American Journal of Infection Control 44 (2016) 873-8

Contents lists available at ScienceDirect

American Journal of Infection Control

journal homepage: www.ajicjournal.org

Major Article

Quantifying the rambunctious journey of the anesthesia provider's hands during simulated, routine care

Chuck Biddle CRNA, PhD [a,*], Kathryn Robinson BSN [a], Benjamin Pike BSN [a], Michael Kammerman AS [b], Beverly Gay MSN [c], Brad Verhulst PhD [d]

[a] Departments of Nurse Anesthesia & Anesthesiology, Virginia Commonwealth University Medical Center, Richmond, VA
[b] Center for Research in Human Simulation, Virginia Commonwealth University Medical Center, Richmond, VA
[c] Department of Nurse Anesthesia, Virginia Commonwealth University Medical Center, Richmond, VA
[d] Virginia Institute for Behavioral Genetics, Virginia Commonwealth University, Richmond, VA

Key Words:
Handwashing
Anesthesia workstation
Contamination
Medical simulation

Background: The role of anesthesia providers in dispersing potentially pathogenic material from one patient to another during intraoperative care needs further study. In this study we aimed (1) to quantify the dispersion of a surrogate pathogen from a simulated patient's mouth to the anesthesia workstation during routine anesthetic induction, (2) to test the hypothesis that there would be fewer contamination sites by providers who used a double-gloving technique, and (3) to examine the effectiveness of between-case anesthesia apparatus disinfection.

Methods: Twenty subjects were randomized to a single pair of gloves group (group 1) or a double-gloved group (group 2) and completed a simulated general anesthesia induction, completing a standardized set of interventions. Dispersion of a surrogate pathogen dye placed in the oral cavity of the simulated patient was tracked by a blinded observer and photography. Standard cleaning of the workstation was performed, and residual dye was quantified. Group performance was plotted using regression analysis and rate of contamination compared using parametric statistics.

Results: Group 1 contaminated an average of 16.0 (SEM = 0.89) sites compared with group 2, who contaminated an average of 7.6 (SEM = 0.85). The cart drawers, gas flow dials, medication vials, and ventilator controls were significantly contaminated by group 1, but not by group 2 ($P < .05$ in all cases). There were similar rates of contamination in both groups for the airway equipment, breathing system, intravenous access ports, and the roll of tape used to secure the endotracheal tube. Once the airway management phase of the induction ended, new site contamination continued at a high rate in group 1 but not group 2.

Conclusions: A double-gloving technique was associated with less spread of an oral inoculum to the workstation but was not uniformly protective. Between-case cleaning was ineffective in removing the contaminant, indicating that biologic material from one patient may be present when subsequent patients are cared for. This suggests risks for the current patient (eg, skin or oral site transfer to an intravenous site) and also may place future patients at risk. Importantly, using models that simulate actual clinical events can inform clinical practice and decipher challenging areas of ergonomics.

During the course of even routine care, anesthesia providers may serve as vectors, contributing to the genesis of nosocomial infection.[1-8] Poor technique, inconsistent use of gloving, high task density, production pressure, poor ergonomic design, forgetfulness, and difficulty in readily accessing hand hygiene products all are contributory.

Munoz-Price et al demonstrated a unique and novel method to study potential vectors of transit of biologic material in the operating room.[9] This work was extended on by Birnbach et al who applied these techniques, using a fluorescent marker, to the anesthesia care domain.[8] It was this body of work that inspired the present study and served as a foundation from which to extend our understanding of the potential role that anesthesia providers play in pathogen dispersion during routine operative care.

* Address corresponcence to Chuck Biddle, CRNA, PhD, Departments of Nurse Anesthesia & Anesthesiology, Virginia Commonwealth University Medical Center, Richmond VA 23298-0226.
E-mail address: cjbiddle@vcu.edu (C. Biddle).
Conflicts of Interest: None to report.

0196-6553/
http://dx.doi.org/10.1016/j.ajic.2016.02.014

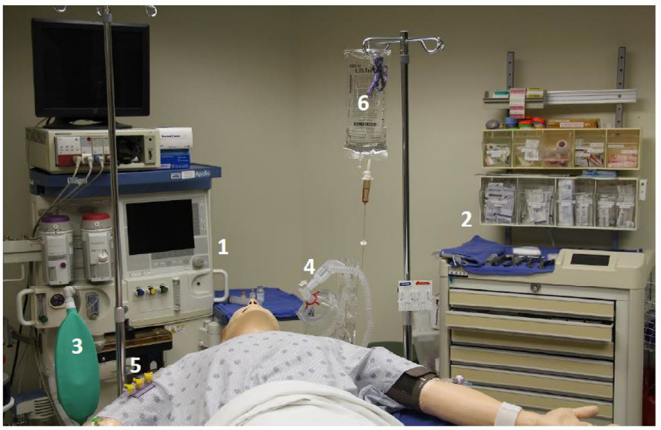

Fig 1. Anesthesia workstation and patient simulator. *IV*, intravenous.

We aimed (1) to quantify the dispersion of a surrogate pathogen from a simulated patient's mouth throughout the anesthesia workstation during routine general anesthetic induction, (2) to test the hypothesis that there would be fewer contamination sites caused by providers who used a double-gloving technique, and (3) to examine the effectiveness of the between-case anesthesia apparatus disinfection protocol.

METHODS

This study was approved by the Institutional Review Board at Virginia Commonwealth University and performed at Virginia Commonwealth University's Center for Research in Human Simulation. The patient was simulated by a SimMan 3G (Laerdal Medical, Wappingers Falls, NY), shown in Figure 1. The source of surrogate biologic contamination was a nonpathogenic inoculum in the form of DAZO (Ecolab, St Paul, MN), a clear and odorless fluorescent marking gel used as an analog for biologic material from the patient's mouth. One ampule of gel was mixed with 5 g of a water-soluble lubricant to create a saliva-like consistency. A standard Wood's lamp, emitting long-wave ultraviolet light, was used to fluoresce the dye, quantifying the dispersion of the surrogate biologic material. Dispersion of the dye from the oral cavity to other sites was considered to be caused by the actions of the anesthesia provider and served as the outcome variable.

A convenience sample of 20 experienced anesthesia providers performed a simulated, routine, uncomplicated induction of general endotracheal anesthesia. One member of the research team monitored their performance and gave verbal cues, if necessary, to ensure performance of a set of standardized interventions, as listed in Table 1. The 20 subjects were randomly divided into 2 groups. Group 1 (n = 10) was told to wear a single pair of gloves throughout the induction period and immediately after successful tracheal intubation but before attaching the breathing system to the endotracheal tube. The laryngoscope was managed at the provider's discretion. Laryngoscope management ranged from placing it on the surgical bed, on the drug-supply cart, on the mannequin's chest, or in a basin attached to the cart. All are common behaviors in routine clinical practice. No provider in group 1 put on (or was asked to do so) a second pair of clean gloves. Group 2 (n = 10) was told to double-glove, and immediately after successful intubation of the trachea, but before attaching the breathing system to the endotracheal tube, the outer gloves were removed and placed, along with the laryngoscope, into a collecting basin attached to the side of the drug-supply cart. If the outer gloves were not removed at this point the participant was prompted to do so. Each simulation was conducted in a high-fidelity, realistic manner except participants were told that there was no need to chart what was done.

Table 1
List of routine interventions performed by all providers

Scenario steps
Preoxygenation
Administering IV midazolam, fentanyl, lidocaine, propofol, succinylcholine
Adjusting the flow control of the intravenous fluids
Controlling ventilation by mask with an oral airway in situ
Performing laryngoscopy and placing an endotracheal tube
Connecting the circle system to the endotracheal tube and inflating pilot balloon
Auscultating breath sounds
Securing the endotracheal tube with tape
Adjusting the mechanical ventilator settings to achieve normocarbia
Administering a volatile anesthetic agent via the anesthetic vaporizer
Readjusting the flow control of the intravenous fluids
Placing an orogastric tube and an esophageal temperature probe
Administering an intravenous antibiotic
Administering an intravenous antiemetic

NOTE. All of the interventions were performed by each provider. These represent routinely performed clinical actions occurring with the induction of general anesthesia. *IV*, intravenous.

Participants were unaware of the nature of the gel and lubricant used in the mannequin's mouth or to the true reason for their performing the induction sequence. Participants were informed that their induction sequences were being videotaped for use in future didactic training of anesthesia providers just starting their education and training. After a 10-minute familiarization process with the simulation setup, the participants were taken to another room to obtain gloves and surgical masks. With the participants absent from the simulator, the mannequin's tongue and incisors were inoculated with 1.5 mL of the dye mixture. Prior to each scenario, the entire workstation and mannequin were scanned with the Wood's light by 2 members of the research team to ensure the absence of the dye from any surface.

On completion of the scenario, participants exited the simulator. At that time the mannequin, intravenous lines, cables, anesthesia circuit, supply cart, and machine were swept with the Wood's light by a technician blind to the participant's group assignment. A standardized data collection tool was used to inventory areas of contamination. The data collection tool consisted of photographs of the mannequin and anesthesia workspace where dye dispersion was observed and recorded by the scanning technician using a pen. In a prestudy assessment, 4 anesthesia providers who were nonparticipants in the study examined the collection tool as having high face validity. A checklist of specific target areas was included to ensure consistency and comprehensiveness in the Wood's light sweep. Additional clarifying notes could also be added as necessary. Each data sheet was coded, for follow-up analysis, to indicate if the participant was in group 1 (single pair of gloves) or group 2 (double pairs of gloves) with no other identifiers. After each scenario, the entire workstation and mannequin was photographed during Wood's lamp exposure using a Canon EOS Rebel T5i digital camera (Canon, Tokyo, Japan). Photos were archived and quantified to ensure reliable capture of all contaminated domains by the initial technician sweep (100% capture was validated). Participants received a $10.00 gift card at a local eatery.

After the data were collected, all surfaces were cleaned with soap and water per the DAZO manufacturer's recommendation. The dye is readily removed with a light wiping of soap and water. Masks, circuits, reservoir bags, laryngoscope handles, laryngoscope blades,

endotracheal tubes, tongue depressors, syringes, drug vials, intravenous manifolds, and other disposable equipment were removed and replaced with clean equipment for each scenario. The entire workstation, machine, and patient simulator were then scanned again with the Wood's lamp by the same technician to ensure all surfaces were free of the dye. To further ensure a dye-free workstation, the cleaning protocol was repeated; using the Wood's lamp again, 2 members of the research team further ensured that there was no cross-contamination between participants.

The power to detect significant differences in overall contamination between the single- and double-gloved conditions in the current study was 0.94. With the same effect size, 7 subjects per group would be sufficient to achieve 80% power; in the current study, 10 subjects were used per group. A 2 sample *t* test was performed to determine if differences existed between the groups in the number of observed dispersion sites. Two-by-two contingency tables were constructed for each of the potential contamination sites, and Fisher exact tests were performed. Finally, we assessed the cumulative contamination of the tested surfaces during general progression of the experimental design by plotting the average cumulative contamination levels for each surface and their 95% confidence intervals.

RESULTS

Participants in each scenario consistently completed the protocol involving all of the elements listed in Table 1. For purposes of sequencing and categorizing the influence of the time course on the cumulative number of contamination sites, 4 phases of the induction were categorized as seen in Table 2, providing insight on how dispersion of the oral inoculum occurred over time.

A cursory examination of the most prolific contamination sites, where there was at least a 50% chance (≥10 touches) of contamination (across both groups 1 and 2), included the circle system, the tape roll used to secure the endotracheal tube, the intravenous flow control, the laryngoscope, the patient's head (outside the mouth), the reservoir bag, the stethoscope, the suction tubing, and the vaporizer dial. Table 3 is a list of contaminated sites by groups 1 and 2.

To test the hypothesis that the double-glove group would have an average lower level of contamination on completion of the simulation, a 2-group *t* test was performed. The single-glove group contaminated an average of 16.0 (SEM = 0.89) discrete sites compared with the double-glove group who contaminated an average of 7.6 (SEM = 0.85) discrete sites (i= 6.82, $P < .001$); there was a substantially greater degree of contamination by group 1.

To further examine the source of differential contamination by gloving technique, Fisher exact tests were conducted on all of the individual sites throughout the anesthesia workstation. The number of times that each site was contaminated in each group, along with the odds ratio and *P* value, are presented in Table 3. Because of low frequencies of some contamination sites, there was limited power to conduct tests for each specific surface, and in some cases the odds ratios may be overly sensitive to zero contamination counts. In light of that, several of the 34 surfaces deserve special mention. The cart drawers, fresh gas flow dial, medication vials (antibiotic, dexamethasone), and ventilator controls were significantly contaminated by group 1, but not contaminated by group 2 ($P < .05$ in all cases). In addition, the adjustable pressure limiting valve and temperature probes were also more contaminated in group 1 relative to group 2, but this was not statistically significant ($P = .070$ for both surfaces). Furthermore, there were similar rates of contamination in both groups for the laryngoscope, the endotracheal tube pilot balloon inflation syringe, the ETT stylet, the circle system, including the reservoir bag, and the roll of tape used to secure the ETT.

Table 2
Potential and observed contamination sites by phase of induction sequence

Phase 1
a—Patient's chest
b—Patient's head (outside of mouth)
c—IV tubing
d—IV stopcocks
Phase 2
a—Endotracheal tube stylet
b—Endotracheal tube paper wrapper
c—Laryngoscope handle
d—Endotracheal tube pilot inflation syringe
e—Reservoir bag
f—Reservoir bag swing-arm
g—Circle system
h—Stethoscope
i—Breathing circuit pressure valve
j—Fresh gas flow dial
k—Endotracheal tube securement tape roll
Phase 3
a—Ventilator selection button
b—Ventilator switch
c—Ventilator work surface
d—Ventilator drawers
e—Vaporizer dial
f—Cables (temperature probe/orogastric tube)
g—Cables (ECG, other)
h—Suction tubing
i—Vitals monitor
Phase 4
a—Drug and supply cart drawer handles
b—Drug and supply cart bins
c—Drug and supply cart inside drawers and bins
d—Medication vials
e—Medication syringes
f—Cart top
g—IV bag
h—IV injection port
i—IV roller clamp
j—Operating room table

NOTE. We divided the activities associated with anesthetic induction into 4 phases, with different components of the anesthesia workstation accessed in each of those phases. This allowed us to quantify elements contaminated across the continuum of care.
IV, intravenous.

Because there is a general ordering of the anesthetic induction procedure, it is possible to construct a timeline of the spread of contamination in the 2 groups. Figure 2 tracks the cumulative mean levels of contamination by both groups. As seen in the figure, during the first phase of the induction protocol, there are no differences in the contamination rates based on the glove group.

During the second phase of the induction protocol, the amount of contamination between the 2 groups begins to diverge significantly. The vertical black line specifies the approximate point where a subject in group 2 removed the outer pair of gloves. At this point, the contamination rates begin to slowly but conspicuously diverge. Then, about two-thirds of the way through the second phase of the protocol, group 2 (double gloving) effectively ceases novel contamination, whereas group 1 (single pair of gloves) continues contaminating the workstation at approximately the same rate as the earlier phases. Accordingly, by the end of the protocol, we observed large differences in contamination as a function of the manner of gloving used by the participants (as noted by the significant *t* tests previously mentioned).

At the conclusion of each scenario, we instituted on a thorough cleaning protocol based on the published recommendations of 2 national anesthesiology societies regarding the cleaning and disinfection of the anesthesia workstation.[10,11] We amended the cleaning protocol using soap and water instead of a disinfectant solution because the dye marker is water soluble and because we were

Table 3
Frequencies of contamination in both groups, odds ratios, and *P* values as a function of the workstation surface

Workstation components	Touches in the single-glove group	Touches in the double-glove group	Odds ratio	95% confidence interval	*P* value
Breathing circuit pressure valve	7	2	0.12	1.13-0.01	.07*
Cables (temperature probe)	7	2	0.12	1.13-0.01	.07*
Cables (other)	2	0	0.00	5.23-0.00	.47
Cart drawer handles	7	0	0.00	0.39-0.00	.003†
Cart supply bins	3	0	0.00	2.26-0.00	.21
Cart supply inside drawers	1	0	0.00	39.0-0.00	1.00
Cart top	3	0	0.00	2.26-0.00	.21
Circle system	9	5	0.13	1.57-0.00	.14
Tracheal tube inflation syringe	2	2	1.00	17.08-0.06	1.00
Tracheal tube tape roll	6	4	0.46	3.61-0.05	.66
Tracheal tube stylet	1	1	1.00	87.05-0.01	1.00
Tracheal tube paper wrapper	2	2	1.00	17.08-0.06	1.00
Fresh gas glow dial	7	0	0.00	0.39-0.00	.003†
IV bag	2	0	0.00	5.23-0.00	.47
IV injection port	2	1	0.46	10.51-0.01	1.00
IV roller clamp	8	4	0.18	1.66-0.01	.17
IV stopcocks	7	5	0.45	3.67-0.05	.65
IV tubing	1	0	0.00	39.0-0.00	1.00
Laryngoscope handle	7	8	1.67	25.60-0.14	1.00
Medication syringes	5	4	0.68	5.36-0.08	1.00
Medication vials	5	0	0.00	0.84,-0.00	.03‡
OR table	2	0	0.00	5.23-0.00	.47
Patient (chest)	2	1	0.46	10.51-0.01	1.00
Patient (head and face)	7	7	1.00	10.33-0.10	1.00
Breathing reservoir bag	9	7	0.28	4.35-0.00	.58
Breathing reservoir bag swing-arm	5	4	0.68	5.36-0.08	1.00
Stethoscope	9	6	0.18	2.45-0.00	.30
Suction tubing	7	3	0.20	1.68-0.02	.18
Vaporizer dial	8	4	0.18	1.66-0.01	.17
Ventilator selection buttons	4	1	0.18	4.35-0.00	.30
Ventilator switch	6	0	0.00	2.45-0.00	.01‡
Ventilator work surface	2	2	1.00	0.57-0.00	1.00
Vitals monitor	2	0	0.00	17.08-0.06	.47

NOTE. The values represent the number of times that each workstation site was contaminated with the dye in each gloving group, along with the respective odds ratio, the 95% confidence interval for the odds ratio, and the associated *P* value.
IV, intravenous; OR, operating room.
*$P < .10$.
†$P < .01$.
‡$P < .05$.

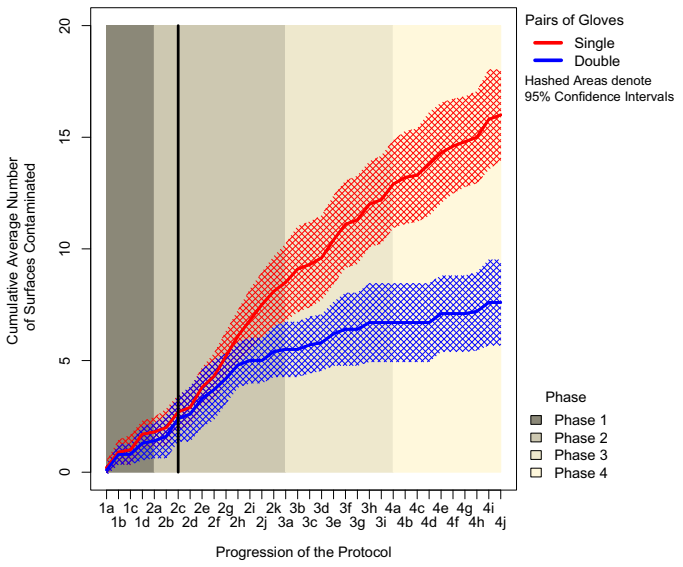

Fig 2. Cumulative mean number of surfaces contaminated in the single- and double-gloved groups as a function of the progression of the simulated induction of general endotracheal anesthesia in single- and double-gloved participants (95% confidence intervals in hashed areas). The vertical black line on the graph indicates the approximate location where the double-glove group removed the outer pair of gloves. During the second phase, the amount of contamination between the 2 groups begins to diverge significantly. See Table 2 to define elements related to progression of the protocol.

not dealing with biologically active material. Despite following the recommended protocol, the standardized end-of-case cleaning protocol was inconsistent in removing the water-soluble dye from the anesthesia workstation. We found significant residual dye throughout the workstation, that otherwise was then easily removed with cleaning of those sites identified by the Wood's lamp.

DISCUSSION

There is a body of published research directed at concerns related to pathogen transfer between the anesthesia workstation and the patient.[1-9] Of particular interest is the concern that compliance among anesthesia providers in performing hand hygiene is very low despite frequent, well-defined hand hygiene opportunities.[12-14] The use of a fluorescent marker enabled us to study inadvertent dispersion of a surrogate oral biologic contaminant as the direct result of the anesthetic care provided in performing a routine, uncomplicated general anesthetic induction by experienced anesthesia providers. We found widespread dispersion of oral contaminant throughout the anesthesia workstation in each of the 20 anesthetic inductions. The major, frequent contamination sites included the reservoir bag, breathing circuit pressure valve (APL valve), distal Y-piece of the breathing circuit, the vaporizer control dial, the intravenous flow control, the ventilator controls, the intravenous stopcocks, the drug cart surface and drawers where drugs and equipment are stored, the stethoscope, and the patient's face.

With respect to our hypothesis regarding gloving, we observed a marked decrease in overall dispersion of the oral inoculum in subjects who wore 2 pairs of gloves, removing the outer pair in the immediate aftermath of successful endotracheal intubation. This finding is in agreement with Birnbach et al, who found that providers who removed their outer set of gloves immediately after intubation reduced subsequent contamination of the anesthesia workstation compared with those providers who did not shed their gloves.[15]

Although we observed widespread contamination across myriad sites, there was a significant reduction in the contamination in the double-glove group for the cart drawer handles, the fresh gas flow dial, the medication vials, and the ventilator controls, with a slight decrease in the contamination in the breathing circuit pressure control valve (APL) and the temperature probe. The initial phase of the induction of anesthesia showed no difference in the rate of contamination between groups prior to the removal of the exterior pair of gloves in the double-glove group because both groups are procedurally equivalent up to this point. However, the rate of contamination in subsequent phases of the induction procedure was distinctly higher in the single pair of gloves group, which is entirely consistent with our original hypothesis.

Although double gloving was effective in reducing the overall level of contamination, it is essential to reiterate that there was still substantial contamination in the double-glove group. Specifically, the intravenous stopcock assembly was frequently contaminated in both the single- and double-glove groups. This is noteworthy because intravenous medications are administered through stopcocks, representing a direct portal to a patient's bloodstream. The potential for delivery of pathogenic material via the stopcock or some other intravenous access portal has been demonstrated by other researchers.[1-3,16] Our observations validate those of Loftus et al, who reported stopcock contamination during actual patient care within the first few minutes of anesthetic care.[1,2,16] Our findings seem particularly relevant in light of Munoz-Price et al, who observed stopcock access occurring 66 times in an observation period; however, those access ports were disinfected on only 10 occasions.[17] Redesign of the stopcock assembly to mitigate contamination is the focus of recent research and innovation.[16,18,19]

The rate of contamination notwithstanding, it is also important to keep in mind that the standardized cleaning protocol based on established recommendations[10,11] was highly ineffective in removing the dye, a material that is easily eliminated with a simple swipe of a cloth with soap and water. This suggests that better designed cleaning protocols should be considered to decrease the possibility for subsequent patient and provider contamination. This is not without challenges as a result of the complex work surfaces that characterize anesthesia equipment.

A design goal might be to develop equipment with more flat surfaces, for example replacing buttons and nobs with pressure-sensitive touch pads like those used on electronic tablets. Using knobs or easy to clean handles on drawers, instead of inserting fingers under a lip to pull open a drawer, would facilitate efficient cleaning. Because this was a single patient protocol, quantifying any increased risk associated with poor between-patient cleaning and enhancing ergonomics is left for future research.

Our study is comprehensively unique in that it involved only experienced providers, it assessed the provider gloving effect that consistently involved 14 discrete induction elements, and it assessed cleaning effectiveness using established national protocols. Furthermore it was a statistically powered randomized design, was devoid of a Hawthorne effect regarding pathogen dispersion, and we used both a technician (blinded to group assignment), and photographic documentation to assess the surrogate biologic material dispersion.

Several aspects of this study should be carefully considered that prevent any definitive extrapolations to living patient care. First, we did not study the role of anesthesia record keeping; therefore, we make no inferences about the potential contamination of charting surfaces or devices. Second, we limited the study to the brief (<10 minutes) induction phase of general anesthesia, where task density and production pressure is universally high, and make no inference about what might occur during the maintenance or emergence phases of the anesthetic course. Third, although participants were highly skilled in the conduct of an anesthetic, there are likely nuances in care that may differ from a simulated patient to that provided to a living patient. Fourth, we did not study the potential pathogenicity or what role dispersion of biologic material might have on a patient's outcome; however, knowledge of the extent of dispersion provides a stronger foundation for interpreting the work of others studying the anesthesia provider's role as a vector in nosocomial infection. Fifth, we studied only macroscopic dispersion and make no inference about microscopic contamination. Finally, the dye is likely to be easier to remove from the workstation than biologic material.

CONCLUSIONS

We tracked dispersion of an oral inoculum occurring as a result of the anesthesia providers' hands during a simulated general anesthetic induction. The use of double gloving, compared with single gloving, was associated with less spread of the oral inoculum throughout the anesthesia workstation, but it was not uniformly protective. Additionally, we found that routine, between-case cleaning was often ineffective in removing the dye contaminant, indicating that biologic material from one patient might be present in the workstation when subsequent patients are cared for. Not only does this suggest risk for the current patient (transfer of biologic material from one domain of the patient to another, for example, skin and oral site transfer to intravenous site), but it also may place future patients at risk who subsequently come to that operating room.

Importantly, using models that simulate actual clinical events can inform clinical practice and decipher challenging areas of ergonomics. The opportunities for simulation to advance our understanding of nosocomial disease processes and enhance patient safety are limitless.

References

1. Loftus RW, Koff MD, Burchman CC, Schwartzman JD, Thorum V, Read ME, et al. Transmission of pathogenic bacterial organisms in the anesthesia work area. Anesthesiology 2008;109:399-407.
2. Loftus RW, Brown JR, Koff MD, Reddy S, Heard SO, Patel HM, et al. Multiple reservoirs contribute to intraoperative bacterial transmission. Anesth Analg 2012;114:1236-48.
3. Biddle CJ, Shah J. Quantification of anesthesia providers' hand hygiene in a busy metropolitan operating room: what would Semmelweis think? Am J Infect Control 2012;40:756-9.
4. Birnbach DJ, Rosen LF, Fitzpatrick M, Carling P, Arheart KL, Munoz-Price S. Double gloves: a randomized trial to evaluate a simple strategy to reduce contamination in the operating room. Anesth Analg 2015;120:848-52.
5. Rowlands J, Yeager MP, Beach M, Patel HM, Huysman BC, Loftus RW. Video observation to map hand contact and bacterial transmission in the operating room. Am J Infect Control 2014;42:698-701.
6. Roy RC, Brull SJ, Eichorn JH. Surgical site infections and the anesthesia professionals' microbiome: we've all been slimed! Now what are we going to do about it? Anesth Analg 2011;112:4-7.
7. Loftus RW, Koff MD, Birnbach DJ. The dynamics and implications of bacterial transmission events arising from the anesthesia work area. Anesth Analg 2015;120:853-60.
8. Birnbach DJ, Rosen LF, Fitzpatrick M, Carling P, Munoz-Price LS. The use of a novel technology to study dynamics of pathogen transmission in the operating room. Anesth Analg 2015;120:844-7.
9. Munoz-Price LS, Birnbach DJ, Lubarsky DA, Arheart KL, Fajardo-Aquino Y, Rosalsky M, et al. Decreasing operating room environmental pathogen contamination through improved cleaning practice. Infect Control Hosp Epidemiol 2012;33:897-904.

10. American Society of Anesthesiologists. Recommendations for infection control for the practice of anesthesiology. Disinfection of equipment. 1999. Available from: http://www.mtpinnacle.com/pdfs/infectioncontrol_anesthesiology.pdf. Accessed August 11, 2015.
11. American Association of Nurse Anesthetists. Infection prevention and control guidelines for anesthesia care. 2015. Available from: http://www.aana.com/resources2/professionalpractice/Pages/Infection-Prevention-and-Control-Guidelines-for-Anesthesia-Care.aspx#EEC. Accessed August 11, 2015.
12. Munoz-Price LS, Riley B, Banks S, Eber S, Arheart K, Lubarsky DA, et al. Frequency of interactions and hand disinfections among anesthesiologists while providing anesthesia care in the operating room: induction versus maintenance. Infect Control Hosp Epidem 2014;35:105-1059.
13. Koff MD, Loftus RW, Burchman CC, Schwartzman JD, Read ME, Henry ES, et al. Reduction in intraoperative bacterial contamination of peripheral intravenous tubing through the use of a novel device. Anesthesiology 2009;110:978-85.
14. Munoz-Price LS, Patel Z, Banks S, Arheart K, Eber S, Lubarsky DA, et al. Randomized crossover study evaluating the effect of a hand sanitizer dispenser on the frequency of hand hygiene among anesthesiology staff in the operating room. Infect Control Hosp Epidem 2014;35:717-20.
15. Birnbach DJ, Rosen LF, Fitzpatrick M, Carling P, Arheart KL, Munoz-Price LS. Double gloves: a randomized trial to evaluate a simple strategy to reduce contamination in the operating room. Anesth Analg 2015;120:848-52.
16. Loftus RW, Patel HM, Huysman BC, Kispert DP. Prevention of intravenous bacterial injection of healthcare provider hands: the importance of catheter design and handling. Anesth Analg 2012;115:1109-19.
17. Munoz-Price LS. Interactions between anesthesiologists and the environment while providing anesthesia care in the operating room. Am J Infect Control 2013;41:922-4.
18. Muffly MK, Beach ML, Tong YC, Yeager MP. Stopcock lumen contamination does not reflect the full burden of bacterial intravenous tubing contamination: analysis using a novel injection port. Am J Infect Control 2010;38:734-9.
19. Loftus R, Brindeiro B, Kispert D, Patel HM, Koff MD, Jensen JT, et al. Reduction in intraoperative bacterial contamination of peripheral intravenous tubing through the use of a passive catheter system. Anesth Analg 2012;115:1315-23.