SURGICAL INFECTIONS
Volume 15, Number 6, 2014

DOI: 10.1089/sur.2014.011

Surface Contamination in Operating Rooms: A Risk for Transmission of Pathogens?

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Abstract

Background: The role of surface contamination in the transmission of nosocomial pathogens is recognized increasingly. For more than 100 years, the inanimate environment in operating rooms (e.g., walls, tables, floors, and equipment surfaces) has been considered a potential source of pathogens that may cause surgical site infections (SSIs). However, the role of contaminated surfaces in pathogen acquisition in this setting generally is considered negligible, as most SSIs are thought to originate from patients' or healthcare workers' flora.
Methods: A search of relevant medical literature was performed using PubMed to identify studies that investigated surface contamination of operating rooms and its possible role in infection transmission.
Results: Despite a limited number of studies evaluating the role of surface contamination in operating rooms, there is accumulating evidence that the inanimate environment of the operating room can become contaminated with pathogens despite standard environmental cleaning. These pathogens can then be transmitted to the hands of personnel and then to patients and may result in SSIs and infection outbreaks.
Conclusion: Contaminated surfaces can be responsible for the transmission of pathogens in the operating room setting. Further studies are necessary to quantify the role of contaminated surfaces in the transmission of pathogens and to inform the most effective environmental interventions. Given the serious consequences of SSIs, special attention should be given to the proper cleaning and disinfection of the inanimate environment in operating rooms in addition to the other established infection control measures to reduce the burden of SSIs.

Modern operating rooms (ORs) have strict measures to reduce contamination, including sterilization of instruments, environmental cleaning and disinfection, and advanced air handling and ventilation. Notwithstanding these measures, infections affect 2%–5% of all surgical patients, and surgical site infections (SSIs) represent a significant factor in perioperative morbidity, poor surgical outcomes, and total healthcare expenditure [1,2]. In the U.S. alone, it has been estimated that more than half a million SSIs occur annually, with a direct cost of as much as $10 billion [3].

The role of surface contamination in the transmission of nosocomial pathogens is being recognized increasingly [4]. Contaminated surfaces act as reservoirs on which microorganisms can survive for several months, increasing the risk of cross-contamination through direct or indirect contact with patients. Pathogens responsible for SSIs, including multidrug-resistant (MDR) strains, can originate from endogenous and exogenous sources. Some SSIs originating from an exogenous source could be acquired indirectly after transmission of pathogens from contaminated surfaces to the hands of healthcare workers. Transmission is exacerbated in settings with a high number of interactions among healthcare workers' hands, patients, and the environment. Failures in cleaning and disinfection or poor compliance with proper infection control practices, in particular hand hygiene and gloving, also contribute to transmission [5–7]. Recent literature shows that both the cleaning and the disinfection of the OR environment as well as the frequency of hand hygiene among anesthesiologists while providing care in ORs is less than optimal [7–10]. Thus, there is a potential for transmission from the environment in ORs where there are multiple and frequent contacts between patients, the hands of healthcare personnel, and the environment, combined with skin breaches during surgery. Given this dynamic interchange between patients, surfaces, and the hands of healthcare personnel, it is difficult to determine the source of an SSI accurately. Although for

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more than 100 years, the inanimate environment in the OR (e.g., walls, tables, floors, and equipment surfaces) has been considered a potential source for pathogens that may cause SSIs [11], few studies have evaluated the importance of OR surface contamination. Thus, the role of the environment in the patient acquisition process within this setting is still debated [12,13]. Here, we review accumulating evidence that the inanimate environment in the OR can become contaminated and contribute to the transmission of certain nosocomial pathogens to the hands of healthcare workers in OR.

Searches were performed in PubMed (between 1990 and 2013) using a combination of the search terms ''operating room'' or ''operating theatre'' and ''contamination,'' ''environmental,'' ''bacteria,'' ''transmission,'' or ''surface.'' Bibliographies of the relevant articles were hand-searched for additional references. We included only papers discussing surface contamination of the inanimate OR environment.

Sources of Infection in ORs

Most contamination in the OR originates from patients or staff [13–16]. For instance, opportunistic pathogens normally associated with the skin of patients or healthcare personnel cause more than half of the infections after clean surgery [13,14]. In such surgery, there is a correlation between the number of bacteria colonizing the skin and the likelihood of site contamination [15]. Contaminated air is another important source of infection in the OR [13,14,17–20]. In one study, airborne bacteria accounted for 98% of the bacteria found in incisions during orthopaedic joint surgery performed in a conventionally ventilated OR [17]. Moreover, reduction in the airborne bacteria in the OR resulted in a reduction in site contamination [18], and the use of ultraclean air reduced infection rates significantly in orthopaedic implant surgery in some [14], although not all [21], studies.

Other possible sources of infection include contamination of staff hands [7], cleaning and disinfection solutions and equipment [5], water supply and pluming [5], medical equipment [6], and inanimate surfaces [22,23]. In addition, there is a dynamic interchange between airborne and surface contamination in ORs: Airborne organisms can settle on OR surfaces [24], and bacteria on surfaces can be disturbed and contaminate the OR air [25]. This review focuses on literature related to contaminated inanimate surfaces as a potential source for pathogen transmission.

Contamination of the Inanimate Environment in ORs

Contamination of different inanimate surfaces in the operating room with various pathogens has been reported in the literature (Table 1). A recent study assessed contamination of the inanimate environment in 35 ORs of a U.S. teaching hospital ◄T1

Table 1. Contamination of Inanimate Environment in Operating Rooms

Setting	*Location*	*Environmental Surfaces Contaminated*	*Organism(s)*	*Series*
Cardiac surgical ward	Belgium	Operating room furniture	*Aspergillus flavus*	[23]
Cardiac surgery	Spain	Dual reservoir cooler-heater	*Aspergillus flavus*	[47]
Large medical center ORs	USA	Telephones	Coagulase-negative staphylococci, *Acinetobacter*, *Pseudomonas, Agrobacterium, Micrococcus,* and others	[31]
Hospital ORs	Italy	Walls, floors, and furnishings	Not reported	[32]
Neurosurgery OR	USA	Drapes & sterile instrument table	Coagulase-negative staphylococci, *Staphylococcus aureus*	[22]
Adult ICU and ORs	Netherlands	Roll boards	Multidrug-resistant *Klebsiella pneumonia*	[35]
Medical center ORs	USA	IV stopcocks and anesthesia machine	Coagulase-negative staphylococci, MRSA, VRE, *Micrococcus, Bacillus, Corynebacterium, Streptococcus, Enterobacter,* and others	[6,27]
Hospital ORs	USA	Anesthesia equipment, Mayo stands, doors, nurses area, beds, IV pumps and poles, and floors	*Pseudomonas, Enterobacter, S. aureus*, inc MRSA, *Enterococcus, Acinetobacter, Klebsiella, Escherichia,* and others	[8]
Hospital ORs	USA	Floors, anesthesia carts, OR table, phones, Bair huggers, OR cords, computer mice, and other flat surfaces	Staphylococci and other bacteria	[28]
Hospital OR	Japan	Computer keyboards	Mostly coagulase-negative staphylococci and *Bacillus* spp.	[29]
Hospital operating suite	Japan	Floors and other surfaces such as walls and surface of equipment	Mostly coagulase-negative staphylococci but also *Bacillus* spp., gram-negative bacilli, gram-positive bacilli, *Micrococcus, Pseudomonas* spp., and *S. aureus*	[30]

Abbreviations: ICU = intensive care unit; MRSA = methicillin-resistant *Staphylococcus aureus*; OR = operating room; VRE = vancomycin-resistant enterococci.

over a nine-month period [8]. The hospital's OR cleaning policies for between procedures and terminal cleaning were consistent with the Association of periOperative Registered Nurses (AORN) protocols [26]. Nevertheless, 16.6% of the 283 objects sampled (including anesthesia equipment, beds, intravenous (IV) pumps and poles, and floors) were positive for pathogens (gram-negative bacilli, *Staphylococcus aureus*, including methicillin-resistant *S. aureus* (MRSA), or *Enterococcus* spp.), and 57.6% yielded cultures that grew skin flora. Frequently, the floors were found to be contaminated, with 65% of these surfaces being positive for pathogens.

Contamination of the floors could be important because OR floors can transmit organisms to patients through the generation of airborne contamination or inadvertent contamination of surfaces during routine care. For instance, Hambraeus et al. [25] calculated that about 15% of the bacteria found in the air of ORs were disbursed from floors, and that higher numbers were associated with walking. Additionally, some equipment can come into contact with the floor in ORs. For example, IV tubing frequently contacts the floor as it drapes between the patient and the pump. Alarmingly, Munoz-Price et al. [8,9] found that objects that fall onto OR floors often were returned either to horizontal work surfaces or the patients themselves during operations. During 8 h of observation of seven surgical procedures, Munoz-Price et al. [9] found that contact with objects from the floor occurred in 17 instances; none of them was followed by hand hygiene procedures. The OR personnel, including anesthesia providers, have frequent and multiple contacts with equipment as well as with the patients and horizontal surfaces, leading to the potential for transmission [6,27].

Duhaime et al. [22] sampled the OR environment after routine skin preparation during 111 unselected shunt operations. Bacteria were collected from the patients' prepared skin underneath the drapes, on top of the drapes in the operative field, or on the sterile instrument table. Positive cultures were found on 13.5% of drapes, 9.1% of the instrument tables, and 2.1% of sampled skin. Coagulase-negative staphylococci (CNS), one of the bacteria most commonly involved in SSIs, were isolated most frequently, but *S. aureus* also was isolated from the instrument table. Following an outbreak of sternal SSIs caused by *Aspergillus flavus* after cardiac surgery, Heinemann et al. [23] performed a mycologic survey of air and surfaces throughout a surgical ward and in other areas of the hospital. They found substantial air and surface contamination by the outbreak organism in the surgical ward, including ORs, and more than 100 colony-forming units (CFU)/contact plate frequently were observed on some surfaces in the surgical ward. Patient isolates and organisms isolated from environmental sites throughout the surgical ward showed the same genotype, suggesting clonal dissemination and the intraoperative acquisition of the *A. flavus* outbreak strain in the sternal SSIs.

In a recent report, Alexander et al. [28] sampled 517 sites from 33 ORs, including flat surfaces, personnel attire, and equipment. Most samples from flat surfaces were obtained from clean ORs in the morning before surgery began. Staphylococci were present at almost all sites from which aerobic cultures were taken. The aerobic counts from surfaces undergoing regular decontamination (e.g., floors, OR tables, anesthesia carts, and patient warming machines) had low bacterial counts. However, surfaces that were not decontaminated regularly and were routinely in contact with OR staff, such as badges and computer mice, had greater overall contamination.

Similar observations have been reported by others showing higher bacterial contamination on surfaces readily in contact with OR personnel and highlighting the importance of cleaning and disinfection. For instance, Fukuda et al. [29] reported significant contamination of computer keyboards by anesthesia providers in ORs, including with MRSA. Disinfection of the keyboards with ethanol effectively reduced bacterial counts. Suzuki et al. [30] found that OR floors cleaned with disinfectants had a bacterial load of only 0.33 CFU/cm^2, whereas floors cleaned with detergents had as many as 7.1 CFU/cm^2. Other surfaces in the OR, when cleaned with disinfectants, had an average of 0.28 CFU/cm^2 compared with an average of 25.3 CFU/cm^2 for surfaces not cleaned with disinfectants.

Standard cleaning and disinfection in ORs is rarely optimal and does not always reduce or eliminate contamination on environmental surfaces. For example, Jefferson et al. [10] evaluated 71 ORs across six acute care hospitals and found an average terminal cleaning rate of 25% of objects monitored using a fluorescent marker. Munoz-Price et al. [8] found that almost 17% of OR surfaces contained bacterial pathogens despite routine terminal cleaning protocols being in place. The introduction of educational and environmental services interventions improved the thoroughness of cleaning but did not significantly change the percentage of samples from which pathogenic organisms were recovered (16.6% vs. 12.5%; $p = 0.998$). Nelson et al. [31] investigated bacterial contamination of OR telephones by taking 26 cultures from 14 ORs and two non-sterile rooms at a large teaching medical center. They found that the telephones were contaminated with an average of 23.3 CFU or 0.81 CFU/cm^2 per telephone. The CNS were the most commonly isolated (82.8%); other isolates were gram-negative bacilli such as *Acinetobacter calcoaceticus–baumannii* complex and *Pseudomonas aeruginosa* (both 1.9%). Interestingly, a telephone cultured after the room had been cleaned between two procedures had the second highest number of organisms (2.16 CFU/cm^2).

Frabetti et al. [32] found surfaces in an OR of a modern hospital were contaminated before and after the hospital's cleaning protocol, which involved a dry dust mopping followed by a wet cleaning using microfiber cloths and a 400 ppm sodium dichloroisocyanide solution. Bacterial contamination on vertical surfaces was lower than on horizontal surfaces, and the increase in the post-cleaning bacterial load over time was greater on smooth than on porous materials.

Transmission of Pathogens Between Patients, Staff, and the Inanimate Environment in ORs

Loftus et al. [6,27] found that the hands of anesthesia providers in ORs, patient IV tubing, and the immediate patient environment were contaminated immediately before or during patient care with a wide range of bacterial pathogens, leading to transmission of bacteria. In one study [27], pathogenic organisms, including MRSA and vancomycin-resistant enterococci (VRE), were transferred between patients and the immediate intraoperative patient environment during administration of general anesthesia. Contaminated IV tubing was associated with higher nosocomial infection rates and associated increases in deaths. The anesthesia work area was shown to become contaminated in as little as 4 min, and transmission of bacteria to IV tubing occurred in 32% of the cases investigated. In one case, molecular typing confirmed transmission of VRE from a patient to the anesthesia work area and back to the IV stopcock set. The patient was known to be colonized with VRE, suggesting that the likely mode of transmission was the hands of the anesthesia provider.

In a followup study [6], intraoperative bacterial transmission to the anesthesia work area (patient environment) was identified in 89% (146/164) of cases investigated, 12% (17/146) of which were of anesthesia provider origin. Intraoperative bacterial transmission to the IV stopcock set was identified in 11.5% (19/164) of cases, 47% (9/19) of which were of anesthesia provider origin. The contaminated hands of anesthesia providers serve as a significant source of patient environmental and stopcock set contamination. Contamination of the environment before the start of the subsequent case (a measure of the efficacy of decontamination practices) occurred in 7% (6/82) of ORs studied and was linked to stopcock contamination in 5% of cases (1/19). Ineffective hand and environment decontamination led to persistent contamination of the IV stopcock between two cases [6].

Poor hand and surface disinfection in the OR also was reported by Munoz-Price et al. [9], who observed seven surgical procedures during a span of 1 wk. They found that anesthesia providers touched 1,132 objects during the 8 h of observations but performed a total of only 13 hand disinfections. No hand disinfections were witnessed at any time during 3 (43%) of the procedures observed. Furthermore, hand hygiene failed to precede or follow procedures, blood exposure, or contact with the floor. For instance, stopcocks were accessed 66 times, and 31 (47%) of the handlings were preceded by contact with the anesthesia machine's clean green field. Disinfection of the stopcocks prior to access occurred only on 10 occasions (15%). The study also found that gloves were used without change for extended periods, resulting in contact with as many as 88 consecutive objects. Transmission of pathogens from contaminated gloves to environmental surfaces and vice versa has been reported by Fukada et al. [29]. In the same study, only 17% of anesthesia providers were reported to have performed hand hygiene before anesthesia, whereas 64% and 69% performed hand hygiene after administering anesthesia or before lunch, respectively.

In another study [33], the relative contributions of anesthesia provider hands, the patient, and the environment to stopcock contamination was examined. Two hundred seventy-four case pairs in three hospitals were analyzed. Stopcock contamination was 23% (126/548) and was significantly associated with increased mortality rates. Bacterial contamination of patients, provider hands, and the environment contributes to stopcock transmission events, but the surrounding patient environment was the most likely source. The environment was the source of cross-transmission in 52% of the 44 cases where the source was identified.

Transmission in ORs involving anesthesia providers appears to be common. This in part because the anesthesia machine, the object most commonly touched by anesthesia providers, is complex, with many components, making it difficult to clean and disinfect. Other reasons include the anesthesia provider's behavior and attitude toward disinfection, including confusion on when and how often to perform hand hygiene during a procedure.

The direct link between contamination of the inanimate OR environment and SSIs has not been established. However, contamination of environmental surfaces in the OR can lead to contamination of the hands of OR staff [6,27,33], which has been implicated in surgical infection outbreaks [34]. Furthermore, contamination of environmental surfaces in ORs has been implicated in outbreaks. For example, van't Veen et al. [35] reported an outbreak of infection with MDR *Klebsiella pneumonia* in an intensive care unit (ICU) of a Dutch hospital associated with contaminated roll boards in ORs. The outbreak was contained only after thorough disinfection or replacement of these boards and implementation of additional barrier precautions for colonized or infected patients. The strain was an extended-spectrum beta-lactamase (ESBL) producer and caused fatal infection in four of seven patients (57%). Cultures of environmental specimens in the ORs revealed contamination with the MDR strain of the roll boards used to transport patients from the bed to the operating table. Molecular typing indicated that isolates from patients and the environment were closely related or indistinguishable. The authors concluded that the inanimate environment within the ORs played a key role in the transmission of the MDR strain between ICU patients during the outbreak.

Concluding Remarks

It is clear that the inanimate environment of the OR, including medical equipment, can become contaminated with pathogens that cause SSIs despite infection control measures such as standard environmental cleaning. This may in part be attributable to the fact that suboptimal cleaning in ORs is a widespread issue in hospitals [10,32]. These pathogens can then be transmitted to the hands of healthcare workers and have the potential to cause infection. There is an increasing recognition of the potential role that the inanimate OR environment plays in the transmission of pathogens. This is reflected in reinforced guidelines on environmental cleaning in ORs and the development of environmental surveillance methods to monitor OR suites [28,36]. The national standards of cleanliness for the U.K.'s National Health Service (NHS) [37] classifies ORs as ''very high risk functional areas,'' where the required cleaning standards are of critical importance to patient care and where the outcomes must be achieved through the highest level of intensity and frequency of clearing. Most of the operating room building and fixtures, as well as patient equipment, require constant cleaning so that problems are rectified immediately. In practice, individual healthcare facilities in the U.K. have their own cleaning/disinfection procedures for ORs. Inanimate surfaces generally are cleaned daily or after each procedure, as required, with warm water and detergent. Cleaning with disinfectant (normally a chlorine-releasing agent) usually is done when there has been contamination with blood/body fluid spillage or aerosol. In the U.S., the AORN recommends that the OR should be cleaned before and after each surgical procedure, during surgical procedures if necessary, and at the end of each day. The AORN recommends cleaning and disinfection with a clean, lint-free cloth moistened with an Environmental Protection Agency (EPA)-registered hospital-grade disinfectant [26].

To reduce the burden of SSIs, there may be a need for more stringent cleaning and disinfection of the OR environment alongside the current standard infection control procedures used in surgery. This is particularly relevant when virulent or

MDR strains are involved. For instance, regular microbiological analysis of surface hygiene, the use of fluorescent markers or ATP assays to assess the thoroughness of cleaning, feedback of cleaning performance, and educational campaigns all are effective in improving the thoroughness of cleaning and reducing contamination of surfaces [38–42]. Incorporation of antimicrobial surfaces such as copper alloys, which reduce microbial bio-burdens on surfaces [43], into the OR environment also could be beneficial. Finally, the use of automated, no-touch room decontamination systems for the terminal disinfection of ORs will help reduce or eliminate residual contamination on surfaces. These systems remove or reduce reliance on the operator to ensure distribution, contact time, and repeatability of the disinfection process and improve the level of disinfection compared with a manual process [44]. However, because of the practicalities, these systems are not suited to the disinfection of ORs between patients, although they may have a role in periodic or in the terminal disinfection of ORs at the end of the working day.

According to the available literature, ORs are not the clean settings that the general public, and some healthcare workers, commonly believe them to be. The inanimate environment of ORs can become contaminated with pathogens, which can then be transmitted. Further studies are necessary to quantify the role of contaminated surfaces in the transmission of pathogens and to inform the most effective environmental interventions in the ORs. Given the serious consequences of SSIs, special attention should be paid to the proper cleaning and disinfection of the inanimate environment in ORs in addition to the other established measures to reduce the burden of SSIs. These should include addressing the human behavior that contributes to environmental contamination and transport of surface pathogens into the vulnerable sites of patients during surgery. Such measures include reducing human traffic in ORs, stricter adherence to the standard operating protocols during procedures, and compliance with proper hand hygiene and gloving to avoid introduction of contamination into the surgical wound. Specific hand hygiene guidelines tailored to OR personnel maybe needed, given the large number of hand contact events per hour in these settings [9]. Nevertheless, optimization of standard operating procedures to improve work flow practices for anesthesia providers can improve hand hygiene compliance significantly and decrease the number of opportunities mandating hand rubs [45]. In addition, improving awareness of hand hygiene and the basic knowledge regarding this procedure among OR personnel as well as close monitoring of the process would be useful, as a recent study found that in addition to poor adherences to local hand-hygiene protocols, basic knowledge about surgical antiseptics was low among surgical staff [46].

Author Disclosure Statement

SY and JAO are employed by Bioquell UK Ltd.

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