Infection Control & Hospital Epidemiology (2021), **42**, 1071–1075
doi:10.1017/ice.2020.1359

Original Article

Simulating the effects of operating room staff movement and door opening policies on microbial load

Kevin M. Taaffe PhD[1], Robert W. Allen PhD[2], Lawrence D. Fredendall PhD[3], Marisa Shehan BS[1], Mary Grace Stachnik BS[1], Taliyah Smith BS[4], Alfredo M. Carbonell DO[2], Emily Glover MS[1] and Alexis Fiore MS[1]

[1]Department of Industrial Engineering, Clemson University, Clemson, South Carolina, [2]Prisma Health Upstate, Greenville, South Carolina, [3]Department of Management, Clemson University, Clemson, South Carolina and [4]Department of Biological Sciences, Clemson University, Clemson, South Carolina

Abstract

Objective: To identify factors that increase the microbial load in the operating room (OR) and recommend solutions to minimize the effect of these factors.

Design: Observation and sampling study.

Setting: Academic health center, public hospitals.

Methods: We analyzed 4 videotaped orthopedic surgeries (15 hours in total) for door openings and staff movement. The data were translated into a script denoting a representative frequency and location of movements for each OR team member. These activities were then simulated for 30 minutes per trial in a functional operating room by the researchers re-enacting OR staff-member roles, while collecting bacteria and fungi using settle plates. To test the hypotheses on the influence of activity on microbial load, an experimental design was created in which each factor was tested at higher (and lower) than normal activity settings for a 30-minute period. These trials were conducted in 2 phases.

Results: The frequency of door opening did not independently affect the microbial load in the OR. However, a longer duration and greater width of door opening led to increased microbial load in the OR. Increased staff movement also increased the microbial load. There was a significantly higher microbial load on the floor than at waist level.

Conclusions: Movement of staff and the duration and width of door opening definitely affects the OR microbial load. However, further investigation is needed to determine how the number of staff affects the microbial load and how to reduce the microbial load at the surgical table.

(Received 1 July 2020; accepted 1 December 2020; electronically published 21 December 2020)

Although they are medically necessary and beneficial for the patient, surgical procedures can result in surgical site infections (SSIs) at a rate of ~0.6%–8.8%, depending on the surgical specialty and wound classification.[1] SSIs are caused by microbes, such as bacteria and fungi, entering a patient's incision site through airborne particles in the operating room (OR). SSIs lead to extensive physical, emotional, and financial consequences for individual patients due to elongated hospital stays, further surgeries, and possibly sepsis and death, all of which increase annual healthcare expenditures substantially.[2–5]

Environmental risk factors are unavoidably present in an OR. These include patient comorbidities, surgical procedure complexity, air circulation, equipment sterilization, and certain staff behaviors.[4] Operating rooms can reduce SSI risk by following sterilization guidelines and protocols,[6–11] and practicing disciplined behaviors (eg, restricted OR door openings) known to affect the SSI rate.[12,13]

Operating rooms are "isolated, positive-pressure environments designed to recirculate air through filtered ventilation ducts."[14] Laminar, or nonturbulent, airflow produced by the OR ventilation system helps maintain a sterile field around the wound.[15] Door openings may reduce air pressure and possibly disrupt the laminar airflow, creating a path for new contaminants to enter the OR and making it difficult to clear potentially dangerous particles.[15] Measuring the microbial activity in the OR can provide valuable insights about how door openings and OR traffic affect microbial activity in the OR.[16,17] Although studies have reported mixed results, there appears to be evidence that door openings and OR traffic can increase microbial activity.[18–20]

Using air sampling during orthopedic and implant procedures, studies have demonstrated positive correlation between total traffic flow and total microbial colony forming units (CFU), and between CFU and infection.[21,22] However, the correlations among the number of people in the OR, CFU count, and SSI are not clear.[16,23,24] A weak positive correlation has been detected between the total number of people present and total CFU,[21] while a retrospective study of patients who developed a superficial SSI did not reveal an association between the number of personnel in the OR and infection rate.[4]

Author for correspondence: Kevin M. Taaffe, E-mail: taaffe@clemson.edu
Cite this article: Taaffe KM, *et al.* (2021). Simulating the effects of operating room staff movement and door opening policies on microbial load. *Infection Control & Hospital Epidemiology*, 42: 1071–1075, https://doi.org/10.1017/ice.2020.1359

Table 1. Number of Door Openings and Staff Movements During the Operation Room Preparation and Intraoperative Phases for 30 Minutes

		Door Openings by Role, No.				Movements by Role, No.			
Phase	Factor Settings	Anesthesia	Surgeon	Circulating Nurse	Scrub Nurse	Anesthesia	Surgeon	Circulating Nurse	Scrub Nurse
Preparation	Low	2	0	15	0	12	30	180	0
	High	6	7.5	20	5	180	120	360	180
Intraoperative	Low	0	0	7.5	0	2	1	60	0
	High	1	2	11	0	30	15	120	30

In a previous study, the research team collected data from 27 procedures using settle plates and air samplers to determine how movement and door openings within the OR affect microbial loads at various locations.[17] They also videotaped and observed these procedures to gain further insight. However, the settle plates and air samplers were not in the same locations for each procedure due to the OR team requesting that the devices be placed further away from the operating field or high-traffic areas. Another limitation was that the frequency and path of staff movements varied between surgeries resulting from unique procedure characteristics (eg, patient, OR staff, procedure length, etc).

In the current study, the research team addressed these limitations by creating a script to simulate movements and door openings during surgical procedures, allowing the OR environment to be controlled. The team reviewed 27 procedures then counted and measured all staff movements and door openings during 4 orthopedic cases that were videotaped. These 4 cases were between 3 and 4.5 hours in length (15 total hours). The script was enacted at 2 hospitals in upstate South Carolina while bacteria and fungi samples were collected. Enacting a simulation allowed data collection devices to be placed in identical locations across all tests and ensured that the exact level of staff movements and door openings were performed in each test.

Data were gathered in 2 phases of simulation experiments. Phase 1 was conducted in the spring of 2019 to test the hypotheses that increasing the number of door openings and staff movements increased the overall microbial load in the OR. Phase 2 was conducted in the fall of 2019 to gather more data and to adjust the study factors in response to an OR management request for more information. Phase 2 included the width and duration of door openings and excluded the number of door openings as experimental factors.

Methods

Simulation script development

The simulation script was developed by first identifying the minimum and maximum number of door openings and zone-to-zone staff transitions (Table 1) for each role (ie, surgeon, anesthesiologist, circulating nurse, and scrub nurse) during both the OR preparation and intraoperative phases for 4 orthopedic procedures. More than 15 hours of zone-to-zone transitions were summarized, with the preparation phase defined as "case cart emptied" to "incision made" and the intraoperative phase defined as "incision made" to "incision closed." Each staff member's movements were converted into rates appropriate for a 30-minute simulation. The data counted all zone-to-zone transitions (Fig. 1) as a movement, so the movement count was higher than actual origin-to-destination trip counts. Because our goal was to study the effect of movement, counting zone transition movements increased the differences between the low and high settings.

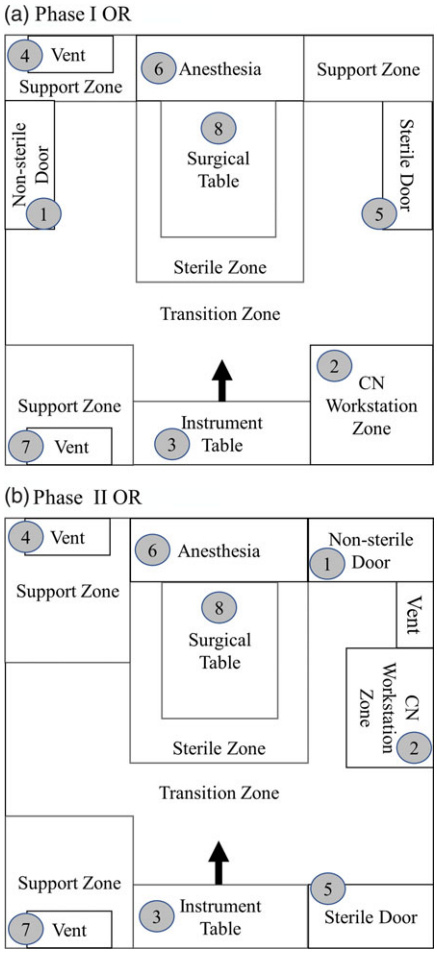

Fig. 1. Settle plate locations for phase 1 and phase 2.

Data collection

Five 30-minute trials were conducted each day. The first trial was a control that had no movement or door openings. Samples were collected from the same 8 locations for each of the 5 trials. As shown in Figure 1, the locations were (1) nonsterile door, (2) circulating nurse workstation, (3) instrument table, (4) intake vent 1, (5) sterile door, (6) anesthesia area, (7) intake 2, and (8) surgical table. At each location, settle plates were placed at 2 different heights labeled "H" for high and "L" for low. The "H" plates were placed about waist high, while the "L" plates were placed at floor level. Each location and each height had both an Sabouraud dextrose agar (SDA) plate to collect fungi and a blood agar (BA) plate to collect bacteria, resulting in a total of 32 settle plates per trial. All settle plates, which were labeled with their location, height, and

Table 2. Phase 1 Statistical Results on Hypotheses (*P* values recorded)

Hypotheses: Microbial count is higher . . .	Bacteria (n=63)	Fungi (n=64)	Total (n=127)
1.1 . . . at the floor-level compared to the waist-level locations	Not supported	Not supported	Not supported
1.2 . . . movement high compared to low movement	**Supported**[a]	Not supported	Not supported
1.3 . . . when the number of door openings is high compared to low number of door openings	Not supported	Not supported	Not supported
1.4 . . . for the preparation phase compared to the control trial	**Supported**[b]	Not supported	Not supported
1.5 . . . for the intraoperative phase compared to the control trial	**Supported**[b]	Not supported	Not supported
1.6 . . . for the preparation phase compared to the intraoperative phase	Not supported	Not supported	Not supported

[a]Reject at $P = .05$.
[b]Reject at $P = .01$.

Table 3. Phase 2 Statistical Results on Hypotheses (*P* values recorded)

Hypotheses: Microbial count is higher . . .	Bacteria (n=64)	Fungi (n=64)	Total (n=128)
2.1 . . . at the floor level compared to waist-level locations	**Supported**[b]	Not supported	**Supported**[a]
2.2 . . . during high movement compared to low movement	Not supported	Not supported	**Supported**[a]
2.3 . . . for long door openings compared to short duration door openings	**Supported**[b]	Not supported	**Supported**[b]
2.4 . . . for wide door openings compared to narrow door openings	Not supported	Not supported	**Supported**[a]
2.5 . . . for the intraoperative phase compared to the control trial	**Supported**[b]	Not supported	**Supported**[b]

[a]Reject at $P = .05$.
[b]Reject at $P = .01$.

trial number, were open for the entire 30-minute trial with the lid right side up. They were collected at the end of the trial, secured with parafilm, and placed into Ziploc bags for transport. The BA plates were placed in an incubator for 48 hours at 37°C and then refrigerated for 2 days. The SDA plates were kept at room temperature (23°C) for 4 days. After their incubation period, the number of CFUs on each plate were counted.

Phase 1 experiment

In phase 1, a total of 10 trials over 2 days had the experimental factor settings given in Table 1: staff movement (low vs high), number of door openings (low vs high), and surgical phase (preparation vs intraoperative). Each combination of factors was tested (using a preparation or intraoperative sequence), along with one control trial at the beginning of each day. The specific hypotheses tested in phase 1 are listed in Table 2. This table provides conclusions on tests that compare whether differences in microbial load were detected based on sample location height in the OR, staff movement, door openings, and surgical phase.

Phase 2 experiment

The phase 2 factor settings were amount of staff movement (low vs high), duration of door openings (6 seconds vs 12 seconds), and width of door opening (45° vs 90°). Phase 2 trials were conducted across 2 days in a different hospital than phase 1, but the locations in the OR and the methodology used to manage the settle plates were the same as in phase 1. We tested 5 hypotheses (Table 3); 4 examined the effects of the experimental factors. The fifth hypothesis compared all trials with movement and door openings to the control trial. In all trials, the number of door openings was constant at what had been the high setting in phase 1 by opening the door at 2-minute intervals.[7] Instead, door openings varied based on duration and width as described above. To ensure consistency between trials, tape was placed on the floor to mark each door opening angle and a watch was used to confirm the door opening time.

Results

Statistical analysis was conducted using paired *t* tests for all phase 1 and phase 2 hypotheses. There were 3 contamination variables: number of CFUs on BA plates only, number of CFUs on SDA plates only, and number of CFUs on BA plates and SDA plates combined. In phase 1, 1 BA plate (the waist-high plate at the instrument table) was used to test for high movement. High door openings were not used due to condensation on the plate that resulted in "swirling" of the bacteria so a valid CFU count could not be made. The resulting phase 1 sample size for bacteria was n = 63.

We detected no significant differences in the level of fungi in the OR for any experimental setting. Discussion with the hospital's infection control staff revealed that the hospital was experiencing higher-than-normal levels of fungi during the experimental period. Table 2 presents the phase 1 results for each hypothesis about the bacterial load. Overall, 3 hypotheses were supported: hypothesis 2, that the bacteria CFUs are higher with high movement compared to low movement ($P = .028$); hypothesis 4, that bacteria CFUs are higher for the prep phase compared to the control phase ($P = .005$); and hypothesis 5, that bacterial CFU are higher for the intraoperative phase compared to the control phase ($P = .007$).

There were no significant differences in the level of fungi in the OR for any experimental setting during phase 2, but there were significant differences for the bacterial and combined microbial load. Hypothesis 1, that the microbial load is higher at floor level versus waist level, was supported for both bacterial and combined microbial counts ($P = .009$, bacteria; $P = .011$, combined). Hypothesis 2,

that the microbial load is higher for high versus low movement, was not supported for either bacteria or fungi alone, but the results were significant for the combined microbial count ($P = .079$, bacteria; $P = .062$, fungi; $P = .032$, combined). Hypothesis 3, that long door openings result in higher microbial loads than short door openings, was supported for both bacterial and combined microbial counts ($P = .008$, bacteria; $P = .032$, combined). Hypothesis 4, that wide door openings have higher microbial load than narrow door openings, was not supported for bacteria or fungi but was significant for the combined load ($P = .047$, combined). Finally, Hypothesis 5, that the intraoperative phase has more microbial load than the control phase, was supported for the bacteria and combined count ($P < .01$, bacteria; $P < .01$, combined).

Discussion

An important contribution of this study is the development of 30-minute simulations that allow testing the effects of different staff behaviors on microbial load in an actual, functioning OR. These simulations allowed more control of the experimental variables, such as replication of the exact position in an OR at which microbes are measured. The phase 1 experiment identified significantly higher bacterial load when staff movement was high versus low. As expected, both the preparation and intraoperative phases had higher bacterial loads than the control trial. Counterintuitively, we detected no significant differences in the bacterial load as the number of door openings increased. This finding differed from the team's prior research,[17] in which fewer door openings slightly decreased the microbial load. Using the simulation allowed a second test of this counterintuitive finding in phase 2, in which the duration and width of door openings served as experimental variables. The findings from the phase 2 experiments, holding the number of door openings constant, revealed that increased levels of movement, increased width of door openings, and increased duration of door openings increased microbial load.

The simulation methodology allowed consistent, repetitive measurements, such as the duration of the door opening, to be made to examine their effect on the microbial load at various locations in the OR. Additional research is needed to investigate other factors that occur in actual surgical procedures. First, how does the number of individuals in an OR and in a particular location affect microbial load in that location and in the OR? Given that anesthesia and the circulating nurses' workstation have the highest microbial loads, how can process or operating room design help reduce the microbial loads in these areas? How do the number, width, and time of door openings affect the air pressure and flows in the OR overall and specifically at the surgical table? In this study, we examined how movement and door opening factors affected the microbial load in 8 well-spaced locations in the OR, but a more focused study is needed to understand microbial load distribution at the surface of the surgical table.

The primary limitation of this study is the amount of data gathered. The simulations required the use of an unscheduled OR, and there were limited opportunities for collecting the phase 1 and phase 2 data. In addition, there was a lag between conducting the experiment phases (phase 1 in the spring and phase 2 the following fall). It is possible that the seasonal environment affected the bacteria and fungi counts, and the hospital infection control staff agreed with this assessment. Further controls can be introduced to ensure that all staff movement occurs within their designated space. For example, the circulating nurse has the greatest number of movements (see Table I), but the circulating nurses' path through the OR was not precisely controlled.

Acknowledgments.

Financial support. This work was partially supported by the Harriet and Jerry Dempsey Professorship in Industrial Engineering at Clemson University, as well as the Creative Inquiry program at Clemson University.

Potential conflicts of interest. All authors report no conflicts of interest relevant to this article.

Manuscript preparation. The authors appreciate the support from perioperative nursing staff at both facilities as well as the Infection Control staff for their expertise, feedback and study suggestions. The authors would also like to thank other participating members of the Creative Inquiry project team from Clemson University.

References

1. Birgand G, Azevedo C, Toupet G, *et al.* Attitudes, risk of infection and behaviours in the operating room (the ARIBO Project): a prospective, cross-sectional study. *BMJ Open* 2014;4(1):e004274.
2. de Lissovoy G, Fraeman K, Hutchins V, Murphy D, Song D, Vaughn BB. Surgical site infection: incidence and impact on hospital utilization and treatment costs. *Am J Infect Control* 2009;37:387–397.
3. Benenson S, Moses AE, Cohen MJ, *et al.* A practical tool for surveillance of surgical-site infections: a 5-year experience in orthopedic surgeries. *Infect Control Hosp Epidemiol* 2017;38:610–613.
4. Wanta BT, Glasgow AE, Habermann EB, *et al.* Operating room traffic as a modifiable risk factor for surgical site infection. *Surg Infect* 2016;17:755–760.
5. Graves N, Nicholls TM, Morris AJ. Modeling the costs of hospital-acquired infections in New Zealand. *Infect Control Hosp Epidemiol* 2003;24:214–223.
6. Durando P, Bassetti M, Orengo G, *et al.* Adherence to international and national recommendations for the prevention of surgical site infections in Italy: results from an observational prospective study in elective surgery. *Am J Infect Control* 2012;40:969–972.
7. Birgand G, Saliou P, Lucet JC. Influence of staff behavior on infectious risk in operating rooms: what is the evidence? *Infect Control Hosp Epidemiol* 2015;36:93–106.
8. Mangram AJ, Horan TC, Pearson ML, Silver LC, Jarvis WR. Guideline for prevention of surgical site infection, 1999. Centers for Disease Control and Prevention (CDC) Hospital Infection Control Practices Advisory Committee. *Am J Infect Control* 1999;27:97–132.
9. Castella A, Charrier L, Legami VD, *et al.* Surgical site infection surveillance analysis of adherence to recommendations for routine infection control practices. *Infect Control Hosp Epidemiol* 2006;27:835–840.
10. Yinnon AM, Wiener-Well Y, Jerassy Z, *et al.* Improving implementation of infection control guidelines to reduce nosocomial infection rates: pioneering the report card. *J Hosp Infect* 2012;81:169–176.
11. Munoz-Price LS, Bowdle A, Johnston BL, *et al.* Infection prevention in the operating room anesthesia work area. *Infect Control Hosp Epidemiol* 2018. doi: 10.1017/ice.2018.303.
12. Crolla RMPH, Van Der Laan L, Veen EJ, Hendriks Y, Van Schendel C, Kluytmans J. Reduction of surgical site infections after implementation of a bundle of care. *PLoS One.* 2012;7(9):e44599.
13. Van Der Slegt J, Van Der Laan L, Veen EJ, Hendriks Y, Romme J, Kluytmans J. Implementation of a bundle of care to reduce surgical site infections in patients undergoing vascular surgery. *PLoS One* 2013;8(8):e71566.
14. Lynch RJ, Englesbe MJ, Sturm L, *et al.* Measurement of foot traffic in the operating room: implications for infection control. *Am J Med Qual* 2009;24:45–52.
15. Hamilton WG, Balkam CB, Purcell RL, Parks NL, Holdsworth JE. Operating room traffic in total joint arthroplasty: identifying patterns and training the team to keep the door shut. *Am J Infect Control* 2018;46:633–636.
16. Anthony CA, Peterson RA, Polgreen LA, Sewell DK, Polgreen PM. The seasonal variability in surgical site infections and the association with warmer

weather: a population-based investigation. *Infect Control Hosp Epidemiol* 2017;38:809–816.
17. Taaffe K, Lee B, Ferrand Y, *et al.* The influence of traffic, area location, and other factors on operating room microbial load. *Infect Control Hosp Epidemiol* 2018;39:391–397.
18. Perez P, Holloway J, Ehrenfeld L, *et al.* Door openings in the operating room are associated with increased environmental contamination. *Am J Infect Control* 2018;46:954–956.
19. Wang C, Holmberg S, Sadrizadeh S. Impact of door opening on the risk of surgical site infections in an operating room with mixing ventilation. *Indoor Built Environ* 2019. doi: 10.1177/1420326X19888276.
20. Panahi P, Stroh M, Casper DS, Parvizi J, Austin MS. Operating room traffic is a major concern during total joint arthroplasty. *Clin Orthop Rel Res* 2012;470:2690–2694.
21. Andersson AE, Bergh I, Karlsson J, Eriksson BI, Nilsson K. Traffic flow in the operating room: an explorative and descriptive study on air quality during orthopedic trauma implant surgery. *Am J Infect Control* 2012;40:750–755.
22. Darouiche RO, Green DM, Harrington MA, *et al.* Association of airborne microorganisms in the operating room with implant infections: a randomized controlled trial. *Infect Control Hosp Epidemiol* 2017;38:3–10.
23. Wan GH, Chung FF, Tang CS. Long-term surveillance of air quality in medical center operating rooms. *Am J Infect Control* 2011;39:302–308.
24. Babkin Y, Raveh D, Lifschitz M, *et al.* Incidence and risk factors for surgical infection after total knee replacement. *Scand J Infect Dis* 2007;39:890–895.
25. Napoli C, Marcotrigiano V, Montagna MT. Air sampling procedures to evaluate microbial contamination: a comparison between active and passive methods in operating theatres. *BMC Public Health* 2012;12:594.
26. Napoli C, Tafuri S, Montenegro L, *et al.* Air sampling methods to evaluate microbial contamination in operating theatres: results of a comparative study in an orthopaedics department. *J Hosp Infect* 2012;80:128–132.