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Perioperative Infection Transmission: the Role of the Anesthesia Provider in Infection Control and Healthcare-Associated Infections

Archit Sharma [1] · Patrick G. Fernandez [2] · John P. Rowlands [3] · Matthew D. Koff [4] · Randy W. Loftus [1]

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Abstract

Purpose of Review This review aims to highlight key factors in the perioperative environment that contribute to transmission of infectious pathogens, leading to healthcare-associated infection. This knowledge will provide anesthesia providers the tools to optimize preventive measures, with the goal of improved patient and provider safety.

Recent Findings Over the past decade, much has been learned about the epidemiology of perioperative pathogen transmission. Patients, providers, and the environment serve as reservoirs of origin that contribute to infection development. Ongoing surveillance of pathogen transmission among these reservoirs is essential to ensure effective perioperative infection prevention.

Summary Recent work has proven the efficacy of a strategic approach for perioperative optimization of hand hygiene, environmental cleaning, patient decolonization, and intravascular catheter design and handling improvement protocols. This work, proven to generate substantial reductions in surgical site infections, can also be applied to aide prevention of SARS-CoV-2 spread in the COVID-19 era.

Keywords Surgical site infection · Hand hygiene · Nosocomial infections · Anesthesia work area · Bacterial transmission · COVID-19

Introduction

On May 15, 1850, the Hungarian obstetrician *Ignaz Semmelweis* lectured at the Vienna Medical Society and implored his colleagues to wash their hands in order to prevent the spread of infection between patients. [1] According to the Centers for Disease Control (CDC), 1 in 25 hospitalized patients in the United States is diagnosed annually with an infection that is the result of simply being hospitalized. [2] The healthcare-associated infection (HAI) risk in the operating room is even higher with 7% of surgical patients suffering from one or more infections. It is estimated that the direct cost of HAIs is upwards of $45 billion annually. [3]

Over the past decade, much has been published about the role of the perioperative environment in cross-contamination. [4••, 5, 6••] In this review, we detail what is known to date

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✉ Randy W. Loftus
Randy-Loftus@uiowa.edu

Archit Sharma
Archit-Sharma@uiowa.edu

Patrick G. Fernandez
Patrick.Fernandez@childrenscolorado.org

John P. Rowlands
John.P.Rowlands@gmail.com

Matthew D. Koff
Matthew.D.Koff@hitchcock.org

1 Department of Anesthesia, University of Iowa, 200 Hawkins Drive, 6512 JCP, Iowa City, IA 52242, USA

2 Department of Anesthesia, University of Colorado School of Medicine, Children's Hospital Colorado, 13123 E. 16th Ave, Aurora, CO 80045, USA

3 Delaware Orthopaedic Specialists, Pain Management, 3401 Brandywine Parkway, Wilmington, DE 19803, USA

4 Department of Anesthesia and Critical Care Medicine, Dartmouth-Hitchcock Medical Center, Geisel School of Medicine, 1 Medical Center Drive, Lebanon, NH 03756, USA

about factors contributing to perioperative pathogen transmission and present the importance of an infection prevention bundle that will allow anesthesiologists to impact the perioperative safety of patients and providers by preventing the spread of infectious pathogen. An editorial comment by Drs. *Roy*, *Brull*, and *Eichhorn* characterizes so well the need for anesthesiologists to address the issue of surgical site infections, "we've all been slimed! Now what are we going to do about it?" [7] In response, much work has been done to show exactly what we can and should do to address this persistent and significant issue.

Modes of Transmission of Healthcare-Associated Infections

Despite advances in surgical technique, sterilization, and improved disinfection programs, the U.S. health care system has struggled to generate a sustained, overall improvement in HAI rates. [8–10] The operating room (OR) environment includes health care tools and surfaces used within the anesthesia work environment (AWE), the surrounding air, as well as the patient and the anesthesia providers themselves. [11–14] This is a significant issue for both patients and providers because of current cleaning failures and/or lapses in practice that increase the risk of cross-contamination during patient care. [15] Further, contamination of intravascular devices has been repeatedly associated with increased patient mortality. [15, 16]

The risk of HAI is especially problematic in the COVID-19 era where the highly transmissible and infectious SARS-CoV-2 virus is transmitted to providers and patients even without evidence of aerosolization in some studies. [17] Such work highlights the importance of fomite transmission where contact with residual contamination can lead to recurrent, downstream provider, and/or patient transmission events that can lead to devastating consequences including death. [17] Importantly, COVID-19 can remain viable for at least 4 days on a variety of materials commonly encountered in ORs. [18] Other enveloped viruses such as hepatitis continue to cause HAIs as a result of unsafe injection practices and contaminated medical equipment. [19–21]

Emerging knowledge has shed light on three important sources of perioperative pathogen vectors: (1) the anesthesia provider, (2) the operative patient, and (3) the operative environment. A complex dynamic exists as an anesthesiologist must interface rapidly with these vectors in parallel to provide safe perioperative patient care which makes the risk for pathogen cross-contamination seemingly inevitable. For example, due to the high task density of the anesthesia work environment, there are up to 150 World Health Organization (WHO)-based hand hygiene opportunities per hour of anesthesia care. [22] As shown in Fig. 1, there are a very high number of patient-provider-environmental interactions for anesthesia providers during routine, elective surgery. This task density can lead to failures in basic preventive measures, further highlighting the need for ongoing surveillance for system optimization, an effective approach for prevention of perioperative *Staphylococcus aureus* spread and surgical site infection development that can be applied to control the perioperative spread of SARS-CoV-2. [23••, 24••] The evidence pertaining to the components of this effective strategy is summarized below.

The Anesthesia Provider

Intraoperatively, the hands of the anesthesia providers have been directly linked by advanced molecular techniques to stopcock contamination and postoperative infection. [14, 16] Fukada et al. sought to examine bacterial contamination on the anesthesiologists' hands during general anesthesia and found that they were contaminated with bacterial pathogens throughout all phases of anesthesia care. [14] Another study examining bacterial cross-contamination reported that the contaminated hands serve as a source of environmental and stopcock set contamination in the OR. [15] Yet, perioperative hand hygiene compliance remains low.

Barriers to hand hygiene compliance include environmental and cultural issues. [22] Physical access to hand sanitizers plays a large role, as does continuous education regarding the risks. [25] Biddle and Shah (2012) reported a hand hygiene failure rate of 82% for anesthesia providers. [26] Tait and Tuttle surveyed anesthesiologists and reported that 95% of the providers reported hand washing after caring for "high-risk" patients, but only 58% washed their hands in "low-risk" situations. [27] In a study by Munoz-Price, only 13 hand hygiene events were witnessed during 8 h of observation of 19 anesthesiologists who collectively interacted with their work environment more than 1000 times. [28] When characterized, evidence reveals that these lapses frequently involve failure to wash one's hands before and/or after aseptic tasks involving line insertions, bronchoscopy, or even after blood administration and handling. [29] As highlighted by Fernandez et al., many of these lapses are related to knowledge deficits pertaining to the importance of the contaminated environment in cross-contamination events involving infectious pathogens; the anesthesia environment is in fact the most potent transmission vehicle. [15, 16, 30]

When taken together, these data support the potential links between anesthesia providers and postoperative infectious outbreaks reported as early as the 1960s. One outbreak involved group A β-hemolytic *streptococci*-derived puerperal sepsis occurring in the postoperative period, whereas another involved two outbreaks of *Staphylococcus aureus* surgical site infections (SSIs) thought to originate with the contaminated hands of an anesthesia provider suffering from psoriasis. [31–33] Unfortunately, these early findings have been further substantiated by recent work involving single-nucleotide variant analysis that definitively links the hands of anesthesia providers to transmission of high-risk desiccation tolerant sequence type 5 *Staphylococcus aureus* strain characteristics that resulted in downstream infection development. [34] Thus, there is a substantial body of evidence highlighting the role of anesthesia provider hands in perioperative infection and the need to act for patient safety. This is even more important in the COVID-19 era with the tremendous transmission pressure related to SARS-CoV-2 community spread, a risk to both patients and providers during elective surgery that is in part related to OR hand hygiene compliance. [35] Importantly, when employed as a single measure, hand hygiene improvement strategies in the perioperative and similarly fast-paced intensive care unit (ICU) may increase the risk of HAI development. [3, 9] Hence, it is an important component of a multifaceted approach shown to reduce SSIs by greater than 80%. [23••]

Another provider infection control consideration involves the common practice of wearing masks in the OR for the purpose of decreasing the aerosolization of bacteria originating in the providers nasopharynx. A Cochrane review in 2014 suggested that it is unclear whether the wearing of surgical masks by OR personnel during "clean" surgery either increases or reduces the risk of SSIs. [36] However, for prevention of perioperative viral spread, there is evidence that various types of masks, whether donned by the provider or patient, can help to reduce shedding of the virus from the person to the surrounding environment. A limitation is coughing where the beneficial impact of the mask is attenuated. [37]

The Operative Patient

Pathogenic organisms from patient colonization of the nose, mouth, and skin are a known source of SSIs, with *Staphylococcus aureus* being the most commonly implicated organism. [38] Rectal colonization that commonly occurs in conjunction with skin colonization and the antecubital fossa, where the blood pressure cuff comes into contact with the axilla, have also been shown to be significant predictors of gram-negative bacterial transmission. [39, 40] In a prospective randomized observational study, the authors reported that for *Acinetobacter*, *Pseudomonas*, *Brevundimonas*, *Enterobacter*, and *Moraxella*, provider hands are less likely to serve as the reservoir of origin for transmission events than contaminated environmental or patient skin surfaces such as the axilla. [41] Bitkover prospectively investigated 20 operating rooms and reported that bacteria in the sternal wound originated from both the patient's own skin and the surgical team. [42] Recent work involving a study design across 20 institutions demonstrated an association between a bundled intervention involving preoperative *Staphylococcus aureus* screening combined with customized decolonization and prophylactic antibiotic selection and a significant reduction in complex infections for patients undergoing hip and knee surgeries (17 fewer infections per 10,000 surgeries; 95% CI − 39 to 0; risk ratio 0.48). [43] While preoperative decolonization represents an evidence-based strategy for SSI prevention, the impact of this approach alone is far less effective than a multifaceted approach. [23••]

The Operative Environment

It has been well established that syringes and intravascular catheters can become contaminated directly via bacterial contamination of the provider's hands, or indirectly during connection to patient intravenous (IV) tubing. [44–46] *Blogg* et al. reported that syringes can become contaminated with bacterial pathogens after a single use, thereby providing a plausible mechanism for the bacterial contamination of propofol vials linked to a series of *Staphylococcus aureus* bloodstream infections. [47–49] Breaches in aseptic practices and failure to decontaminate vials lead to microbial contamination of the vials, and then subsequently line associated bloodstream infections. [50] Residual microbial contamination of laryngoscopes, associated with suboptimal disinfection practices, has been linked to infectious outbreaks. [51] Contamination of anesthesia machine surfaces with blood, mucus, and bacterial organisms after standard cleaning processes has been confirmed. [11, 52] Other reports have documented an association of residual contamination of the anesthesia machine circuit and Ambu-bag with outbreaks of *Pseudomonas aeruginosa* respiratory infections. [53]

Early work by Albrecht and Dryden identified an association between combined preoperative decontamination of the external surface of anesthesia machine circuits and use of new absorbers with a reduction in postoperative pneumonia. These authors concluded that contaminated anesthesia machines can indeed transmit bacteria to patients. [54, 55] Leijten et al. published the results of a study in which they found that without an in-line circuit filter in place, bacterial organisms were universally transmitted to the patient circuit. [56] Edmiston et al. published the results of a study whereby air samples were taken during 70 different vascular procedures from a single OR. Coagulase-negative *Staphylococcus* and *Staphylococcus aureus* were recovered from 86% and 64% of all samples, respectively, with Gram-negative bacteria recovered less frequently (33%). [57] Isolation of 100 colony-forming units per surface area sampled (CPSS) from the AWE is associated with increased probability of high-risk stopcock contamination events that are in turn associated with increased mortality. [15, 16] A study by *van Vlymen* demonstrated that poor hand hygiene practices inadvertently cause tiny amounts of hepatitis C virus to be placed on the outside of a medication vial, leading to further contamination and infection. [58] Improved frequency and quality of environmental cleaning of the AWE following induction and emergence of anesthesia have reduced the proportion of environmental sites reaching the 100 CFU threshold associated with high-risk stopcock transmission events. [59] This involved post-induction cleaning with a surface disinfection wipe containing both a quaternary ammonium compound and alcohol along with improved organization with designation of clean and dirty spaces, decreasing the proportion of sites reaching or exceeding 100 CFU from > 40 to 12%. A port-guard designed to shield stopcocks from the contaminated environment significantly reduced contamination of injected fluid. This involved an ex vivo study where 33 providers injected 1 mL of sterile saline into 4 different devices with the primary outcome effluent contamination. [60] Thus, this study shows directly that shielding from the contaminated environment can reduce high-risk transmission events.

Overview of a Perioperative Infection Control Bundle

We have summarized evidence characterizing the epidemiology of perioperative transmission. As this is a complex problem occurring in a fast-paced arena with a high task-density, a multi-faceted approach is indicated. [16] The impact of a strategic, multifaceted approach on the incidence of *Staphylococcus aureus* transmission and SSI development has been evaluated. A significant reduction in *Staphylococcus aureus* transmission events was achieved, events tightly associated with SSI development. In turn, SSIs were reduced by > 80%. [23••] The timely implementation of an evidence-based, perioperative infection control program can be used for prevention of SSI development and perioperative SARS-CoV-2 spread, especially when the interventions are augmented by parallel implementation of efficient OR management strategies (Table 1). The elements of this evidence-based approach as applied to each contributing reservoir are described below. A key point is that these interventions should be implemented in parallel during the process of patient care, not as single interventions.

The Anesthesia Provider

In the high task density perioperative environment, nadirs in hand hygiene compliance occur during the fast-paced periods of induction and emergence of anesthesia. [61] This barrier can be effectively combated by leveraging proximity to the provider. In the study by *Koff* et al., simple provision of personalized, body-worn, alcohol dispensers increased hourly hand decontamination events by 20-fold which correlated with a significant reduction in environmental and stopcock contamination and postoperative infections. In a randomized trial investigating the effect of basic preventive measures on prevention of perioperative *Staphylococcus aureus* transmission and the incidence of SSIs, the concept of proximity to the provider was again leveraged by placing a one-handed 70% alcohol dispenser on the IV pole to the left of the provider. [23••] Thus, to augment perioperative provider hand hygiene, an evidence-based approach includes hand sanitizer placement in proximity to the provider. [3, 23••, 61] Double gloving during induction allows the anesthesia provider to reduce environmental contamination by removing the outer glove to sheathe the laryngoscope blade which serves as a vector to both patients and providers. [62]

The Operative Environment

Hand hygiene improvement initiatives are directly tied to environmental cleaning, as hand hygiene noncompliance correlates with peaks in environmental contamination occurring during induction and emergence of anesthesia, and environmental contamination is linked to contaminated provider hands. [61, 63] It is important to maintain clean and dirty areas within the AWE. [59] Based on a proven multifaceted approach, we recommend that the following areas be designated as "clean": IV pole to left of provider, IV stopcock set, all medication syringes and the anesthesia supply/medication cart. Similarly, following areas should be designated as "dirty": the IV pole to the right of the provider, the anesthesia machine, and computer screens attached. Further, a specific area should be designated for storage of contaminated airway instruments (laryngoscope blades and handles). For example, a wire basket with zip closure bag on the IV pole to the right of the provider or a kidney emesis basin on the shelf of the anesthesia machine. [23••]

Following induction of anesthesia and patient stabilization, it is recommended that the anesthesia provider wipe down any surfaces that the provider interacted with following his/her interaction with the patient (stethoscope, anesthesia machine, computer, ventilation bag), with disinfection wipes that contain quaternary ammonium compound and alcohol. SARS-CoV-2 antiseptic effect will be achieved with 30% alcohol. [24••] Single-dose containers should only be used once for a single procedure on a single patient and the use of multi-dose vials should be limited, to prevent transmission of viral diseases like HCV from the surrounding environment to the multi-dose vial. [64]

Poor attention to intraoperative vascular care is a well-documented source of bacterial transmission that results in HAIs. The aim is to maintain an aseptic interface between medication syringes and IV stopcock ports. Use of closed lumen IV systems during perioperative care is recommended as these have been shown to decrease IV pathogen contamination when compared to open lumen systems. [65] Alcohol-impregnated disinfection caps are to be placed on IV lumens until use and replaced when syringes are not in place on the lumen. Use of a disinfection workstation for improving intravascular device disinfection (DOCit™ and HubScrub™

devices-Braun Medical Inc) optimizes aseptic medication administration. [23••]

Effective surface disinfection of the operating room, between operative cases and during terminal cleaning at end of day, is critical. A key component to this is routine assessment of whether or not current disinfection strategies are adequate. This can be achieved by use of evidence-based OR PathTrac surveillance that will also provide guidance for strategic use of UV-C, or it is equivalent, for augmentation of surface disinfection. [23••, 24••, 35, 66••, 67, 68, 69]

The Operative Patient

Extensive evidence shows the impact of preoperative patient decolonization across multiple surgical patient populations. [70] Preoperative patient decolonization has historically targeted known carriers of *Staphylococcus aureus* using intranasal mupirocin, and now, intranasal povidone-iodine has emerged as an alternative. [71, 72] Most authorities (such as the Society for Healthcare Epidemiology of America and the Infectious Disease Society of America) have been inconclusive in their recommendations whether bathing with antiseptic soap (i.e., chlorhexidine) prevents SSI. [73] That being said, the use of chlorhexidine soap preoperatively is recommended for total joint surgery. A randomized trial incorporating preoperative use of povidone iodine chlorhexidine gluconate as part of a multifaceted approach generated substantial reductions in *Staphylococcus aureus* transmission and SSIs. [23••] These agents are also effective antiseptics for SARS-CoV-2, and by addressing the patient reservoir, these may help to attenuate further environmental contamination and fomite spread to patients and providers. [24••, 35, 74•]

Preoperative patient decolonization for all surgical patients should include (a) use of 2% chlorhexidine gluconate wipes to the entire body, (b) 0.12% chlorhexidine gluconate oral mouthwash swish and spit, and (c) intranasal povidone-iodine treatment. Given evidence that infants younger than 2 months of age are at risk for skin burns when exposed to chlorhexidine, this antiseptic should be avoided in this population. [75]

Importance of Surveillance

All of the above interventions are behavioral and therefore prone to early fatigue and/or failure. The multifaceted approach described above was only effective after data feedback generated by OR PathTrac surveillance. Further, specific contributions of a particular vector and thus the particular intervention may differ in different institutions. For example, hand hygiene by anesthesia providers may be particularly poor at one hospital while aseptic IV care may be subpar at another. [23••] Hence, one must first assess baseline pathogen burden and modes of transmission. The use of validated surveillance failure mode analysis (OR PathTrac™, RDB Bioinformatics) is key to this process. [66••] This can be used to determine reservoirs that are temporally associated with pathogen transmission events thus providing targets for improvement. [6, 67] Furthermore, failure mode analysis can be used to regularly evaluate the initial impact of improvement strategies and the fidelity of those strategies over time. Contamination can help mitigate human factors known to limit the impact of environmental surface cleaning alone. [76, 77] An effective sampling strategy for OR PathTrac analysis has been delineated. [67] A 5-step strategy with simple interventions to decrease the incidence of HAI has been described in Table 2.

Conclusion

In summary, the role of anesthesia providers and surrounding reservoirs in transmission of infectious pathogens and infection development has been clearly delineated over the last decade. Anesthesia providers, historical and current leaders in patient safety, are poised to lead a national dissemination of an evidence-based, best practice for perioperative infection control as outlined above. In addition to reducing the incidence of SSIs, these measures can be used to help prevent the perioperative spread of viral pathogens such as SARS-CoV-2 in the COVID-19 era. This will improve both patient and provider safety.

Compliance with Ethical Standards

Conflict of Interest Archit Sharma declares that he has no conflicts of interest. Patrick G. Fernandez declares that he has no conflicts of interest. John P. Rowlands declares that he has no conflicts of interest. Matthew D. Koff is a minor shareholder of RDB Bioinformatics (Coralville, Iowa, USA). Randy W. Loftus is supported by the Anesthesia Patient Safety Foundation, and has previously received grant funding from Sage Medical and Draeger; has served as a guest speaker at education meetings sponsored by Kenall (Indigo-Clean, AORN) and BBraun (APIC); is founder a shareholder of RDB Bioinformatics, which owns OR PathTrac; and is a co-inventor on two pending patents (PCT/US2017/026557 and 62/682,267 - Method and system for differentiating more pathogenic *S. aureus* Strains among commonly isolated intraoperative multilocus sequence type).

Appendix

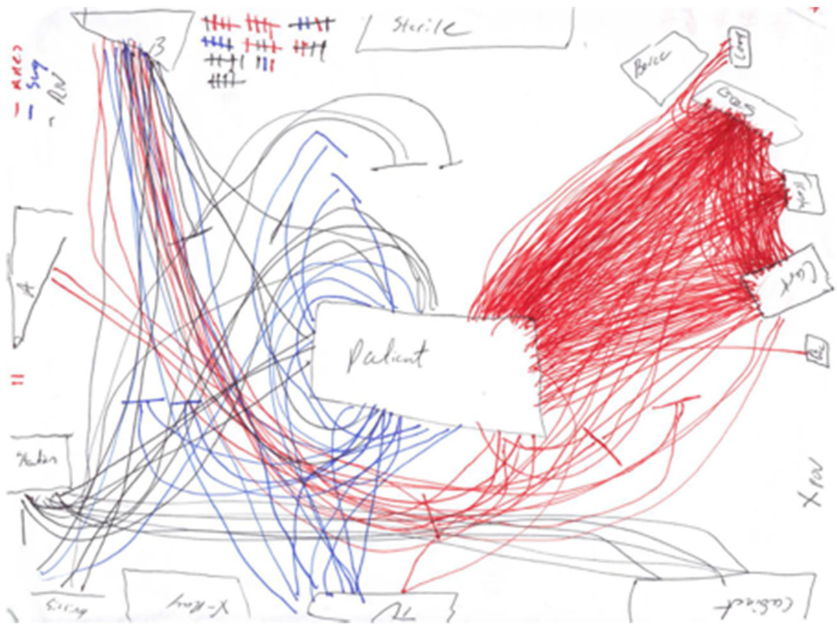

Fig. 1 A figure displaying different levels and frequency of patient-provider-environmental interactions for anesthesia providers during routine, elective surgery. The figure represents interactions during an elective surgical case of approximately 3 h in duration. Each line represents one provider-patient-environmental interaction. Red lines represent the anesthesia team, blue lines represent the surgical team, and black lines represent the circulating nurse. This depicts a high task density work environment for anesthesia providers (picture published with permission from John P. Rowlands, MD)

Table 2 Roadmap to perioperative infection control, describing simple, evidence-based interventions, designed to protect patients and providers

Step 1: hand hygiene
Place alcohol-based sanitizer on the IV pole to left
Double glove during induction
Place dirty equipment in sealed bag
Step 2: environmental cleaning
Organizing-place “dirty” bag for collecting all contaminated instruments to the providers right
Frequency: wipe down all equipment after induction with sanitizing wipes
Quality: use top down approach, wiping AWE with quaternary ammonium compounds and then follow up by wiping with microfiber cloth
UV-C: use UV-C to treat At-risk rooms, along with enhanced terminal cleaning
Step 3: patient decolonization
Apply standard PPE for procedures for known cases
Use preprocedural chlorhexidine, nasal povidone iodine and chlorhexidine oral rinse
Step 4: vascular care
Create a closed lumen IV system
Place disinfection caps for syringe and hub disinfection, in close proximity to provider (left IV pole)
Keep syringes disinfected and scrub all ports.
Step 5: surveillance
Use evidence-based surveillance for system optimization and sustainability.

Table 1 OR management strategies to optimize staff and case assignments during COVID-19

Use relatively long shifts, with as few people required. Follow cases after the first one rather than many first starts, to decrease exposure to providers and patients.
Do 1 case in an OR, followed by terminal cleaning with UV-C, and let anesthesia and proceduralists work in more than one room
Do not recover patients in post anesthesia care unit, to decrease potential contamination. Instead, have the anesthesiologist recover the patient in the OR itself.
If the proceduralist will be operating later in the day, for only one procedure, provide notification at the start of skin closure of the preceding case to decrease exposure time.

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