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Reducing Anesthesia Workstation Contamination

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Reducing Anesthesia Workstation Contamination

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Abstract

Healthcare-associated infections are a source of morbidity and mortality in the United States and have been shown to be more preventable than current incidence. Anesthesia providers may be a source of and vector for some of these infections. Nurse anesthetists provide direct individual care for numerous patients daily, managing airways and invasive devices that contaminate hands with secretions which then may be transferred to the anesthesia workstation. Due to its complexity, the anesthesia machine is difficult to thoroughly clean and may become a reservoir for contaminants.

The purpose of this paper will be to examine new interventions being explored to reduce the contamination of the anesthesia workstation. These interventions will include hand hygiene interventions, ultraviolet (UV) radiation for workstation disinfection, and anesthesia workstation barrier devices. Analysis of which interventions are the most effective may help to guide the direction of interventions to help reduce anesthesia machine contamination.

Reducing Anesthesia Workstation Contamination

Introduction

The Centers for Disease Control and Prevention (CDC) estimated in 2018 that healthcare-associated infections (HAIs) affected at least one in 31 hospitalized patients (CDC, 2018).

Similarly, according to the World Health Organization (WHO), the incidence of HAI in 2002 was at 4.5%, affecting 1.7 million patients and causing 99,000 deaths with an estimated financial impact of \$6.5 billion in 2004 (WHO, 2009).

The cost of HAIs in financial terms, patient mortality, and loss of quality of life cannot be underestimated. A meta-analysis by Umscheid et al. in 2011 of data from the National Nosocomial Infections Surveillance System (NNIS), the National Hospital Discharge Survey, and the American Hospital Association identified 1,737,125 total infections in 2002, with 98,987 deaths. Central line-associated blood stream infections (CLABSI) and ventilator associated pneumonia (VAP) accounted for two-thirds of deaths and had a five-fold increase in mortality compared to other HAIs. Costs per HAI ranged from a low of \$5,600 with surgical site infections (SSIs) to a high of \$110,800 for CLABSIs; with potential savings ranging from \$115 million from catheter-associated urinary tract infections (CAUTIs) to \$18.2 billion from CLABSIs. From evidence-based practice studies examined, it was estimated that certain percentages of various HAIs are preventable. CLABSI and CAUTI could potentially be reduced by 65-70%, while VAP and SSIs could reasonably be prevented in 55% of cases. (Umscheid et al., 2011).

Another study, a multistate survey including 183 hospitals and 11,290 patients by Magill et al. in 2014 found a 4% incidence of HAIs and an 11.5% rate of mortality from HAI. Infections related to invasive devices such as VAP, CAUTI, and CLABSI accounted for 25.6% of HAIs, with SSIs accounting for another 21.8%. Median time until presentation of HAI was six days,

and present on admission HAIs were 19.4% of the total, with 67.3% of these being SSIs (Magill et al., 2014). These factors may help obscure the role of anesthesia in contributing to infection. As providers constantly in direct contact with patients, nurse anesthetists are in a prime position to either be a significant vector for HAIs or to help find ways to solve this costly problem.

These challenges illuminate the important task of anesthesia providers becoming involved in finding unique solutions to anesthesia's role in propagating HAIs. Solutions that work in much of the hospital may not be effective for the operating room (OR) setting. In that vein, this paper will investigate the scope and nature of the problem of anesthesia workstation contamination as well as several avenues of solutions proposed to help reduce contamination. These include novel methods of hand hygiene customized for anesthesia providers, use of UV radiation to help decontaminate the complex permanent parts of the anesthesia workstation, and a novel cover system to help prevent any contamination of the anesthesia machine.

Methods

Articles for inclusion in this literature review were found by searching PubMed and CINAHL. Studies were chosen from within the last five years, with exceptions made for studies with great impact on the state of the literature that provided a basis for future study. Keywords set forth below were used to identify appropriate studies. Additionally, the reference sections of identified articles were searched to help identify all appropriate articles for inclusion. Level of evidence of studies was assigned using the evidence hierarchy used by Polit and Beck (2017).

Anesthesia Workstation Contamination: “anesthesia workstation,” “infection transmission,” and “hygiene.”

Hand Hygiene—Double Gloving: “double glove,” “anesthesia,” “anesthesia workstation,” “infection control,” and “contamination.”

Hand Hygiene—Disinfecting Gloves: “anesthesia,” “glove disinfection,” “infection control,” and “hand hygiene.”

Ultraviolet Radiation: “ultraviolet,” “UV,” “infection control,” and “anesthesia workstation.”

Anesthesia Machine Covers: “anesthesia workstation cover,” “anesthesia machine cover,” “anesthesia machine wrap,” and “infection control.”

Literature Review

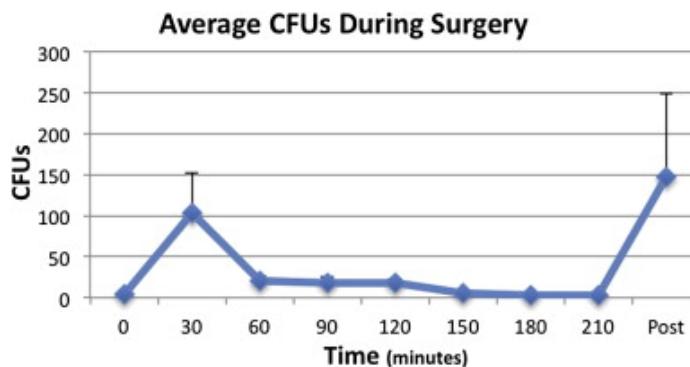
Anesthesia Workstation Contamination

Nine observational studies of evidence Level V were identified. The level of evidence is due to the observational nature of the studies, since they were intended to assess the problem of anesthesia contamination rather than to test an intervention. Of these studies, five were secondary analyses of a large, multicenter observational trial by Loftus et al. in 2012. Outcomes of interest include the organism reservoir sources; number of hand decontamination events (HDEs); association between contamination of intravenous (IV) stopcocks and development of infection and mortality; high-frequency touch locations in the anesthesia workstation and transmission between them; between and within case transmission events of pathogens; and number of colony forming units (CFUs) per surface area.

Hand hygiene opportunities were defined in almost all cases by the WHO “five moments for hand hygiene,” which includes conducting hand hygiene prior to touching a patient, before performing clean or aseptic procedures, following a body fluid exposure, after a patient touch, and after touching the patient’s environment (WHO, 2009). The heavy patient care density of anesthesia care makes following these guidelines particularly difficult for the anesthesia provider. These studies delineate the challenges facing nurse anesthetists in reducing contamination. The strength of this evidence is limited by the fact that only a few of the included

studies make efforts to track the potential HAI incidence resulting from contamination of the anesthesia workstation; future studies should focus on this aspect of workstation contamination. Studies were included based on being conducted in live OR environments. One article not discussed here also assessed transmission dynamics (Robinson et al., 2019). Two articles particularly exemplify these results: a study by Rowlands et al. in 2014 and the 2012 Loftus et al. study that prompted five secondary analyses.

The Rowlands study identified that high frequency objects in the OR were touched between 20 and 77 times per case, with gloves used less than 40% of the time. However, there was no correlation observed between number of touches or the use of gloves and a positive surface contamination. The greatest correlation found was large increases in contamination at case start and end as seen in Figure 1 below, which correlated with the largest number of hand hygiene opportunities and lowest compliance (Rowlands et al., 2014). Limitations of this study include its small sample size and that providers were aware of observations, making it vulnerable to the Hawthorne effect, where the studied outcome may be changed based on participant



awareness (Polit & Beck, 2017).

Figure 1

Note. Average CFUs found in 20 most frequently touched sites at 30-minute intervals from beginning to end of surgery. Reprinted from Rowlands et al. (2014). Video observation to map hand contact and bacterial transmission in operating rooms. <http://dx.doi.org/10.1016/j.ajic.2014.02.021>

Loftus et al. in 2012 conducted a large, randomized, prospective observational trial of OR case pairs at three academic medical centers over 12 months. Aims of the study included finding the original source of stopcock transmission events as well as which sites acted as vectors for transmission both between and within cases. Secondly, the study attempted to find risk factors for stopcock contamination and to determine if there was an association between stopcock contamination and the development of HAIs (Loftus et al., 2012).

Across three sites, 274 case pairs with 548 patients were chosen, with samples taken from 2,170 environmental sites, 2,640 provider hands, and 1,087 patient sites. Stopcock contamination was found in 126 out of 548 patients, or 23% of cases. There was positive identification of 14 between case and 30 within case transmissions. For between case events, contributing sources included the environment (64%), provider hands (21%), and the patient (14%). For within case events, contributing sources included the environment (47%), provider hands (30%), and the patient (23%). Of the three, the most likely source of contamination was the environment, followed by provider hands ($P = 0.029$), and finally patients ($P = 0.002$). Environmental contributions to stopcock contamination sampled at case end were present 26 times. Provider hands were a vector for transmission between the environment and the stopcock for 27% of between and within case transmission events, or 12 of 44. There was no significant difference in transmission events with either routine or active decontamination. (Loftus et al., 2012).

Predictors for stopcock contamination included surgery at site zero and second case of the day, whereas the frequency of HDEs did not influence results. Physical status, hospital site, and SENIC score (Study on the Efficacy of Nosocomial Infection Control, an SSI risk index based on factors such as abdominal surgery, contaminated surgical wound, greater than two diagnoses at discharge, and surgery longer than two hours) were all independent risk factors for

developing HAI. HDE events averaged 0.39 +/- 1.06 per hour. Gloves were used 2.39 +/- 1.60 times per hour, with hands not being washed after removal 40% of the time (Loftus et al., 2012).

Postoperatively, 48 infections were found in 44 patients, totaling 8% of all cases. Physical status ($P = 0.002$) and positive stopcock contamination ($P = 0.014$) were independent risk factors for mortality. Potential pathogens numbered over 6,000, while there were 2,184 true pathogens identified. Causative organism of infection was identified in 45% of cases with HAIs; 13.6% of all HAIs were confirmed to have been caused by a pathogen present in OR reservoirs, or six out of 44 (Loftus et al., 2012).

Limitations of this study include somewhat insensitive culturing methods that have the potential to underestimate actual contamination levels. Much of the association of contamination and transmission events was based on temporal association rather than pulsed-field gel electrophoresis (PFGE) analysis, which leaves some room for error in attribution of infection sources. Additionally, a large portion of the identified contaminated stopcocks were not able to have a source identified based on the areas sampled in the study. This could be the result of the small number of sites in the environment and on the patient that were sampled and could be rectified with later studies (Loftus et al., 2012). Indeed, the 2014 study by Rowlands et al. identified 20 of the most frequently touched objects in the anesthesia work area, only three of which were included as sampling sites in this study. As with many studies, it is possible that providers were aware of observations, making it vulnerable to the Hawthorne effect.

This 2012 study by Loftus et al. provided data that became the source of five more studies investigating the transmission dynamics of various organisms in the OR environment. Using samples collected in the large multicenter trial, many of this same group of authors issued three studies in 2015 analyzing the transmission of gram-negative bacteria, *Enterococcus*, and

Staphylococcus aureus (Loftus et al, 2015a; Loftus et al., 2015b; Loftus et al., 2015c). Likewise, two studies in 2018 examined the transmission characteristics of *Klebsiella*, *Acinetobacter*, *Pseudomonas*, and *Enterobacter* organisms (Hadder, Patel & Loftus, 2018; Loftus, Dexter, & Robinson, 2018). These studies helped to refine the understanding of organism transmission between cases, within cases, from a variety of sources, and which phenotypes of individual organisms were the worst offenders.

The 2012 Loftus study based much of its methodology from a study in 2008 done by Loftus and other authors. This study helped establish that colonies per surface area greater than 10 had a 20% risk of infection, and greater than 100 increased the risk to 50%. The study also demonstrated that contamination occurred at significant levels in cases as short as four minutes, and that level of contamination was not associated with increasing length of case but was more likely related to provider aseptic practices (Loftus et al., 2008).

Hand Hygiene—Double Gloving

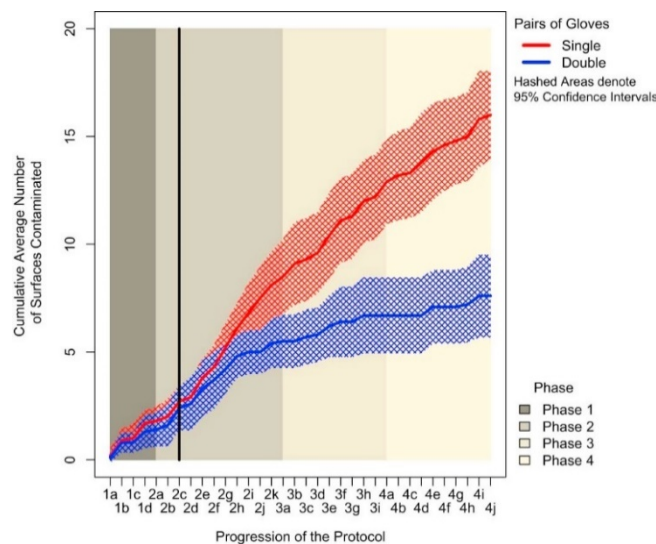
Five articles were identified for inclusion, including three randomized controlled trials of Level II evidence and two quasi-experimental studies of Level III evidence. All trials tested the intervention of double gloving during induction with removal of gloves following placement of the endotracheal tube against a control group of single gloves throughout induction. Two trials are examined in further detail—a randomized controlled trial by Biddle et al. in 2016 and a 2019 quasi-experimental trial by Jaffe and Moriber. The trial by Biddle et al. was chosen because in addition to describing the rate and number of contaminated sites for both groups, it also evaluated the efficacy of standard cleaning protocols and the association of contamination with time during induction. Jaffe and Moriber's trial was chosen because it was the only trial of this intervention performed in a live OR environment. Of the remaining trials, two were performed

by Birnbach et al. both in 2015 evaluating first double gloving and then double gloving plus sheathing the laryngoscope in the outer glove in simulation; however, these only assessed the rate and number of sites contaminated. A 2018 simulation study by Porteous et al. evaluated participants in a crossover design, having them first perform the standard induction and then performing the double gloving intervention, with participants acting as their own controls, though obviously this meant the potential intentions of the intervention could not be blinded.

Biddle et al.'s 2016 randomized controlled trial of Level II evidence was a simulation study performed with the aims of determining the extent of oropharynx secretion spread during induction, to determine if double gloving techniques reduced the spread and density of contamination, and if the terminal disinfection protocol was effective in reducing contamination from the anesthesia workstation. (Biddle et al., 2016).

The sites of greatest contamination in both groups were the circle system, the tape roll for endotracheal tube (ETT) securement, the IV flow control, the laryngoscope, the patient's head, the reservoir bag, the stethoscope, the suction tubing, and the vaporizer dial. Each had at least a 50% chance of contamination in both groups. The control group contaminated 16 sites on average, while the double-glove group averaged 7.6 sites, $P < 0.001$. Certain sites were not contaminated frequently enough to power an analysis of specific site contamination; however, a significant decrease in contamination was found for the double glove group in the cart drawers, the fresh gas flow dial, medication vials, and ventilator controls, $P < 0.05$ for all. There was also a trend towards less contamination for the intervention group with the APL valve and the temperature probes, $P = 0.07$ for both. Contamination rates were statistically similar for the laryngoscope, the ETT pilot balloon inflation syringe, the ETT stylet, the circle system, the reservoir bag, and the tape roll (Biddle et al., 2016).

Division of sites by phase of induction allowed for quantifying contamination by time as seen in Figure 2; during the first phase of induction, no differences between contamination rates were seen between groups. Contamination rates separated for the two groups starting in the second phase, near the time where the outer gloves were removed in the double-gloving group. This resulted in a general decrease in contamination for the intervention group and by two-thirds of the way through phase two, cessation of new contamination; this contrasts with the control group which continued to increase contamination in a linear fashion. Residual contamination was generally seen following terminal disinfection, requiring further cleaning to remove prior to next



cases, though this was not quantified in the study (Biddle et al., 2016).

Figure 2

Note. Cumulative mean contaminated surfaces in control and intervention groups over time; hashed area = 95% confidence interval; vertical black line = outer gloves removed in double glove group). Reprinted from Biddle et al. (2016). Quantifying the rambunctious journey of the anesthesia provider's hands during simulated, routine care. <http://dx.doi.org/10.1016/j.ajic.2016.02.014>

Limitations of this study include its simulated setting, which may lead to different responses than are seen in a live OR environment. The study also only recruited experienced

providers; while this may have limited variance in responses, it may also limit data generalizability. Observation of providers may have led to a change in participants' behaviors via the Hawthorne effect. The study was limited to the approximately ten minutes involved in induction and may not account for contamination during the maintenance and emergence phases. Additionally, use of fluorescent dye in a simulated setting only allows the study of macroscopic dispersion of pathogenic material, rather than the microscopic analysis used in some studies to detect anesthesia workstation contamination; this setting also denies the ability to determine the effect of the intervention on pathogenicity and HAI outcomes (Biddle et al., 2016). Overall this study helped identify that double-gloving can lead to reduced contamination of a variety of surfaces in the anesthesia workstation. It does note that there remains significant contamination of the area, including of the IV stopcock assembly, which has been identified in other studies as a potential entry point for pathogens that can cause HAIs (Biddle et al., 2016).

Jaffe and Moriber's 2019 quasi-experimental study of Level III evidence was performed in a live OR environment to determine whether the use of double gloving during induction can help to reduce anesthesia workstation contamination over a period of time after education (Jaffe & Moriber, 2019). This study showed significant decreases in contamination for the APL valve, vaporizer, reservoir bag, and anesthesia circuit; but no difference with the drug cart, IV stopcock, or the IV bag. Perhaps the most pertinent finding of this study was that contamination increased between the trials one week after education and one month after education, possibly due to erosion of the teaching intervention (Jaffe & Moriber, 2019). Limitations included testing only one provider type in an anesthesia care team model, where IV medication administration is separated from airway management. The small sample size and short duration of the trial may

also have limited the ability to draw conclusions from data. Finally, no attempt was made to assess included patients' records for possible HAI development (Jaffe & Moriber, 2019).

Hand Hygiene—Disinfecting Gloves

Four articles were identified, including one review and one evidence-based practice guideline with Level I evidence and two randomized controlled trials with Level II evidence. Outcomes studied in this group included whether using alcohol-based hand rub (ABHR) compromised glove integrity, dexterity of gloves after multiple applications of ABHR, glove contamination and cross transmission, hand hygiene compliance with continued glove use, efficacy of ABHR on reducing glove contamination, and impact on HAIs.

Most studies examined in this group (Scheithauer et al., 2016; Gao et al., 2016; Birnbach et al., 2019) were tests of the effect of ABHR on the integrity of gloves, which is a necessary but not sufficient component of determining if this would be an effective intervention for reducing anesthesia workstation contamination. More research is needed to determine the effect of this intervention on HAI transmission, specifically in the OR with anesthesia providers. Examined here in more detail is the review by Kampf and Lemmen in 2017, which examines the largest number of outcomes of any of the articles. The review of the evidence surrounding disinfecting gloved hands with Level I evidence by Kampf and Lemmen in 2017 included 15 studies on glove use and hand hygiene compliance, six studies on disinfection efficacy, nine studies on glove integrity, and one study on the adjustment of risk for HAIs (Kampf & Lemmen, 2017).

Studies of the effect of increased glove usage on hand hygiene compliance also studied its effect on infection control. Identified studies found evidence that during normal patient care, gloves became contaminated but remained in use for further procedures, including aseptic procedures, 65.7-82.3% of the time. Another study showed the changes with hand hygiene

compliance based on the amount of time gloves were worn. When gloves were worn for 31.7% of all patient contacts, hand hygiene compliance before patient contact was 18.7% and 57.7% after contact. Comparatively, when gloves were worn 87% of all patient contacts, compliance before patient contact was 11.4% and after contact 52.5%, showing that as glove use went up, hand hygiene compliance decreased. Particularly notable was that in the period of greater glove use, CLABSI rates went from 6.2 to 14.1 cases per 1000 patient days, CAUTIs increased from 4.4 to 7.4 cases per 1000 patient days, and VAP increased from 0 to 2.3 cases per 1000 patient days. Predominantly with patients in contact precautions, providers were found to don gloves before patient contact and then not remove them until leaving a patient room, with no hand hygiene performed in between despite indications, viewing gloves as an adequate substitute for hand hygiene (Kampf & Lemmen, 2017).

The authors identified studies where glove disinfection efficacy had been tested. The outer surfaces of surgical gloves were easier to disinfect than bare hands. In three studies where the EN 1500 European Standard test evaluating bactericidal effect for hand hygiene rubs was used, ABHR was shown to be as effective on gloved hands as for bare hands in various combinations of gloves and hand rubs, even when gloves were perforated. Similar virucidal and sporicidal efficacy rates were seen, and with virucidal particularly gloved hands were more effectively decontaminated than bare hands. These results were sound enough to be the basis of the intervention's inclusion in recommendations by the 2016 Commission for Hospital Hygiene and Infection Prevention at the Robert Koch Institute in Germany and by the Association of the Scientific Medical Societies (AWMF) in Germany, as well as the WHO's 2018 guidelines for personal protective equipment (PPE) when managing patients with suspected Ebola (Kampf & Lemmen, 2017; WHO, 2018).

Three studies examined whether use of ABHRs on gloves would cause them to leak at higher rates than control. For the most part, leakage rates were the same as untreated gloves, though certain combinations of ABHR and glove brand resulted in 15% leakage after five ABHR treatments. Clinically distinguishable leakage was not seen with ABHR use and may be more impacted by movement stress in daily practice. One study evaluated the effect of ABHRs on the elongation and tensile strength of gloves with different types of ABHR. Ethanol reduced latex glove tensile strength by 4.3%, while iso-propanol reduced it by 18.1%. In contrast, nitrile glove tensile strength was reduced 26% with ethanol and 35.3% for iso-propanol. Similarly, latex gloves did not change in elongation, while nitrile gloves changed elongation over a range of decreasing 17.3% to increasing 30.5%. Smallest changes were seen in latex gloves treated with ethanol, and largest changes were seen in nitrile gloves treated with iso-propanol. All changes were still within acceptable regulatory limits (Kampf & Lemmen, 2017).

Permeability of the gloves was tested in three studies. Various composed gloves were exposed to ethanol hand rub, and the range of times before ethanol permeated the glove was between two and ten minutes. Another study assessed whether exposing three glove types to iso-propanol for 15 minutes would allow increased permeability of 17 cytotoxic drugs; only latex gloves increased permeability, still within safe acceptable limits (Kampf & Lemmen, 2017).

To show the effect of glove disinfection on HAI rates, a single study was examined where this intervention was instituted on a neonatal ICU. Gloves were donned and disinfected prior to patient contact and after touching objects in the patient care area. With all other factors held similar, there was a significant decrease in late-onset infection from 13.5 to 4.8 cases per 1000 days. Particular reductions were seen in necrotizing enterocolitis, which dropped from three

to 0.8 cases per 1000 patient days. Though this outcome is of great interest, its limited setting greatly hampers its generalizability (Kampf & Lemmen, 2017).

Limitations of this review included a lack of studies with data that were easily combined and compared, which the authors recommend as opportunities for further study. End-user feasibility studies are also lacking to demonstrate that this is an easily implementable change accepted by providers. Additionally, no studies were identified that included its use in the OR by anesthesia providers, which is needed to help test this intervention's effect on anesthesia workstation contamination and infection transmission. The authors also point out that while current manufacturer's guidelines and the guidance of the WHO does not currently specifically prohibit this intervention for everyday use, it remains something of a gray area in the guidelines, which deserves further clarification in the face of this data. This review identified no studies that showed evidence that the disinfecting gloves intervention was unsafe, increased infection rates, or increased cross-contamination. The authors indicated some guidelines that are necessary for use of this intervention. Providers should be educated on indications for removing gloves rather than disinfecting, reinforcing that gloves are for single patients only. Three of the five moments for hand hygiene should be performed while gloved, including before aseptic tasks, after body fluid exposure risk and after contact with patient surroundings. Gloves should be changed when perforated or soiled, or after patient care activities are finished, and the maximum number of times for disinfection should be capped at ten disinfections (Kampf & Lemmen, 2017).

Ultraviolet Radiation

This group of studies concerns the use of mobile UV light for decontamination of complex surfaces. Very few studies with this technology have been performed in the OR or the anesthesia workstation. Most identified studies assess the use of this technology in terminal

cleaning of patient rooms post-discharge. Those performed in the OR are limited to the end of day terminal cleaning due to the necessary duration of exposure to UV light for effect, with two exceptions. Two 2019 studies from similar authors studied a very new modality of focused multivector UV (FMUV) which has a 90 second duration and can be used between cases while allowing environmental personnel to remain in the room (Armellino, Walsh, Petraitis, & Kowalski, 2019a; Armellino, Walsh, Petraitis, & Kowalski, 2019b). However, these are the only two studies identified that assessed this newer modality and thus it was not considered to have enough grounding in the literature.

Outcomes of interest in this group include reduction in CFUs in total and by individual sampling sites, reduction in HAI transmission, as well as time needed for cleaning and changes in costs associated with this intervention. Three studies of Level II evidence and nine studies of Level III evidence were identified. Level II evidence studies included those by Jinadatha et al., 2014; Nottingham et al., 2017; and Andersen et al., 2017. Level III evidence studies included those by Nerandzic et al., 2010; Anderson et al., 2014; Haas, et al., 2014; Napolitano et al., 2015; Nagaraja et al., 2015; Wong et al., 2016; Penno et al., 2017; Simmons et al., 2018; and Raggi et al., 2018. Of these, studies that assessed the effect of UV on CFU reduction alone included two studies of Level II evidence and five studies of Level III evidence, while UV's effect on HAI incidence was studied in one study of Level II evidence and four studies of Level III evidence. Very few studies in the group assessed the use of UV light for the anesthesia workstation, including a randomized controlled trial by Nottingham et al. from 2017 assessing the use of the TruD UV-C SmartUVC to terminally decontaminate ORs. In addition, a large multicenter study by Anderson et al. from 2017 will be discussed in greater detail.

Evidence for this modality of anesthesia workstation contamination reduction is limited by a lack of anesthesia-focused studies. Additionally, no studies identify the level of contamination reduction required to reduce infection transmission, though HAI incidence pre- and post-intervention act as a proxy for this. Most troubling is that the majority of studies in this section have financial ties to the manufacturers of UV disinfection technologies. Future research should include more focus on the OR, including more research on the FMUV modality which could allow UV to be used for case turnover cleaning, as well as greater emphasis on UV's effectiveness at limiting infection transmission.

Nottingham et al.'s 2017 randomized controlled trial of Level II evidence is the only included study testing the use of a mobile UV device for terminally disinfecting anesthesia workstations. A training anesthesia workstation was used, testing high-touch areas in and out of the direct path of UV light. Sites that remained contaminated following direct exposure included the front of the oxygen sensor (10 CFUs), the right side of the APL valve (3 CFUs), and the anesthesia desktop (25 CFUs). Sites that remained contaminated following indirect exposure were more numerous, including the back of the oxygen sensor (96 CFUs), the back and left side of the APL valve (33 CFUs), the isoflurane vaporizer dial (48 CFUs), the left and right sides of the nitrous oxide dial (143 CFUs), the back of the desk handle (38 CFUs), the middle drawer of the anesthesia cart (13 CFUs), and the oxygen tank knob (7 CFUs). After the UV-C decontamination, all locations tested experienced a 2 log₁₀ reduction in CFUs compared to controls (Nottingham et al., 2017).

A concern of UV cleaning is that sites not in direct path of the light may not be adequately cleaned; this study helps to show that despite less efficacious disinfection, these sites will still have significant reductions in bioburden. Limitations of this study include being

performed under lab conditions, despite its location in the OR. This may not be reflective of actual conditions, which could include biological material that impedes the path of UV light and thus reduces the efficacy of decontamination. Lab conditions also means that the study lacks the capability of assessing the intervention's effect on HAI rates (Nottingham et al., 2017).

The 2017 Anderson et al. study was chosen because it was a large multicenter study trialing the efficacy of UV light for terminal disinfection and incorporated not only the changes to HAI transmission but also accounted for the effect of hand hygiene and room cleaning compliance. This study was conducted over a period of two years in nine hospitals of varying types, such as tertiary care centers, community hospitals, and Veterans Affairs centers. Four modalities were studied, with standard cleaning as control against bleach cleaning alone, UV cleaning alone, and bleach plus UV cleaning. All modalities were trialed at all hospitals for seven months each in a randomized order. Interventions were performed in single-patient rooms following discharge of a patient on contact precautions (Anderson et al., 2017).

Organisms targeted by this study included Methicillin-resistant *Staphylococcus aureus* (MRSA), Vancomycin-resistant *Enterococcus* (VRE), *Clostridium difficile*, and multidrug-resistant (MR) *Acinetobacter*. Transmission of HAIs was determined by identifying seed rooms where a patient with a history of infection with a target organism was admitted, and exposed patients who were admitted to the same room next. Outcomes included the incidence of infection among exposed patients to target organisms, whole-hospital incidence of target organisms, adverse events related to the UV device, increased wait times in the emergency room, and healthcare workers perceptions of the device (Anderson et al., 2017).

In total, there were 31,226 exposed patients, and of these 24,585 stayed in the seed room for longer than 24 hours; 21,395 of these met all inclusion criteria. Hand hygiene and room

cleaning compliance were similar in all groups. There were 228 incidences of infection and 195 of colonization in this group, for a total of 423 transmissions. In the control period, there were 51.3 HAIs transmitted per 10,000 patient exposure days. Adding the UV device decreased this level to 33.9 infections per 10,000 exposure days, $P = 0.036$; this overall decrease was seen in the UV group for eight out of the nine study hospitals. There was a 2.2% incidence of MRSA in the control group, which experienced a non-significant drop to 1.6% in the UV alone group ($P = 0.104$) and were essentially unchanged in the bleach and bleach plus UV groups. The baseline VRE incidence was 3.5%, which experienced a non-significant drop in the UV alone group to 1.4% ($P = 0.084$) but did have significant drops to 1.6% and 2.1% in both the bleach and bleach plus UV groups ($P < 0.05$). There were too few cases of MR-*Acinetobacter* to determine significance of interventions. *Clostridium difficile* seed rooms were only included in the bleach and bleach plus UV groups, and there was no significant difference with the addition of UV, $P = 0.997$ (Anderson et al., 2017).

Microbiologically, the three intervention arms all decreased target organism bioburden, with the largest decrease in the UV group. Room cleaning time median was increased by four minutes in the UV and bleach plus UV groups, and although the emergency room wait times were unchanged, the departure from the emergency room following decision to admit was increased by 10-20 minutes longer in all groups compared to control (Anderson et al., 2017).

Overall, this study demonstrated that use of enhanced terminal disinfection strategies could reduce incidence of target organism infection by 10-30%, with the greatest reductions seen with inclusion of UV devices. Limitations include the authors' findings that standard room cleaning may have been enhanced during this study. A 90% rate of cleaning compliance as was found in this study is higher than the rates found in much of the literature on standard cleaning.

This may explain the limited impact of the enhanced interventions, representing a minimum effect. In addition, the UV device was deployed in patient rooms outside of the patient bathroom, which may have reduced its effectiveness particularly for *Clostridium difficile* seed rooms, and indeed when the *Clostridium difficile* rooms were excluded from analysis the UV and bleach plus UV group effect was increased. Also, room cultures were acquired during standard care, potentially causing bias by variability in sampling technique. Molecular analysis was not performed on samples to determine definitively that exposed patients had received infection from the same as seed rooms (Anderson et al., 2017).

Anesthesia Machine Covers

Finally, a much more recent branch of research in reducing anesthesia workstation contamination is the anesthesia machine cover (AMC). Because of the recency of this innovation, the selection of studies is extremely limited; only two studies were found, both randomized controlled trials with level II evidence quality. However, the Society for Healthcare Epidemiology of America (SHEA) expert guidance document on anesthesia work area infection control and an article in the October 2019 Anesthesia Patient Safety Foundation (APSF) newsletter mention the devices as a potential new avenue of research (Munoz-Price et al., 2018; Schaffzin, Johnston, and Munoz-Price, 2019). This may signal that greater academic attention will be given to this modality in the future.

Both studies tested the use of AMCs by anesthesia providers. However, the 2018 study by Biddle et al. was conducted in a live OR environment, while the 2017 Hunter, Goldberg, Lin, and DeMaria study was conducted in a simulation center. Level of contamination was assessed in both studies with varying methods. The Biddle et al. study sampled identified anesthesia workstation hot spots and cultured samples from beginning of the OR day and from the end of

each case to determine the density and diversity of CFUs; while Hunter et al. applied fluorescent dye to a mannequin's oropharynx to simulate transmissible secretions, identifying contamination of similar hot spots at the end of simulation with a black light. Outcomes studied for both included overall level of contamination and contamination level of individual sites, with Hunter et al. study identifying contaminated sites in a binary system based on presence of fluorescence, and Biddle et al. by the number and species of CFUs found.

The 2017 simulation study by Hunter et al. compared rates of contamination between both control and intervention and within groups between residents and attending physicians. The AMC group experienced a 19.4% rate of contamination, while the control group had a 44.8% rate of contamination, $P < 0.001$. In the control group attendings had a much lower rate of contamination, with 3.9% for attendings and 35.7% for residents, $P = 0.001$. The AMC group demonstrated a similar rate of contamination between residents and attendings, $P = 0.561$, potentially demonstrating that the AMC can add greatest benefits to less experienced providers. At individual sites, significant reductions in contamination with the AMC were found for the APL valve, the manual ventilation bag, the ventilator switch, the anesthesia workstation surface, and the ventilator circuit, each at $P < 0.01$; and the IV stopcock, $P = 0.029$ (Hunter et al., 2017).

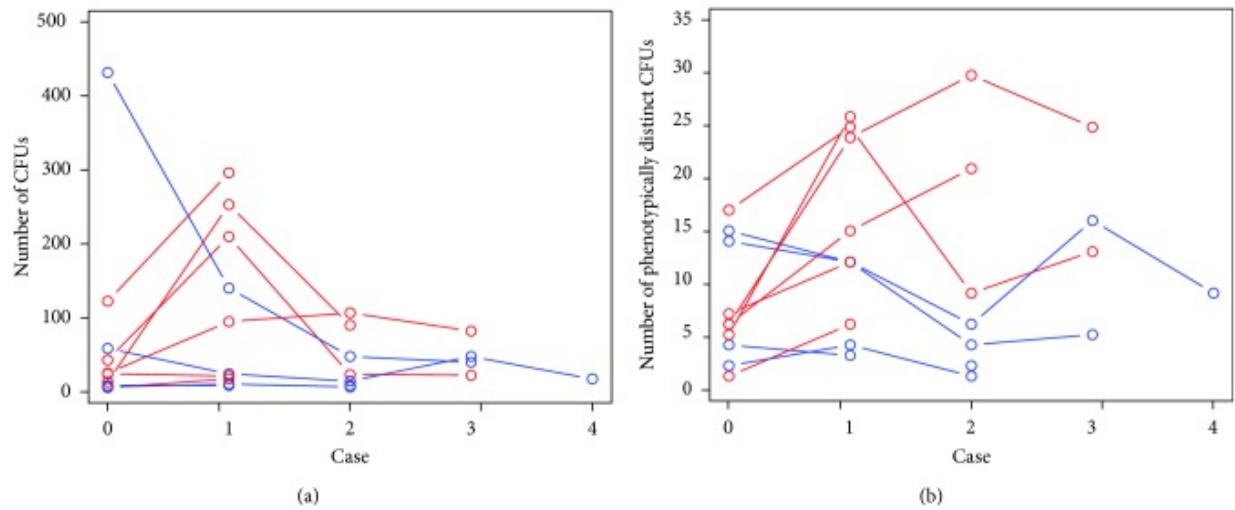
This study suggests that the AMC can help reduce the transference of oropharyngeal secretions from the patient to the anesthesia workstation. Removal of the AMC after induction also presents an important consideration that while the AMC may prevent direct contamination of the anesthesia machine itself, it cannot prevent subsequent transference of secretions on the AMC to other areas of the anesthesia workstation not covered. Conversely, though induction is a high-risk period for machine contamination, the risk of contamination is not strictly limited to induction. Removing the AMC post-induction leaves the machine open to contamination for the

remainder of the case. Limitations of this study include its simulated environment, which may have key differences from a real-world anesthetic such as airway complications that would necessitate less strict attention to hand hygiene or make the use of the AMC unsafe. (Hunter et al., 2017).

Biddle et al.'s 2018 study outcomes were to detect significant differences in the density and diversity of CFUs on anesthesia machines between intervention and control groups, both overall and at individual sites over the course of an OR day. Compared to uncovered machines, AMC-covered machines had significant CFU density reductions in all hot spots, with 108 mean total CFUs for control and 29.2 for intervention, $P = 0.008$. At individual sites, the AMC group had significant reductions of CFU density at the monitor control panel, oxygen flowmeter knob, and mouse. CFU diversity was significantly decreased in the AMC group in all hot spots except the APL valve, with an average total number of distinct CFUs in the control group of 18.7 and in the intervention group of 6.7, $p = 0.0004$. At individual sites, significant reductions in diversity were present in the AMC group for the vaporizer dial, the monitor control panel, the oxygen flowmeter knob, and the mouse. As seen in Figure 3, the intervention group experienced a stabilization or decrease of species, while the control group increased in both density and diversity of CFUs throughout the day (Biddle et al., 2018).

The use of a live OR environment in this study allowed for direct feedback on how the AMC will function in reality. This was only a single-center study with a relatively small sample size, but the results would suggest that the AMC can help to significantly reduce anesthesia workstation bioburden. Larger sample sizes could help delineate how effective this measure is as well as reduce any possible effect that provider variance would have had on the results. The work done in this study suggests the need for further research, possibly at multiple centers with

different practice models. More research on how the AMC might affect the safe delivery of anesthesia by providers is needed, as some training may be necessary to ensure that the AMC does not interfere with practice. In addition, this study does not include an analysis of how the AMC might affect clinical outcomes such as the development of HAI, nor the origin or direction



of the movement of microbes. The results of this study, particularly the increase in diversity and density of CFUs throughout the control OR day, would suggest that anesthesia providers are a significant vector for transmission of microorganisms (Biddle et al., 2018).

Figure 3

Note. Global CFU density [a] and diversity [b]; lines = OR cases throughout day, blue AMC group, red control group. Reprinted from Biddle et al. (2018). Assessing

a novel method to reduce anesthesia machine contamination: A prospective, observational trial.

<https://doi.org/10.1155/2018/1905360>.

Body

Four interventions to reduce contamination of the anesthesia workstation are examined in this paper, including double gloving with induction, disinfecting gloved hands, UV radiation for workstation cleaning, and the use of anesthesia machine covers. Having reviewed the existing

literature, a look at each individual technique and techniques in comparison is needed. In this section, the interventions will be described, their efficacy determined along with their cost of implementation, and comparisons of these factors will be made between individual interventions.

Double gloving is a specialized form of PPE. As a process, it is intended for the wearer to perform hand hygiene and don two sets of disposable non-sterile gloves prior to airway manipulation. Once placement of the ETT or other airway device is complete, the contaminated outer gloves are removed and discarded before confirming airway placement and securing the device while wearing the clean inner gloves. While this process may seem novel to many anesthesia providers, it is in fact already recommended by the AANA Infection Prevention and Control Guidelines for Anesthesia Care, for use during procedures at higher risk for complications from a needle stick and during airway manipulation (AANA, 2015).

The efficacy of double gloving has been examined in the literature. As all but one of the studies concerning the double gloving technique are simulation studies, there is no data regarding the effectiveness of double gloving in reducing CFU bioburden in the anesthesia workstation or the subsequent development of HAIs in OR patients. However, all studies did examine the degree to which double gloving reduced contamination of a variety of sites in the anesthesia workstation. Porteous et al., 2018 found a reduction in site contamination with double gloving of 27.4%, while Biddle et al., 2016 found a reduction of 52.5% and the Birnbach et al. trial studying double gloving alone found a reduction of 75.4% (2015a). Perhaps the most interesting finding is that of Jaffe and Moriber, whose live trial of double gloving in the OR examined contamination levels at one week and one month post-education, finding that initial reduction in contamination was 73%, but was reduced to 48% by one month (2019). This is particularly of importance because like any form of PPE, the efficacy of double gloving relies on provider compliance.

The loss of efficacy of the intervention speaks to a decrease in the effectiveness of the teaching, which may signal increased investment is needed in this intervention rather than simply increasing the number of gloves used. This intervention is also only tested in all studies during induction, and it may be useful to know if using double gloving with emergence and airway device removal also helps to reduce contamination. As this is an intervention solely to help improve hand hygiene compliance during high density portions of anesthesia care, it does not account for other sources of contamination during the case aside from airway manipulation. Other sources might include the provider's hands at other times in the case, emergencies intraoperatively, and direct environmental contamination from the surgery.

Costs associated with this intervention appear at the outset to be minimal. Gloves are a preexisting expenditure for any site that performs surgery, and it is unlikely that a small increase in the number of gloves used during an anesthesia case would affect the number of gloves purchased any more than incidental waste of gloves from poor packaging causes. However, for the sake of comparison, a box of Halyard nitrile exam gloves containing 250 gloves costs \$19.97 (Quantum Labs, 2020). Loftus et al., 2012 estimated an average of 2.39 +/-1.60 glove usages per case in their study examining anesthesia workstation contamination. The Maine Department of Health and Human Services projects that in 2020 Maine Medical Center will perform 23,523 surgeries (Carbonneau & Lawrence, 2017). Rounding up to an average of four glove usages per surgery, this projects 188,184 individual gloves used at this facility by nurse anesthetists for surgeries per year. A projection of 752.7 boxes of glove rounded up to 760 boxes brings it to a yearly expenditure of \$15,177.20 for gloves for anesthesia providers at current rates. Assuming the double gloving intervention would double the need for gloves by anesthesia providers, this would increase the expenditure to \$30,354.40. Glove purchases, particularly non-sterile gloves,

are a required item for a hospital in more areas than the OR. However, this may not be the only cost associated with the double gloving intervention. As the 2019 Jaffe and Moriber study indicated, this intervention would require continued education and leadership support to have a meaningful impact. This may have costs in term of staff hours, educational time, and auditing; representing an important area of study untouched by the literature.

Less conventional than double gloving, disinfecting gloved hands is another PPE intervention. This intervention is proposed to help promote optimal hand hygiene during task dense periods. During the time of induction just after placement of the ETT, the hands become soiled with oropharyngeal secretions, and in keeping with the WHO five moments for hand hygiene, the anesthetist should ostensibly remove gloves, perform hand hygiene, and don a new pair of gloves. Obviously, this lengthy process is impracticable and not consistent with the safety of the patient. Disinfection of gloved hands provides an alternative that takes less time and is less physically difficult than trying to don gloves onto a wet hand.

Currently, there is limited evidence regarding the disinfection of gloved hands in reducing HAIs. One study examined in the 2017 review by Kampf and Lemmen demonstrated a reduction in HAIs of 64.4%, but this study was performed in a neonatal ICU and may have limited applicability to anesthesia. The remainder of studies in this category attest to the virucidal and bactericidal efficacy of cleaning gloves (Kampf & Lemmen, 2017) and the continued integrity of gloves after multiple administrations of hand sanitizer (Birnbach et al., 2019; Gao et al., 2016; Scheithauer et al., 2016). Part of the reason for so little research and evidence on this topic is that it remains something of a gray area in terms of complying with WHO standards—while the 2018 WHO guidelines for caring for Ebola patients specify disinfection of gloved hands in times of emergency, this does not necessarily imply that these

guidelines would hold true under normal circumstances (WHO, 2018). Nevertheless, this is potentially an intervention with wider applicability than the double gloving technique. With double gloving, the provider is obliged to anticipate that there will be a task dense situation and double glove in advance to remain clean. With glove disinfection, the provider can react to unforeseen intraoperative circumstances that contaminate the hands.

In contrast with the double gloving interventions, disinfection of gloved hands should maintain or reduce the number of gloves used by a provider in a case by allowing for continued use. By contrast, use of hand sanitizer may increase. Similar to double gloving, disinfecting gloved hands is an intervention that requires provider compliance and thus would have the hidden costs of education and follow-up to ensure its efficacy.

The Maine Department of Health and Human Services projects that in 2020 Maine Medical Center will have 62,963 OR case-hours (Carbonneau & Lawrence, 2017). A study by Kampf et al. in 2013 found that hand sanitizer doses of at least 2 mL were required to achieve greater than 2 log₁₀ reduction in contamination, which meets the United States Food and Drug Administration standard for efficacy. Rowlands et al. determined in their 2014 study that anesthesia providers had 149+/- 10.3 hand hygiene opportunities per hour of anesthesia time, with a compliance rate of less than 3%, or four HDEs per hour. A 200% increase in hand hygiene compliance represents an achievable goal of 12 HDEs per hour. With these variables, Maine Medical Center could project to use an average of 755,556 mLs of hand sanitizer in the OR in 2020. A 12-bottle carton of Purell bottles containing 591 mLs of hand sanitizer costs \$128.95, per FoodServiceDirect (2020). At this rate, Maine Medical Center would require 1,279 bottles of hand sanitizer, or 107 cartons, totaling \$13,737.87 for the OR in 2020.

An altogether different strategy for reducing anesthesia workstation contamination is the use of UV radiation for terminal cleaning. UV light near the 254-nanometer spectrum causes the formation of pyrimidine dimers created from thymine and cytosine to denature DNA and kill the growth of microorganisms. In various automated devices, a UV-light machine emits a dose of 12,000-22,000 microwatts per square centimeter, depending on the setting and desired organism to kill (Anderson et al., 2013). Because of the harmful nature of UV light, the machine must be placed in the room to be cleaned and then vacated of all personnel. Duration of light exposure depends on the device and the organism to be killed, with ranges in the literature spanning from five minutes to 55 minutes (Health Quality Ontario, 2018; Nottingham et al., 2017).

UV radiation is one of the better studied interventions included in this paper, though most studies are for terminal cleaning of patient rooms rather than the OR. Many of the studies are tied to the device manufacturer as well, which may give them more resources to explore the potential of the UV devices but also introduces an undeniable element of bias. Nevertheless, there is ample data on the ability of UV light to reduce HAIs, decrease CFU bioburden, and decrease site contamination. Haas et al., in 2014 reported a 19.9% reduction in HAIs; with Napolitano et al., in 2015 reporting 35.1%; Anderson et al., in 2017 with 33.9%; and Raggi et al., in 2018 with 20.7%. CFU reductions were reported as between 85.5% (Simmons et al., 2018) and 99.1% (Jinadatha et al., 2014). The only study that reported on reductions in contamination of sites was also one of the only two performed in the OR and concerning anesthesia equipment. Simmons et al. in 2018 reported an overall 43.2% reduction in anesthesia site contamination, with particularly an 87% reduction of CFUs on the anesthesia machine and 41% of surfaces on the anesthesia machine itself still contaminated, a 38% reduction from pre-UV radiation.

The advantage of the UV radiation intervention lies in its proven ability to reduce HAIs, albeit in another hospital setting, as well as in its lack of reliance on provider compliance with the intervention to be effective. The ability of UV radiation to reduce the bioburden of CFUs on the anesthesia machine between cases would be advantageous to supplement the pitfalls of manual cleaning, if it were not that the long duration of UV radiation needed to complete an adequate dose would increase turnover times between cases by a large margin. Even if it were practical to irradiate the anesthesia workstation between every case, this intervention does not account for within case transmissions of organisms, which the literature has shown to be a substantial portion of transmission events.

Perhaps the greatest challenge to the implementation of the UV radiation intervention is the prohibitive cost. Health Quality Ontario in 2018 published a review analyzing UV radiation devices in healthcare and estimated the cost for a facility to purchase two UV devices would come to between \$586,023-\$634,255 CAD, or \$443,320.54-\$479,807.56 USD over a period of five years, with a capital investment of \$249,034-\$284,650 CAD (\$175,139-\$200,180.20 USD) and yearly costs coming to between \$55,675-\$82,387 CAD (\$39,154.84-\$57,940.72 USD). The first year investment for UV devices would cost \$304,708-\$340,324 CAD (\$214,293.52-\$239,341.36 USD). Costs included in this estimate were the device itself, the maintenance and warranty, and employing staff to operate the devices (Health Quality Ontario, 2018).

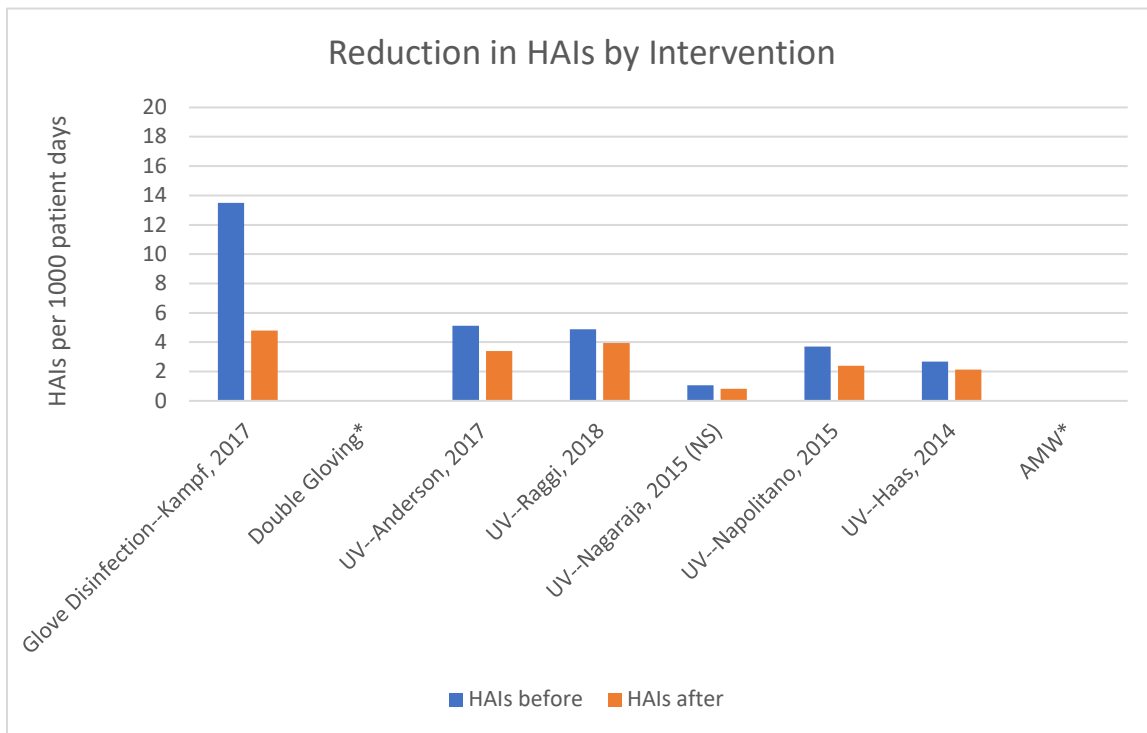
Finally, the anesthesia machine wrap (AMW) is a barrier intervention intended to prevent the anesthesia machine from becoming contaminated. Because the anesthesia machine itself has a variety of challenging areas to clean including numerous valves with irregular fluting and other crevices where contamination can become resistant to manual cleaning, this intervention is intended to prevent any contaminants from contacting the machine at all. Biddle et al. liken the

AMW to the provider wearing gloves and then removing them after completing a procedure (2018). Hunter et al. in 2017 found that using an AMW reduced site contamination of the anesthesia machine by 56.7% to only 19.4% of sites being contaminated, while Biddle et al. in 2018 found that using the AMW resulted in a 72.9% decrease in the CFU bioburden on the anesthesia machine throughout a day of consecutive cases.

The benefit of the AMW is, like the UV radiation devices, that its efficacy is not reliant on provider compliance. It also prevents contamination from reaching the machine in the first place, obviating the need for enhanced cleaning techniques after a case concludes. In the sense that the AMW is not cleaned during the case, it may help to prevent between case transmissions but does not prevent within case transmissions. Although the exact model used in the Biddle et al. 2017 study was not able to be identified, Sharn Anesthesia Inc. offers the “Anesthesia Hygiene Organizer,” which is sold in packs of 50 for \$254.00, or \$5.08 per unit. Multiplied by the projected number of 2020 surgeries at Maine Medical Center set forth above, this would come out to an expenditure of \$119,496.84 per year. The AMW is not as prohibitively expensive as the UV radiation device, but also not as cheap as double gloving or glove disinfection.

Rudimentary comparisons between the efficacy of various modalities of reducing anesthesia machine contamination are possible within the boundaries of this paper, but not conclusive. Further research involving cohort propensity matching, side-by-side analysis, uniform study settings and other measures is needed for truly useful comparisons between these groups. This author’s comparison of various measures employed by the studies includes reduction in HAIs by gross numbers and by percentage, reduction in CFUs, and reduction in site contamination. Not all studies had these measures as components of analysis, so only those studies that used these measures were represented in various graphs.

The highest gross incidence and percentage of HAI reduction was observed in the glove disinfection review by Kampf and Lemmen, 2017, where a reduction from 13.5 HAIs to 4.8 per 1000 patient days resulted in a 64.4% reduction, though as stated before this was an isolated neonatal ICU study. All percent reductions of included studies are shown in Figure 5. In contrast, the 2017 UV radiation study by Anderson et al. demonstrated a reduction from 5.13 to 3.39 HAIs per 1000 patient days after intervention; the percent reduction was 33.9%. The remaining studies from the UV cohort as demonstrated by Figure 4 had similarly lower levels of HAI incidence and



reductions, reinforcing the neonatal ICU study as an outlier. The totality of the UV cohort had a range of HAI percent reductions from 19.9% to 33.9% (Haas et al., 2014 and Anderson et al., 2017, respectively). The variance seen in these studies as well as the dearth of studies with glove disinfection point to the inability to draw solid conclusions from these comparisons. The double gloving intervention and the AMW intervention did not test these variables and thus could not be included.

Figure 4

Reduction in HAIs by Intervention

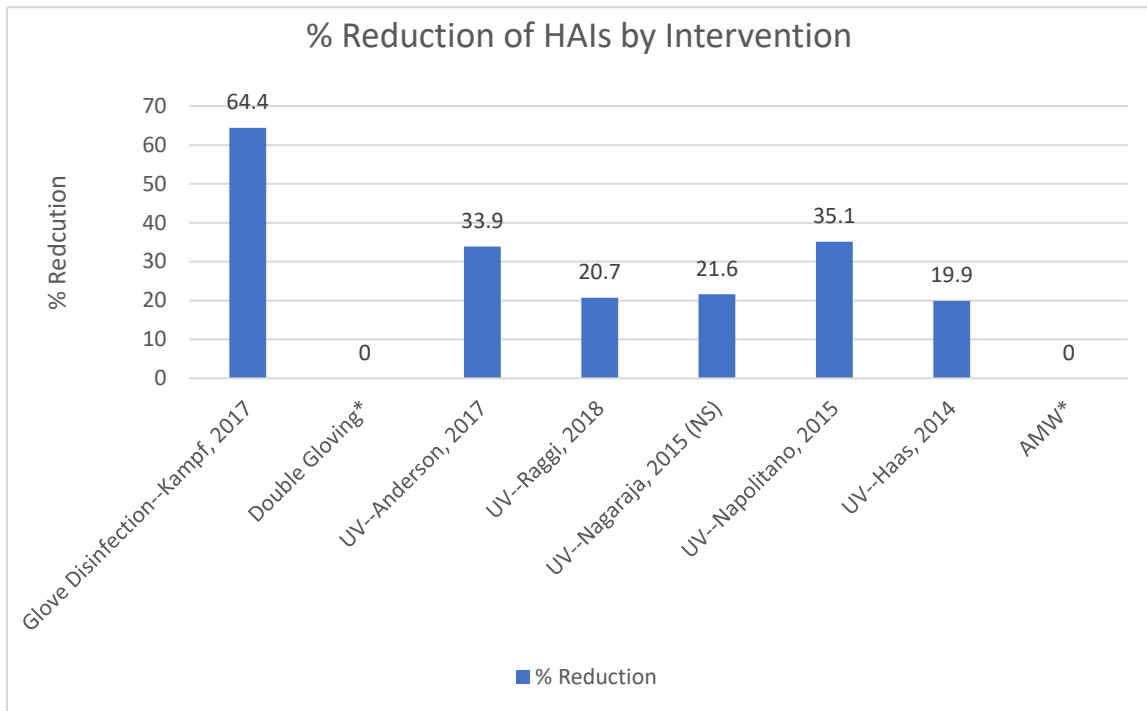


Figure 5

Percent Reduction of HAIs by Intervention

The next set of comparisons assesses the reduction in CFUs by intervention, as seen in Figure 6. The two PPE interventions, double gloving and glove disinfection, did not assess this measure in any of the included studies. The AMW study that included this measure, Biddle et al., 2017, found a reduction from 108 CFUs to 29.2, leading to a 72.9% reduction. The UV radiation studies found initial CFU rates at a range from 28.9 to 114 (Penno et al., 2017 and Wong et al., 2016), with post-treatment low CFU findings from a range of 0.51 to 4 CFUs (Penno et al., 2017 and Anderson et al., 2013). Percent reductions ranged from 85.5-99.1% in this group (Simmons

et al., 2018 and Jinadatha et al., 2014). As with the previous group, there was a much larger group of UV studies than the single AMW study that was included.

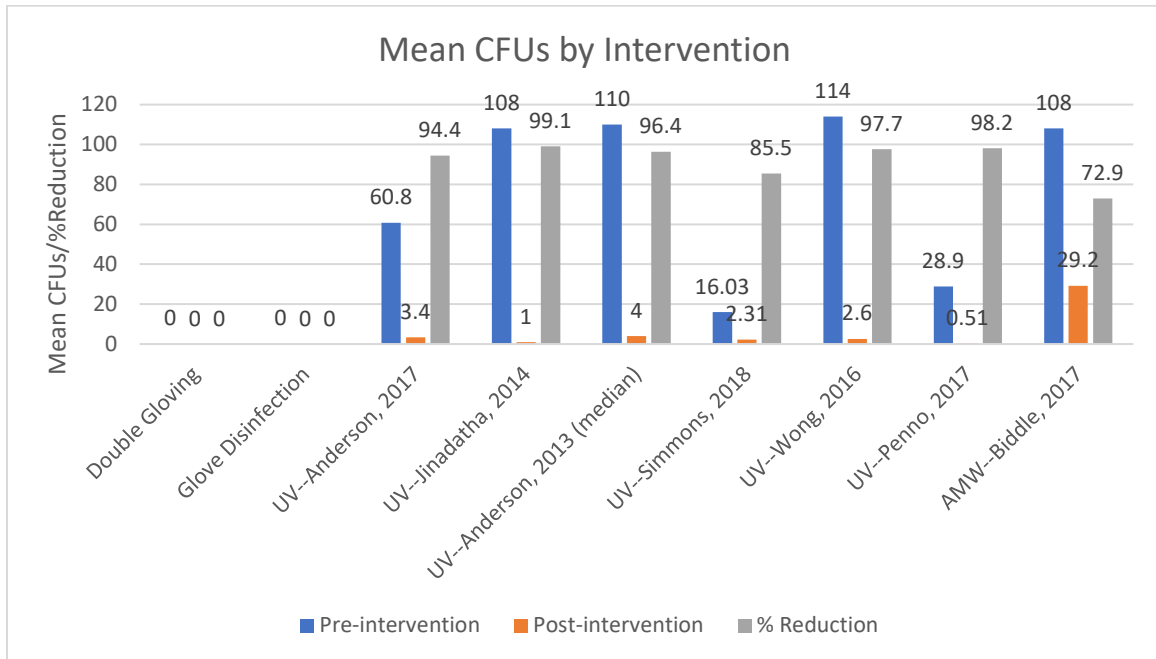


Figure 6

Mean CFUs by Intervention

All intervention categories except for disinfecting gloves included changes in site contamination as an outcome, shown in Figure 7. Three double gloving studies measured this outcome, with a range of initial contamination rates from 47-73% of measured surfaces (Biddle et al., 2017 and Porteous et al., 2017), and a range of post-intervention contamination rates of 12.5-53% (Birnbach et al., 2015a and Porteous et al., 2017). The range of percent reductions in these studies went from 27.4-75.4% (Porteous et al., 2017 and Birnbach et al., 2015a). The 2018 Simmons UV light study showed an initial contamination rate of 67%, reduced to 38%, with a 43.2% relative reduction in contamination. The 2017 Hunter et al. study of the AMW showed an

initial contamination rate of 44.8%, reduced to 19.4%, with an relative reduction of 56.7%. Of all the interventions, double gloving had the highest and the lowest reduction in contamination sites; all achieved significant reductions according to their study protocols. This outcome has the distinction of having been performed in a live or simulated OR for all studies included.

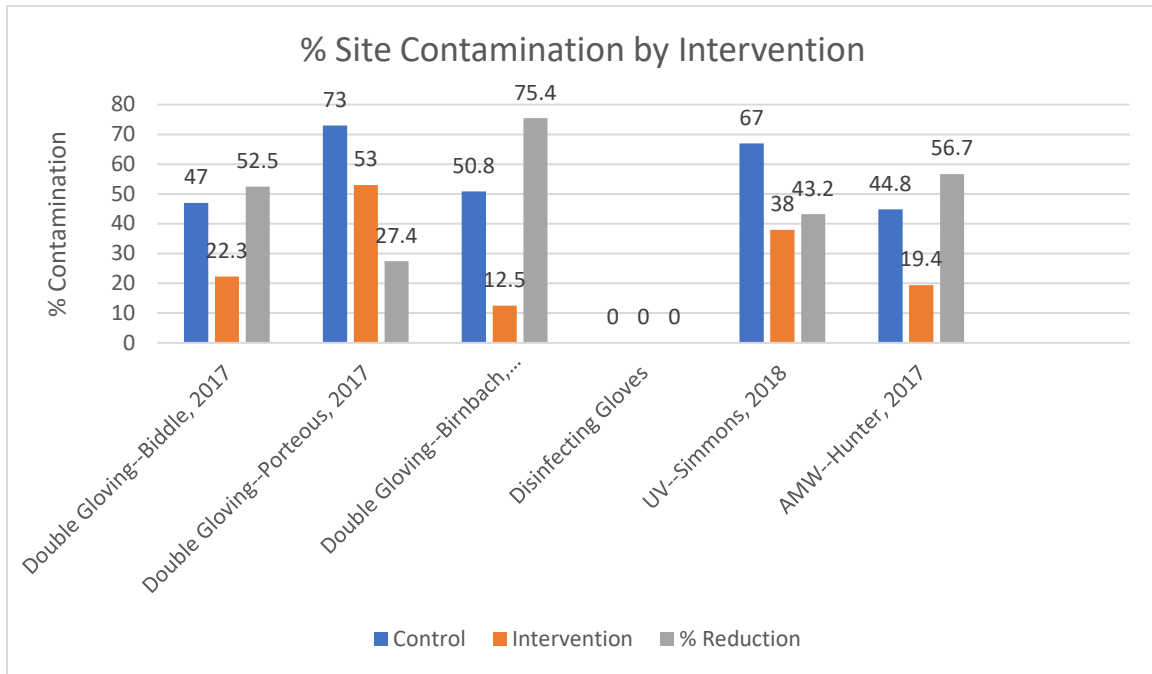


Figure 7

Percent Site Contamination by Intervention

Figure 8 compares the costs of each intervention, as calculated by this author above and from various studies. This may yield a first idea of which intervention may be the most feasible to implement. By far, the most expensive intervention to implement was found to be the UV radiation intervention, as determined by the 2018 Health Quality Ontario review discussed above. Despite its heavy costs, the UV radiation intervention may have greater application in a hospital setting beyond the OR. The AMW intervention was next in cost, though less than half of the financial burden caused by UV radiation devices. Double gloving was third in a projection

where the addition of pairs of gloves to individual anesthetics would increase the requirements for purchasing, which is not necessarily true. Disinfection of gloved hands had the least cost, which like glove purchasing may not reflect a true need to increase the hospital supply. These costs have not been weighed against the potential benefits they might provide to a facility, both in the OR and in other settings. This represents another area of future investigation.

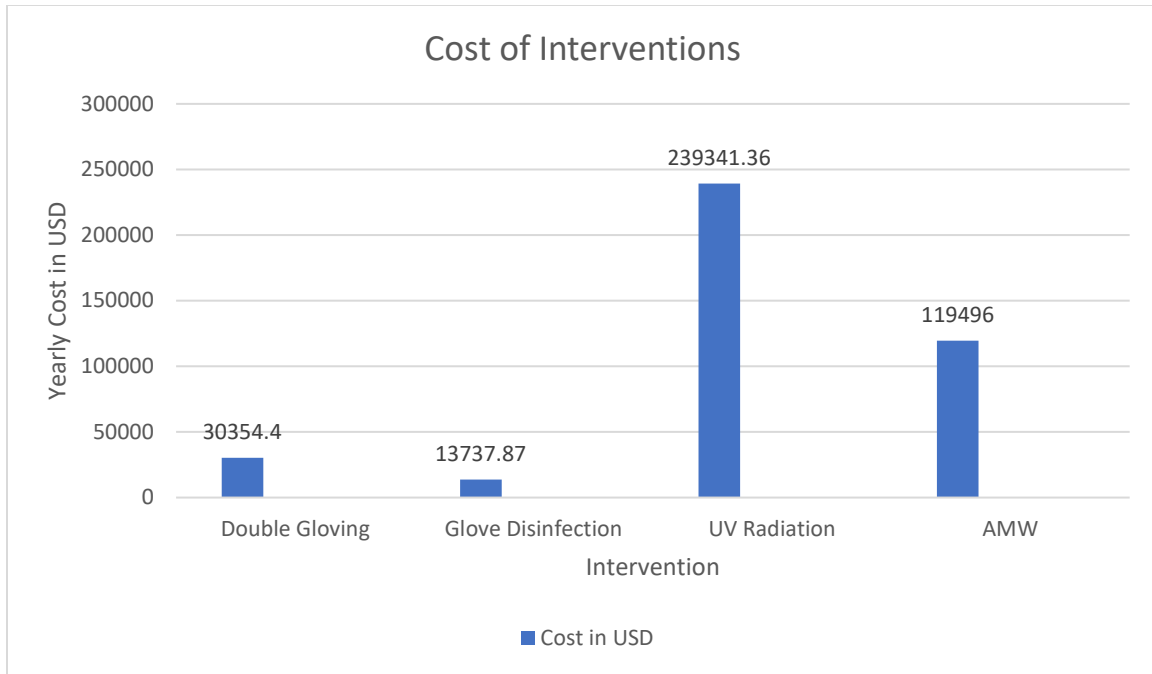


Figure 8
Cost of Interventions

Discussion

The global advent of novel coronavirus, or COVID-19, has focused the attention of all healthcare providers on the importance of PPE, adequate cleaning protocols, and preventing the spread of contaminants. Anesthesia providers are becoming acutely aware of the degree to which airway management can aerosolize contaminants that then remain on equipment and clothing, making the environment and themselves a vector for the virus. This analysis of interventions has changed over the course of the disease spread, as items that before the crisis were in ample

supply are now rationed among healthcare providers. While the interventions contained in this paper are not specific to containing droplet or airborne diseases, greater attention in the anesthesia community is likely to be focused on ways to reduce contamination.

This paper has examined the literature regarding four possible interventions to reduce anesthesia workstation contamination—double gloving, disinfecting gloved hands, UV radiation devices, and AMWs. The efficacy and costs of each intervention have been examined and compared. Despite this, the determination of which intervention is the most beneficial as an addition to anesthesia practice is still unclear. Though the separation of the time of the anesthesia episode and HAI recognition has made this a hidden issue, the literature has demonstrated how anesthesia providers and anesthesia workstations contribute to patient infection and morbidity.

It is imperative that anesthesia providers and hospitals analyze the evidence to determine best practices. Based on costs, it appears that double gloving and glove disinfection are the best options for most hospitals. Indeed, the low material costs associated with these interventions may mean that they should be instituted into anesthesia practice, even if other methods are also included. The main barrier to these interventions, alongside the relative paucity of evidence as to the effectiveness of the glove disinfection intervention, is provider compliance. Relying on provider compliance without a well-supported culture and continual buy-in from key stakeholders is a path to failure for these options.

Despite the high costs of UV radiation devices and the difficulties of using it for case turnover, this intervention has currently the greatest body of evidence to support its use, as well as additional utility in other areas of the hospital. This along with the AMW intervention has the great benefit of not relying on provider compliance, which may be the best insurance of consistent application. The lower cost of the AMW intervention and greater ability to use with

every case compared to UV recommends it, but this intervention appears to be relatively unknown in anesthesia practice and to date has only been trialed in two studies.

To be able to conclusively determine the best intervention or combination of interventions to reduce anesthesia workstation contamination, more research is needed. Areas that specifically should be targeted in future research include a focus on clinical endpoints such as incidence of HAIs, length of stay, morbidity, and mortality. Focusing on these areas may help to determine what level of reduction in contamination is necessary to reduce infectious consequences as well as reinforcing the benefits of reducing contamination and its costly consequences.

More studies should focus specifically on anesthesia and contamination reduction. Anesthesia is such a unique field of healthcare that many of the protocols that guide contamination reduction in other areas of the hospital are not practical in the OR. Indeed, this may mean that much of the results from the UV trials may not apply to anesthesia. That can only be determined if more research focusing specifically on the OR and anesthesia workstation is done. Not only is a focus on anesthesia needed, but also a focus on non-simulated, live anesthesia practice. Only a very few of the studies contained in this paper evaluated interventions being used in a live OR environment.

Some identified areas specific to anesthesia research would be the ability to reliably reduce both between and within case transmission of infections, the relationship between HDEs and infectious risk, the role of timing during an anesthetic correlated to risk, and how to increase provider compliance with interventions across a variety of different anesthetizing settings. Additionally, it is important to examine the literature for contaminated areas of the workstation that remain resistant to intervention even with advanced reduction techniques such as the

reservoir bag, the APL valve, and IV stopcocks, and to determine more effective ways of controlling this.

Finally, the review of the existing literature on this subject has shown that a great deal of research in anesthesia contamination and related topics has been performed by a relatively small number of authors. While this work is laudable, it is hoped that research in the future will expand to include new voices and perspectives. A wider variety of researchers may bring new innovations and prevent unseen biases of existing authors from becoming unquestioned doctrine. Reducing anesthesia workstation contamination is an important issue that deserves attention from the larger world of anesthesia providers.

Conclusion

This paper has demonstrated both the need for finding new ways to reduce anesthesia workstation contamination as well as offering many different solutions to the problem. In almost all areas of study, more research of higher quality is needed. Because the role of anesthesiologists in the care of the patient is often brief, their role in transmitting HAIs is often overlooked. Emphasis in future research should particularly be placed on conducting research in the OR with the focus on anesthesia providers. Additionally, research should be aimed at including larger sample sizes. This will allow greater power for testing interventions, especially when attempting to determine an outcome like HAI incidence that is relatively infrequent. Not only should cases where interventions are used to reduce contamination have records tracked to identify infection, but attempts should be made to identify the level of contamination reduction needed to stop transmission of infection. Regardless, it is imperative that anesthesia providers take an active role in finding and implementing ways to reduce their impact on anesthesia workstation contamination and HAIs.

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