has long been recognized that inanimate objects in the patient’s environment can harbor microorganisms. These objects might be medical tools or common nonmedical objects, such as ball point pens, bedrails and bedside tables, or plumbing components that introduce microbes into the bath water. Only recently have investigators begun to examine the microbial contamination on computer hardware and to ask if these microorganisms might play a role in patient acquired infections.”

Let’s take a look at the medical literature:

Duszak, et al. (2014) sought to quantify and characterize bacterial contamination of radiologist workstations. Dictation microphones and computer mice at the most frequently used radiologist workstations from two inpatient and two outpatient reading rooms at two teaching hospitals in two states were sampled for bacteria. Reference toilet seat and doorknob sampling was performed in the four restrooms nearest those reading rooms. One microphone and one mouse in each reading room were sampled again after quick disinfection with an inexpensive, commercially available antiseptic pad. All sampled radiologist computer workstation and restroom sites were contaminated with bacteria. Mean colony counts were 69.4 ± 38.7 (range, 15-123) for microphones, 46.1 ± 58.1 (range, 1-173) for mice, 10.5 ± 9.7 (range, 1-22) for toilet seats, and 14.8 ± 16.0 (range, 1-36) for restroom doorknobs. Of all workstation sites, 64.3 percent (9 of 14) grew Staphylococcus aureus, and 21.4 percent (3 of 14) grew enteric organisms. Overall microphone and mouse bacterial contamination was significantly higher than that of nearby restroom toilets and doorknobs (57.8 ± 49.0 vs 12.6 ± 12.5, $P = .005$). Microphone and mouse bacterial counts were nearly completely eliminated after brief antiseptic swabbing (from 76.9 ± 53.2 to 0.3 ± 0.7, $P = .002$).

Messina, et al. (2013) analyzed 37 telephone handsets, 27 computer keyboards, and 35 stethoscopes, comparing their contamination in four hospital units. Before cleaning, many samples were positive for Staphylococcus spp. and coliforms. After cleaning, CFUs decreased to zero in most comparisons. The first aid unit had the highest and intensive care the lowest contamination. Keyboards and handsets had higher TBC at 22°C and mold contamination than stethoscopes. Healthcare professionals should disinfect stethoscopes and other possible sources of bacterial healthcare-associated infections. The cleaning technique used was effective in reducing bacterial contamination. The researchers say that units with high patient turnover should practice stricter hygiene.

Enemuor, et al. (2012) sought to isolate and to identify microorganisms associated with computer keyboards and mice in computer centers and cyber café located in Kogi State University, Anyigba, Nigeria and its environs. Samples were collected from five different cyber café and computer centers. The samples were collected from three computer keyboards and mice in each cyber café and computer centers. The collected samples were inoculated on nutrient agar, MacConkey agar and potato dextrose agar by following standard methods. The isolates obtained were examined and identified by colonial morphology, Gram reaction and biochemical characteristics. Four bacterial and four fungal species were isolated from the samples. The bacterial isolates include Staphylococcus aureus, Enterococcus sp., Staphylococcus epidermidis and Streptococcus sp. The fungal isolates are as follows Aspergillus sp., Mucor sp., Penicillum sp. and Rhizopus sp. These microorganisms have pathogenic potential and hence their presence on such surfaces (computer keyboards and mice) may be additional reservoirs for the transmission of microorganisms and become vectors for cross-transmission of bacterial and fungal infections.

Al-Ghamdi, et al. (2011) investigated the bacterial contamination of four objects used daily: computer keyboards, computer mice, elevator buttons and shopping carts handles. A total of 400 samples were collected from the four different objects; 100 from each. Samples were collected from different places (offices, internet cafes, homes, buildings and supermarkets) in the city of Jeddah, Saudi Arabia. 95.5 percent of the total samples collected were contaminated with mixed bacterial growth. Coagulase-negative staphylococci dominated the isolates. The second most common bacterial growth in all specimens was Gram-positive bacilli. Potential pathogens isolated from all specimens were: Staphylococcus aureus, Pseudomonas spp. and Gram negative bacilli. Results indicate that internet café computer keyboards and mice showed 100 percent contamination in comparison with other objects. The presence of pathogenic and commensal bacteria on the four objects indicates that they might act as environmental vehicles for the transmission of potentially pathogenic bacteria.

Pugliese, et al. (2011) assessed the prevalence and type of keyboard contamination in the emergency department environment to determine whether keyboard exchange was warranted. A total of 72 standard, non-silicone rubber keyboards were swabbed by the same investigator on two different days six days apart. All keyboard keys except the function keys were cultured and analyzed for pathogenic organisms. Ten (13.8 percent) of the 72 keyboards were colonized with nine different bacteria. Three keyboards (4.2 percent) grew gram-positive bacteria, and nine keyboards (12.5 percent) grew gram-negative bacteria. None were colonized with Clostridium difficile. A higher degree of contamination was found on keyboards located in non-clinical areas versus clinical areas (31.9 percent vs. 8.9 percent). The researchers noted that the identification of keyboard contamination does not necessarily imply association with an increased infection risk to patients. We found the prevalence of colonization with pathogenic organisms to be low on standard keyboards. Contamination predominantly occurred in non-clinical areas, suggesting that such areas with little hands-on patient contact (and likely less frequent hand washing) may require installation of silicone keyboards. However, additional studies are warranted to determine if measures such as routine cleaning or use of silicone or antibacterial keyboards would decrease this prevalence.

Keyboards were implicated in a norovirus outbreak. Morter, et al. (2011) collected norovirus (NoV) strains over a four-month period during 2009-2010 from hospitalized patients with symptoms of gastroenteritis. These were characterised in order to estimate how many strains were introduced into the hospital from the community. In addition, environmental swabbing was performed after clinical cleaning of bays or wards accommodating infected patients. This was performed in order to assess the efficiency of cleaning and identify any NoV contamination in the environment. A total of eight distinct genetic clusters of NoV GII-4 genotype were identified during the four-month period, with some wards experiencing multiple outbreaks with different GII-4 strains during the season. NoV was detected from 31.4 percent of environmental swabs post cleaning. Notes trolleys, computer keyboards, soap and alcohol dispensers, blood pressure equipment, pulse oximeters and tympanic thermometers were identified as NoV reservoirs but contamination was also found on surfaces around the bedside environment, and furniture, fixtures and fittings associated with toilets and shower rooms.

Lu, et al. (2009) conducted their study in a 1,600-bed medical center of southern Taiwan with 47 wards and 282 computers. With education and monitoring program of hand hygiene for HCWs, the average compliance rate was 74 percent before surveillance. The researchers investigated the association of methicillin-resistant Staphylococcus aureus (MRSA), Pseudomonas aeruginosa and Acinetobacter baumannii, three leading hospital-acquired pathogens, from ward computer keyboards, mice and from clinical isolates in non-outbreak period by pulsed field gel electrophoresis and antibiogram. The results revealed a 17.4 percent (49/282) contamination rate of these computer devices by S. aureus, Acinetobacter spp. or Pseudomonas spp. The contamination rates of MRSA and A. baumannii in the ward computers were 1.1 percent and 4.3 percent, respectively. No P. aeruginosa was isolated. All isolates from computers and clinical specimens at the same ward showed different pulsotypes. However, A. baumannii isolates on two ward computers had the same pulsotype.

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Anderson and Palombo (2009) investigated the number and nature of contaminating microorganisms on the keyboards of personal computers located in three large, multiple-user facilities located on a university campus. These were compared with the computers located in staff offices that were generally handled by one individual. Overall, a greater number of microorganisms was detected on the keyboards of the multiple-user computers, with an average of 20.1 colonies per square centimeters, whereas the single-user keyboards had an average of 4.5 colonies per square centimeters. The number and types of potentially pathogenic bacteria were also greater on the multiple-user keyboards. Forty-seven percent of multiple-user keyboards were found to harbor Staphylococcus aureus, compared with only 20 percent of the single-user key-boards. In one of the multiple-user laboratories, 60 percent of keyboards contained S aureus. Other potentially pathogenic bacteria were also isolated from the multiple-user keyboards, which were not detected on the single-user workstations.

Po, et al. (2009) say that keyboards in intensive care units have been shown to serve as reservoirs for multidrug-resistant microorganisms. The thoroughness of disinfection cleaning of keyboards on computers on wheels (COWs) in an intensive care units of an academic medical center were evaluated using an invisible florescent marker, and the movements of the COWs were tracked using their serial numbers. Following a series of educational and programmatic interventions, the researchers were able to improve the thoroughness of cleaning to 100 percent.

Engelhart, et al. (2008) sought to assess the level of microbial contamination of computer user interfaces in a large tertiary-care center under conditions of practice. A total of 300 samples were collected from 100 workstations by direct contact using Columbia blood agar Rodac plates. In total 32 percent of workstations proved positive for growth of potentially pathogenic microorganisms (Staphylococcus aureus, 12 percent; viridans streptococci, 11 percent; enterococci, 8 percent; Gram-negative microorganisms, 14 percent). The highest contamination rates were found when samples were collected immediately after the computer workstation had been touched by users (47 percent vs. 25 percent). Stratification for other variables (type of patient care, type of room, number of persons using the workstation) yielded no significant differences. Regarding the fungal contamination 25 percent of workstations proved positive, however, with low absolute concentrations (range, 1 to 2 cfu/25 cm2). On general wards fungi were detected significantly more often than in ICUs (44 percent vs. 7 percent).

Wilson, et al. (2008) performed in vitro studies to demonstrate bacterial transfer between keyboard surfaces and gloves. This was followed by a usability study and a controlled trial of keyboard contamination in an intensive care unit both with and without an alarm to indicate the need for cleaning. Eight cleanable keyboards were placed at random beds and compared with standard keyboards. Bacteria were most easily removed from a flat silicone-coated surface. The total viable count on flat keyboards with an alarm was lower than that on standard or other cleanable keyboards (median, 19 colony-forming units [cfu] (interquartile range, 7 to 40 cfu), n = 34; 65 cfu (33 to 140 cfu), n = 50; and 40 cfu (21 to 57 cfu), n = 80). Compliance with hand hygiene before touching the standard keyboard was 27 percent, but the alarmed keyboard was cleaned on 87 percent of occasions on which the alarm was triggered. The usability study found the flat profile of the cleanable keyboard did not interfere with routine use, except for touch-typing.

Rutala, et al. (2006) assessed the effectiveness of six different disinfectants (one each containing chlorine, alcohol or phenol and three con-taining quaternary ammonium) against three test organisms (oxacillin-resistant Staphylococcus aureus [ORSA], Pseudomonas aeruginosa, and vancomycin-resistant Enterococcus species) inoculated onto study computer keyboards. The researchers also assessed the computer key-boards for functional and cosmetic damage after disinfectant use. Potential pathogens cultured from more than half of the computers included coagulase-negative staphylococci (100 percent of keyboards), diphtheroids (80 percent), Micrococcus species (72 percent), and Bacillus species (64 percent). Other pathogens cultured included ORSA (4 percent of keyboards), OSSA (4 percent), vancomycin-susceptible Entero-coccus species (12 percent), and non-fermentative gram-negative rods (36 percent). All disinfectants, as well as the sterile water control, were effective at removing or inactivating more than 95 percent of the test bacteria. No functional or cosmetic damage to the computer keyboards was observed after 300 disinfection cycles.

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Garcia, et al. (undated) swabbed a total of 72 standard, non-silicone rubber keyboards on two different days six days apart. All keyboard keys except the function keys were cultured and analyzed for pathogenic organisms. Ten (13.8 percent) of the 72 keyboards were colonized with nine different bacteria. Three keyboards (4.2 percent) grew gram-positive bacteria, and nine keyboards (12.5 percent) grew gram-negative bacteria. None were colonized with Clostridium difficile. A higher degree of contamination was found on keyboards located in non-clinical areas versus clinical areas (31.9 percent vs. 8.9 percent).

Hartmann, et al. (2004) sought to examine the microbial contamination of computer user interfaces with potentially pathogenic microorganisms, compared with other fomites in a surgical intensive care unit of a tertiary teaching hospital. Sterile swab samples were received from patient’s bedside computer keyboard and mouse, and three other sites (infusion pumps, ventilator, ward round trolley) in the patient’s room in a 14 bed surgical intensive care unit at a university hospital. At the central ward samples from keyboard and mouse of the physician’s workstation, and control buttons of the ward’s intercom and telephone receiver were obtained. Quantitative and qualitative bacteriological sampling occurred during two periods of three months each on eight nonconsecutive days. In all 14 patients’ rooms a total of 1,118 samples: 222 samples from keyboards and mice were collected, 214 from infusion pumps and 174 from the ward’s trolley. From the central ward 16 samples per formites were obtained (computer keyboard and mouse at the physician’s workstation and the ward’s intercom and telephone receiver). Microbacterial analysis from samples in patients’ rooms yielded 26 contaminated samples from keyboard and mouse

(5.9 percent) compared with 18 positive results from other fomites within patients' rooms (3.0 percent). At the physician's computer terminal two samples obtained from the mouse (6.3 percent) showed positive microbial testing whereas the ward's intercom and telephone receiver were not contaminated.

Schultz, et al. (2003) reported that in the Veterans Affairs Medical Center of Washington, DC, more than 2,000 computers are used for many aspects of medical care; computer workstations are used by all levels of staff throughout the hospital. This study was undertaken to evaluate the extent of contamination of computer keyboards in the acute care, ambulatory care, and long-term–care areas of this medical center. The researchers tested 100 keyboards in 29 clinical areas for bacterial contamination. Most were positive for skin organisms: 84 for coagulase-negative Staphylococcus, 44 for Bacillus species, and 8 for Corynebacterium species. There were 9 keyboard cultures positive for streptococci, 4 for Clostridium perfringens, 4 for enterococci (including 1 for vancomycin-resistant Enterococcus), 1 for Staphylococcus aureus, 2 for Pseudomonas luteola, 6 for gram-negative rods, and 2 for fungi. Five of 100 cultures showed no growth of microorganisms. Three of 5 cultures from the operating room were negative, whereas only 2 of 95 cultures from other patient-care areas were negative. As Schultz, et al. (2003) emphasize, "Computers have become ubiquitous in the hospital environment. In our hospital, both fixed and mobile computers are present in patient rooms, offices, examination rooms, operating suites, and other clinical and non-clinical areas. It is of concern that computers in all areas of the medical center were contaminated with microorganisms. It is of interest that in the operating room, where there is heightened awareness of hand hygiene and environmental sanitation, 3 of 5 cultures had no growth of organisms. Healthcare workers must understand that computers represent yet another item in the medical care setting that needs to be considered as a possible source of nosocomial infection. Cleaning of computer equipment must be incorporated into routine cleaning procedures. Options include plastic keyboard covers, or solid, water-resistant keyboards, both of which can be sanitized on a routine basis."

Devine et al. (2001) cultured for MRSA on ward computer terminals in two different hospitals. In hospital A, 12 terminals were cultured and 5 (42 percent) were positive for MRSA. In hospital B, 13 terminals were swabbed and 1 (8 percent) was positive for the bacteria. Not surprisingly, hospital A had a significantly higher rate of MRSA transmission for its patients than hospital B. These data are consistent with computer keyboards playing a role in the transmission of the bacteria.

Bures et al. (2000) cultured a number of microorganisms in an adult intensive care unit (ICU), including methicillin-resistant Staphylococcus aureus (MRSA), Enterococcus, and Enterobacter, from computer keyboards. Cultures from patients in the ICU showed similar microorganisms. Since MRSA can potentially be a particularly dangerous microbe, the MRSA on the keyboards was compared with the MRSA in the infected patients, using pulse-field gel electrophoresis, a particularly sensitive molecular genetics technique for distinguishing among isolates of the same genus and species. This technique showed that the MRSA causing clinical infection in two of the ICU patients was identical to the MRSA isolated from the keyboards, thereby establishing a direct connection between the infected patients and the computers.

Neely et al. (1999) reported a more extensive study in a burn unit in which there had been an increase in acquired Acinetobacter baumannii colonizations. An epidemiologic investigation showed this microorganism to be present more often on computer keyboard covers than on any other objects in the patients' rooms. The increase in patient colonization coincided temporally with the introduction of bedside computers into the patients' rooms. Once control measures were introduced to decrease the presence of microorganisms on the keyboards, the colonization rate for A. baumannii on the burn patients returned to its original low level. Such findings strongly suggest a link between contaminated computer keyboards and colonization in this group of patients.

Isaacs et al. (1998) swabbed keyboards in a burn unit were one time to determine if the keyboards could be contributing to an increase in antibiotic-resistant bacteria in their patients. Resistant isolates were not found, leading the authors to conclude that the computer keyboards were not a significant source of the spread of the resistant bacteria in their unit. It is interesting that while the two types of antibiotic-resistant bacteria that they sought were not found, other bacteria, Staphylococcus aureus and Pseudomonas, both of which are capable of causing serious infections in burn patients, were found on the computer terminals.

Microbial Survival and Transfer

Neely and Sittig (2002) address the factors that influence the link between computer hardware such as keyboards and patients: "Two factors that play a role in the link between any fomite, such as a piece of computer hardware, and the patient are the ability of a particular microbe to survive on a particular surface and the fact that various vectors, such as health care workers, can transfer microorganisms from one surface to another. Microorganisms survive for different periods of time on different surfaces. Survival varies depending upon the particular microbe, the particular surface, and the concentration of the microorganism on the surface. In general, the greater the concentration of the microbe, the longer it survives. Survival can range from minutes to months. Obviously, if a microbe only survives for a few minutes on an inanimate object, such as the computer terminal, then the possibility of that microbe being acquired by a patient is quite small. However, conversely, if particular bacteria or fungi survive for weeks to months on a certain surface, then the odds of that organism being picked up by a patient or healthcare worker are considerably increased."

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Experts are still trying to understand the role that manufactured materials may play in disease transmission. Since many computer components are made of plastic, there is potential for this material to harbor pathogens. A number of studies (Neely and Maley 2000; Neely 2000; and Neely and Orloff 2001) examined the survival of a variety of bacteria and fungi on a number of different fabrics and plastics (including the plastic skins used to protect computer keyboards). The researchers found that microbial survival was often days to weeks on both types of surfaces; however, when there was a difference in survival between the fabrics and the plastics, the microbes tended to live longer on plastics. Thus, Neely and Sittig (2002) point out, "The long survival times of certain microorganisms, particularly on plastics such as those associated with computers, contributes to the possibility of computers acting as reservoirs for these microbes."

Hand transfer of pathogens to and from inanimate surfaces/fomites has been the focus of a number of studies. For example, Rangel-Frausto et al. (1994) found that in 90 percent of their tests the yeast Candida albicans was transferred from a plastic surface to a person's hands and that in 90 percent of their trials, the yeast was transferred from the hands to a plastic surface. Noskin, et al. (2000) showed that the bacterium Enterococcus faecium likewise was directly transferred from a vinyl surface to a person's hands. Studies have also demonstrated that microbes can be transferred from person to person. Rangel-Frausto et al (1994) showed that yeast was transferred from hand to hand 69 percent of the time, and various outbreaks of both bacterial and fungal infections in patients have been traced to a specific individual healthcare worker. Therefore, these studies indicate that it is possible for a long-lived microbe on a computer keyboard to be transferred to a staff member's hands and then to a patient where it could potentially cause an infection.

Cross-Contamination and Pathogen Transmission

One of the easiest ways that pathogens are transferred in the healthcare environment is via hand carriage. Inanimate surfaces come into play as healthcare workers' hands easily become colonized by pathogenic microorganisms from handling contaminated equipment or touching inanimate surfaces in patients' immediate surroundings.

Sexton, et al. (2006) found that pathogens can be transferred from patients to their immediate environment. The researchers isolated MRSA from patients during routine screening that were very similar to those recovered from isolation rooms after the rooms had undergone terminal cleaning. Hardy et al. (2006) found that strains isolated from patients and their immediate environment were indistinguishable 35 percent of the time and that at least three of the 26 patients studied had become colonized with MRSA from the environment. McBryde, et al. (2004) investigated cross contamination between healthcare workers after contact with MRSA-colonized patients or their local environment. It was found that 17 percent of previously un-colonized healthcare workers became colonized with MRSA, and that transfer of organisms by hands was a significant factor. Duckro et al., (2005) found that 10.6 percent of sites that had previously been tested and found to be free of VRE became contaminated after a HCW worked touched them having previously touched a site contaminated with VRE.

As Crnich et al. (2005) observe, "A variety of nosocomial pathogens can be recovered from surfaces of the inanimate hospital environment. The capacity of these organisms to persist for weeks to months on surfaces such as tabletops, bed railings and linens raises concern about indirect horizontal transmission of pathogenic microorganisms. Many Gram-positive organisms, especially enterococci and S. aureus, retain viability for periods in excess of three months when incorporated in dried organic materials commonly found on hospital surfaces. In contrast, Gram-negative organisms subsist for much shorter periods, in the order of hours, with the exception of Klebsiella species, Acinetobacter species, and Enterobacter species, which can retain viability for several days. The capacity of surface organisms to secondarily contaminate HCWs' hands and clothes without any direct patient contact provides support for the role of hospital surfaces in the horizontal spread of hospital pathogens."

Weber, et al. (2010) note that although the main source of nosocomial pathogens is likely the patient's endogenous flora, an estimated 20 percent to 40 percent of HAIs have been attributed to cross infection via the hands of healthcare personnel, which have become contaminated from direct contact with the patient or indirectly by touching contaminated environmental surfaces. They refer to multiple studies that strongly suggest that environmental contamination plays an important role in the transmission of MRSA and VRE. More recently, evidence suggests that environmental contamination also plays a role in the nosocomial transmission of norovirus, Clostridium difficile, and Acinetobacter spp. These aforementioned pathogens survive for prolonged periods of time in the environment, and infections have been associated with frequent surface contamination in hospital rooms and healthcare worker hands. In some cases, the extent of patient-to-patient transmission has been found to be directly proportional to the level of environmental contamination.

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> Many Gram-positive organisms, especially enterococci and S. aureus, retain viability for periods in excess of three months when incorporated in dried organic materials commonly found on hospital surfaces.

Crnich et al. (2005) looked at environmental sources of colonization in the animate and inanimate environments, with the contaminated hands of HCWs as a leading vector. Crnich et al. (2005) report, "Larson found that 21 percent of hospital employees' hands were persistently colonized by Gram-negative bacilli, including Acinetobacter, Klebsiella, and Enterobacter, and Goldmann et al. found that as many as 75 percent of neonatal ICU HCWs' hands were colonized by potentially pathogenic Gram-negative bacilli. Maki found that the hands of 64 percent of ICU personnel sampled at random were colonized at some time by S. aureus, and 100 percent showed transient carriage of a variety of Gram-negative bacilli at least once during the period of surveillance."

Kramer, et al. (2006) note: "In hospitals, surfaces with hand contact are often contaminated with nosocomial pathogens, and may serve as vectors for cross transmission. A single hand contact with a contaminated surface results in a variable degree of pathogen transfer. Transmission to hands was most successful with Escherichia coli, Salmonella spp., Staphylococcus aureus (all 100 percent), Candida albicans (90 percent), rhino virus (61 percent), HAV (22 percent to 33 percent), and rotavirus (16 percent). Contaminated hands can transfer viruses to five more surfaces or 14 other subjects. Contaminated hands can also be the source of re-contaminating the surface, as shown with HAV [55,58]. Compliance rates of healthcare workers in hand hygiene are known to be around 50 percent. Due to the overwhelming evidence of low compliance with hand hygiene, the risk from contaminated surfaces cannot be overlooked." They add, "The main route of transmission is via the transiently contaminated hands of the healthcare worker."

Some studies have also looked at how gloved hands are implicated in transmission of pathogens. Ray, et al. (2007) donned sterile gloves and then touched the bedrails and bedside tables of patients with documented vancomycin-resistant enterococci (VRE) in their stools. Direct culturing of the surfaces showed that 12 of the 13 surfaces (92 percent) were positive for VRE and 6 of the glove cultures (46 percent) were positive.

Stiefel, et al. (2011) demonstrated that hand contamination was likely to be equal after contact with commonly examined patient skin sites and commonly touched environmental surfaces in patient rooms, and that their findings suggest that contaminated surfaces may be an important source of MRSA) transmission. As the researchers note, "The relative importance of environmental surfaces compared with patients' skin as a source for contamination of the hands of healthcare workers is unclear. Because some studies suggest that acquisition of S. aureus on hands is common after contact with contaminated surfaces, we hypothesized that the frequency of MRSA acquisition and the quantity of MRSA acquired on hands is similar after contact with skin sites and environmental surfaces in the rooms of MRSA carriers."

> "The main route of transmission is via the transiently contaminated hands of the healthcare worker.

In their two-month study at a 285-bed Veterans Affairs hospital that conducts surveillance for anterior nares carriage of MRSA for all inpatients, the researchers enrolled a sample consisting of 40 patients admitted with MRSA colonization or infection. During the study, sodium hypochlorite (5,000 ppm) was used for disinfection of rooms after discharge of MRSA patients, but "high-touch" surfaces were not cleaned on a daily basis unless they were visibly soiled. The researchers obtained samples for gloved hand-imprint cultures from patient skin sites such as the abdomen, chest, forearm, and hand, as well as from environmental sites including the bed rail, bedside table, telephone, and call button, to compare the risk of hand contamination after contact with skin compared with the environment,

Stiefel, et al. report that the risk of any gloved-hand contamination after contact with the skin sites and the environmental surfaces was not significantly different (40 percent v ersus 45 percent). They add that there was also no significant difference in the mean number of colony-forming units (CFUs) per gloved handprint acquired after contact with skin and environmental sites . The most frequent skin and environmental sites associated with hand acquisition were the abdomen or chest and the call button, respectively. Of the skin sites, patients' abdomen had the highest number of colonies acquired on gloved hands. Of the environmental sites, the call button had the highest number of colonies acquired by gloved hands.

The researchers write, "Our findings have several practical implications for control of MRSA. First, our findings provide support for the recommendation that healthcare workers routinely disinfect their hands after contact with inanimate objects in the immediate vicinity of patients. In our facility, healthcare workers' compliance with hand hygiene is statistically significantly lower after contact with environmental surfaces only compared with that after contact with patients (authors' unpublished data), suggesting that healthcare workers need education regarding the importance of the environment as a source for hand contamination. Second, because MRSA may survive for long periods on surfaces, our findings reinforce the importance of environmental disinfection after discharge of MRSA patients. Finally, it is possible that daily disinfection of high-touch surfaces in MRSA isolation rooms might reduce the level of contamination and decrease the risk for acquisition on healthcare workers' hands."

"The risk of transmission from contaminated keyboards would be eliminated if staff performed hand hygiene after contact with inanimate objects in the patient care environment.

Solutions to the Problem of Cross-Contamination

As Rutala, et al. (2006) emphasize, "The risk of transmission from contaminated keyboards would be eliminated if staff performed hand hygiene after contact with inanimate objects in the patient care environment. Unfortunately, studies have demonstrated low compliance (approximately 40 percent) with the CDC guidelines on hand hygiene. Therefore, we agree with other investigators who have recommended that routine disinfection be performed on computer keyboards that are used in patient-care areas. Computers in these areas should be disinfected daily and when visibly soiled. In an effort to prevent contamination of computers, healthcare personnel should not touch computer keyboards with contaminated hands. If a keyboard cover is used, we suggest that it should be disinfected using these same recommendations. Additionally, mobile computers used by patients should be disinfected between patient uses. Ideally, computers used by a patient under isolation precautions should remain in the patient's room until no longer needed and should then be disinfected before use by another person. Our data demonstrate that keyboards can be safely and successfully decontaminated with disinfectants, such as quaternary ammonium compounds."

Basic infection prevention and control practices can address the problem of cross-contamination in the healthcare setting. Neely and Sittig (2002) remind us of a key principle when dealing with contaminated inanimate objects: "Before a microbe or its product can even potentially cause an infection in a patient, it must come in contact with that patient. Therefore all of the solutions discussed below have the single purpose of decreasing or eliminating the number of computer-associated microorganisms that come in contact with a patient."

Neely and Sittig (2002) offer a number of suggestions:

1 Engineering or Process Controls Versus Behavioral Controls

"In general, it is preferable to engineer the physical environment or configure a process so that it is difficult for an error, such as contamination, to occur rather than to depend on consistent, meticulous behavior alone to prevent errors (contamination). For example, in many patient rooms, space is at a premium, and it is possible that the computer terminal might be located close enough to the sink so that it could be splattered and thereby contaminated with microorganisms during the course of cleaning objects or hands. One control would be to advise staff to be careful not to splash the keyboard when using the sink; however, with multiple duties, it is unlikely that this care would always occur. A better control would be either to relocate computer or to simply place a water impermeable barrier, such as a plastic panel, between the sink and the keyboard. With the barrier in place, the behavior of the people using the sink becomes a moot point as far as splashing the keyboard is concerned. Other examples of engineering and process controls are the use of a computer keyboard cover and of an infrared mouse to allow the process of computer cleaning/disinfection to be easier and more effective than relying on a person to meticulously clean the keyboard or the mechanical mouse without harming the hardware. Such engineering or process controls may take a little forethought and may also involve a bit of expense. However, if they save staff time, decrease the need for continuous staff behavior surveillance and education, and/or prevent nosocomial infections, they are often worth the up-front time and expense."

2 Cleaning and Disinfecting

"Because dirt can harbor microbes from the normal disinfecting process, successful disinfection should be preceded by cleaning. However, certain disinfectant cleaners may accomplish both tasks in one process. There is no perfect disinfecting agent; each chemical has its own advantages and disadvantages, depending on the situation in which it is used. Therefore, in any medical facility, the infection control personnel should be consulted about appropriate cleaning/disinfecting agents and procedures. Factors to be considered include the level of disinfection necessary for that particular computer, the potential types of organic and microbial contamination that might be present, and the cleaning/disinfecting agents available. When choosing these agents, besides efficacy in disinfection, issues such as patient and personnel safety (e.g., flammability, toxicities), ease of use (e.g., availability, need for pre-mixing), aesthetics (e.g., odors, color changes), and costs need be considered. In addition, one needs to assess the compatibility of the disinfecting chemical with the computer hardware to be cleaned/disinfected. Many chemical disinfectants require that the surface to be disinfected be exposed to the liquid disinfectant for 10 minutes. Such exposure could create an electrical or corrosive problem to certain pieces of computer hardware. In some circumstances, such as the computer keyboard, the problem of chemical damage to the keyboard components can be alleviated by the use of a thin plastic keyboard cover (aka skin), which can be liberally soaked with disinfectant without fear of compromising the computer."

3 Handwashing and Gloving

"Microorganisms on the skin are generally divided into two categories. Resident flora are microbes that normally colonize or live on the skin of most individuals; they generally do not cause infections unless they are introduced into normally sterile body sites and/or unless the host is immunocompromised. In contrast, transient flora are microbes that are present on the skin for only a short time; they tend to be more pathogenic than the resident flora and are responsible for most nosocomial acquired infections. These transient or contaminant flora may be picked up by the hands of a healthcare worker; for example, when they touch a patient or any contaminated object, such as a computer component. Handwashing is a process which removes soil and transient microorganisms from the hands. Hence the simple process of handwashing has long been a mainstay of any control measure for reducing nosocomial infections … In addition to soaps for handwashing, "waterless" agents are available. These alcohol rubs are presently being considered as a replacement for soap and water in the 2002 Guideline for Hand Hygiene of the CDC's Healthcare Infection Control Practices Advisory Committee. It is important to realize that these agents are disinfectants and not cleaners. Therefore, any visible soil must first be removed before the alcohol will be completely effective. Also, it is recommended that after five or six consecutive uses, the hands be washed with soap and water to remove any build-up of agent. A word of caution about gloves: gloves are not a substitute for handwashing. Generally, hands should be washed before gloves are donned; gloves should be picked up by the cuff to prevent contamination of the surface, which may touch a patient or clean object, and hands should be washed after gloves are removed. Gloves provide an extra amount of protection, and therefore may be used as an adjunct to handwashing, but not instead of handwashing. There can certainly be circumstances when gloves can be used to decrease the transfer of microbes, but it is important to note that gloves alone, without an appropriate protocol for use, could potentially increase transfer, by giving the wearer a false sense of security. For example, washing one's hands and putting on gloves prevent the wearer's resident flora from touching the patient or computer and the patient or computer microbes from reaching the hands of the wearer. However, they do not prevent the wearer from transferring microbes from the computer to the patient or vice versa, because the gloves can carry organisms from place to place or person to person as easily as the ungloved hands."

> "Our data demonstrate that keyboards can be safely and successfully decontaminated with disinfectants, such as quaternary ammonium compounds.

Introducing Computer Equipment into the Patient-Care Environment

Neely and Sittig (2002) say that when introducing any piece of computer hardware into any medical situation, the following guidelines might be helpful:

1 Consult with infection control personnel

"There are several advantages to working with the local infection control staff. First, if a new piece of hardware is going into the patient's area, staff will appreciate knowing this, because it constitutes a change in the patient's environment. Hence should any changes in colonization rate or infection rate occur in the patients, the new elements of the environment could be immediately evaluated to see if they are a contributing factor. Secondly, the local infection control staff will know what the routine cleaning and disinfecting agents are as well as what the routine cleaning schedule is. From a practical point of view, if the hospital's cleaning and disinfecting routines are appropriate for the new equipment, these accepted routines should be used rather than introducing a totally different protocol for one piece of equipment. Third, should special infection control-related protocols need to be established relative to the hardware, the infection control staff can advise the computer or technical services department as to how to monitor that the protocols are being correctly followed. Finally, the local staff are an excellent resource for the following two guidelines."

2 Determine the risk level of the patients served at each computer location

"Recognizing that microorganisms are ubiquitous and that most microbes are harmless to most people, it would be a waste of both time and money to impose more computer hardware infection control procedures than are needed to protect the patient population. On the other hand, being cognizant of the morbidity, mortality and costs of nosocomial infections, it is imperative that adequate infection control procedures are in place to protect high-risk patients. Hence, one needs to balance the infection control measures with the level of risk of the patients being served."

3 Determine how the computer equipment is being used

"The actual usage of the computer component also affects appropriate control measures. Do personnel go back and forth between the computer and the patient? Do staff enter a patient room simply to use the computer and then leave and go to another patient's room? Does the piece of computer equipment move from room to room? In the case of the latter two questions, it is important to remember that anything in the patient's environment will probably be contaminated with microorganisms from that patient. In an intensive care unit situation, it is quite likely that the patient will be colonized by microorganisms that can cause nosocomial infections in other ICU patients. Therefore, anyone (such as a staff member) or anything (such as a portable computer) that contacts anything in the patient's room should be considered to be contaminated and needs to be disinfected before leaving the room. For example, a staff person enters an ICU room, washes the hands, and dons gloves, according to hospital protocol; then the person enters data into the handheld computer and sets the device down in the patient's room, retrieves the handheld computer, removes the gloves, and washes their hands before leaving the room. Because the handheld computer contacted a surface in the ICU patient's room, it should be considered to be contaminated with the ICU patient's flora, and it needs be recognized that the staff member, even though they followed all protocols for handwashing and gloving upon entering and leaving the ICU, could still transfer microorganisms to the next ICU patient through his handheld computer device. Hence, if a piece of portable computer equipment comes in contact with any of the environment in a patient's room, then that piece of equipment needs to be decontaminated before being brought into another ICU patient's room. If the decontamination process for the piece of portable equipment is complicated, then consideration should be given to restricting the use of these portable devices in rooms of immunocompromised ICU patients."

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