ORIGINAL ARTICLE

The Influence of Traffic, Area Location, and Other Factors on Operating Room Microbial Load

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OBJECTIVE.   To determine how the movement of patients, equipment, materials, staff, and door openings within the operating room (OR) affect microbial loads at various locations within the OR.

DESIGN.   Observation and sampling study.

SETTING.   Academic health center, public hospital.

METHODS.   We first analyzed 27 videotaped procedures to determine the areas in the OR with high and low numbers of people in transit. We then placed air samplers and settle plates in representative locations during 21 procedures in 4 different ORs during 2 different seasons of the year to measure microbial load in colony-forming units (CFU). The temperature and humidity, number of door openings, physical movement, and the number of people in the OR were measured for each procedure. Statistical analysis was conducted using hierarchical regression.

RESULTS.   The microbial load was affected by the time of year that the samples were taken. Both microbial load measured by the air samplers and by settle plates in 1 area of the OR was correlated with the physical movement of people in the same area but not with the number of door openings and the number of people in the OR.

CONCLUSIONS.   Movement in the OR is correlated with the microbial load. Establishing operational guidelines or developing OR layouts that focus on minimizing movement by incorporating desirable internal storage points and workstations can potentially reduce microbial load, thereby potentially reducing surgical site infection risk.

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Surgical site infections (SSIs) are dangerous for patients; they are associated with significant morbidity and mortality as well as increased healthcare costs.[1] Guidelines exist to mitigate the risk for SSI.[2] However, infections occur in the operating room (OR), even with best practices.[3,4] It is difficult to directly trace an individual SSI to an infection source or variable, so prior studies have measured microbial loads in the OR and/or have used readmissions data for postsurgical infection estimates.[5]

One potential contributing factor to increased risk of SSI is microbial contamination in the OR, which previous studies have suggested could exceed the recommended 10 CFU/m^3 more than 50% of the time.[3] The OR team is a major potential source of contamination[6,7] and their movement in the OR has a statistically significant correlation to the microbial load in the OR. However, findings that correlate the number of people in

the OR to microbial load are mixed[3]. Door openings in the OR have also been investigated to determine how they affect microbial load, and these studies have produced mixed results for orthopedic procedures.[2,8–11] However, studies of OR door openings during cardiac, vascular, and general surgeries have been positively correlated with microbial load.[12–14]

Prior studies have demonstrated that behavioral and safety protocols (eg, maintaining surgical asepsis) and good OR environmental discipline practices (eg, maintaining air pressure, temperature, and humidity) reduce the patient risk for SSI.[6,15] Also, surgical practices,[2] scrub attire,[16] and reduced OR traffic[3] reduce microbial load. The role of external risk factors to the development of SSI has been identified in past research[17–20]; however, the relationship between SSI and microbial load levels is not well understood.[21–23] A recent review of patient infection

rates in the OR found that only 24 of 2,086 studies published prior to 2013 provided evidence-based findings to connect components of an OR procedure to contamination.[6]

In this study, we sought to understand how the movement of the patient, equipment, materials, staff and OR door openings affect OR microbial loads at various locations. We aimed to develop evidence-based guidelines for OR workflow design. Although the general assumption is that these flows occur to support tasks required for the surgical procedures, the traffic may also transfer bacteria and fungi within the OR.[24]

METHODS

In this study, we used hierarchical regression to identify factors influencing microbial load in the OR. Factors considered were the OR itself, sampling time of year, OR temperature and humidity, number of door openings, number of people in the OR, and amount of traffic in the OR. A total of 27 procedures were recorded, beginning with the previous case patient leaving the room and ending with the current case patient leaving the room. The procedures selected ensured a range of OR practices for orthopedic and pediatric surgeries, but were recorded only if the prior consent of the entire surgical team had been obtained. All observed procedures occurred in 4 different ORs in a large academic hospital (>600 beds) in the United States.

To ensure coding validity, 4 researchers independently coded all 4 camera views of a representative procedure, using a standardized coding schema in Observer XT software (Noldus Information Technology, Wageningen, Netherlands). All 27 recorded procedures had similar traffic flows. Observations had 100% interrater reliability of door openings and number of people in the OR. However, coding differences existed regarding the activity of staff and the activity duration. These were addressed by revising the standardized coding schema through multiple group discussions, and the revised coding schema was then used to code door openings and all movement at locations for the remaining 26 videos. Each microbial-load sampling location was classified as either high or low traffic, based on (1) the number of transitions past the location, and (2) the proximity to a doorway. Notably, the proximity to a doorway automatically resulted in assignment to the high-traffic classification.

To measure the microbial load, 2 types of air samplers (Sartorious Stedim MD8 Airscan and AirChek XR5000 Sample Pump) and 9-cm settle plates were used. The 2 air samplers had flow rates of 2.0 m³/hour and 0.24 m³/hour, respectively, and use 3-μm gelatin and 0.8-μm polycarbonate filters, respectively. Post sampling, the gelatin filters were dissolved in basal salts medium to obtain 4 mL liquid, of which 500 μL was plated on the media, while the polycarbonate filters were extracted with 2 mL of basal salts liquid and 200 μL was plated on various media. Colony-forming units (CFU) were counted, and measurements were adjusted to report data as CFU per cubic meter.

The settle plates were incubated at 35°C for 48 hours for bacterial counts and 26°C for 5–7 days for fungal counts.

Resulting CFUs were counted, and measurements were adjusted to report data as CFU/m²/hour. The measurement techniques for both the air sampler and settle plates were made using best practices.[25] Similar procedures were used to sample twice during the same year, the first set in March 2016 and the second set in September 2016. Both pediatric and orthopedic procedures in 4 different ORs were sampled for a total of 21 procedures (12 orthopedic and 9 pediatric procedures); however, 2 procedures were not included in the analysis due to technical difficulties. Observation of the procedures showed that the surgical teams were compliant with surgical attire requirements.

All data were then analyzed using hierarchical regression, with separate models for bacteria and fungi for both air sampler and settle-plate data. The dependent variable was the CFU rate measured from the sampling devices, with a log transformation to reduce the influence of outliers.[26] The final control variables contained in the 6 models presented in the Methods section are as follows:

Model 1: Sampling Period (March or September)
Model 2: Temperature and Humidity + Model 1
Model 3: Operating Room + Model 2
Model 4: Number of Door Openings + Model 3
Model 5: Number of People in the Room + Model 4
Model 6: Amount of Traffic + Model 5

RESULTS

A spaghetti diagram of all staff movements from patient-in-room to patient-out-of-room during 4 sample procedures in a single OR is shown in Figure 1. Similar diagrams exist for each observed procedure. Figure 1A shows only the movements of the circulating nurse, and Figure 1B shows all staff movements. Table 1 presents the average movement (in terms of transitions) near a location in the coded videos, the location proximity to the door, and the resulting designation as a high or low traffic location, the final independent variable tested in the hierarchical regression analysis.

Table 2 reports the average microbial load with bacteria and fungi measures identified by the time of year when they were taken (March and September) for each sampling method. A previous study[5] indicated a seasonality effect on bacteria levels when sampling. Although we did not test for seasonality, all bacteria samples are higher in September than in March. The effect for fungi is not as clear, with some measurements being higher in March than in September. The data for the orthopedic and pediatric procedures were separated due to their distinct nature. It is standard practice for total joint arthroplasty surgical teams to wear surgical attire specific for those procedures, which includes gowns made from higher barrier protection material and head gear with a battery-operated fan that provides greater contamination protection. These teams also restrict traffic from the outer-corridor OR door during the intraoperative phase. As expected, the average microbial load for the air sampler measures was lower for the orthopedic procedures. However,

(a)

(b)

Traffic flow by the circulating nurse in OR 1
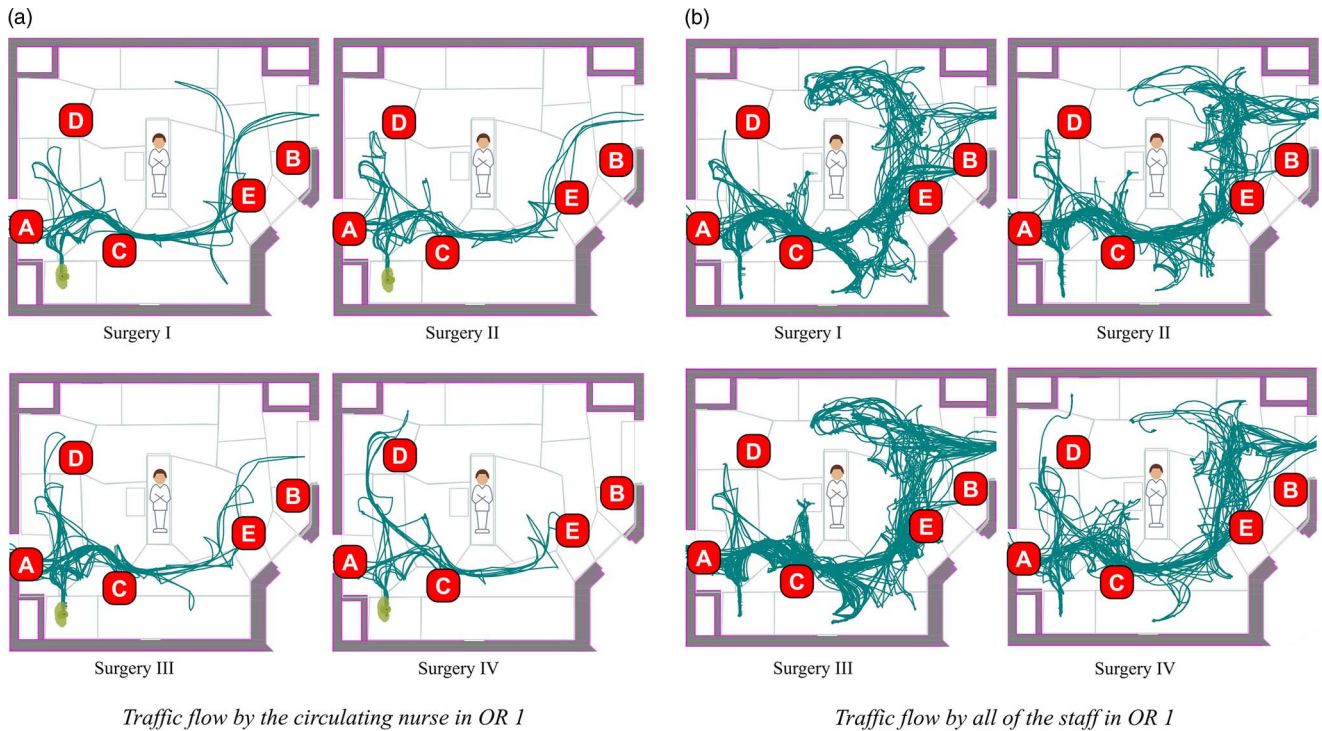
Traffic flow by all of the staff in OR 1

FIGURE 1.   Traffic flow and sampling locations (operating room 1). A: near door 1, high traffic area; B: near door 2, high traffic area; C: transition location, high traffic area; D: low traffic area; E: near door 2, high traffic area.

TABLE 1.   Traffic Classifications (High/Low) for Each Sampling Location and Operating Room

Room	Location	Average No. of Transitions per Hour of Surgery	Doorway	Traffic
OR 1	A	32.45	Door	High
OR 1	B/E	39.75	Door	High
OR 1	C	60.39		High
OR 1	D	13.09		Low
OR 2	A	24.01	Door	High
OR 2	B/E	31.50	Door	High
OR 2	C	32.05		High
OR 2	D	11.42		Low
OR 3	A	22.47	Door	High
OR 3	B/E	9.95	Door	High
OR 3	C	50.01		High
OR 3	D	6.96		Low
OR 4	A	22.47	Door	High
OR 4	B/E	9.95	Door	High
OR 4	C	43.37		High
OR 4	D	6.79		Low
OR 5	A	12.11	Door	High
OR 5	B/E	26.37	Door	High
OR 5	C	62.63		High
OR 5	D	5.09		Low

NOTE. OR, operating room; A: near door 1, high traffic area; B: near door 2, high traffic area; C: transition location, high traffic area; D: low traffic area; E: near door 2, high traffic area.

contrary to expectations, the average settle-plate measures for orthopedic procedures exceeded that of the pediatric procedures during both the March and September samples.

Tables 3 and 4 present the results of the hierarchical regression analysis using air sampling data and settle-plate data, respectively. Notably, all orthopedic procedures took place in the same OR, and the pediatric cases took place in the other 3 observed ORs. This aspect of our study was captured in model 3 using 3 categorical variables for the pediatric procedures where the OR used for orthopedic procedures was coded as 0.

The 6 regression models using air sampling data all have nonsignificant adjusted R^2 values (Table 3). All 6 models using the settle-plate data yielded statistically significant results, and at least 1 control variable per model is significant (Table 4). In Table 4, model 1 shows an increase in bacteria in September ($P < .001$). The amount of traffic (model 6) at a location also significantly affects the microbial load ($P < .05$). Temperature, humidity, operating room, and number of door openings were nonsignificant in all models. The number of people in the room (model 5) also did not produce a statistically significant result with a P value between .05 and .10.

DISCUSSION

Analysis of the air sampling data did not demonstrate differences by location in the bacterial load. Although the level of

TABLE 2. Average by Sampling Time, Sampling Method, and Procedure Type

| | | Air Sampler (CFU/m^3) | | | | | | | | | Settle Plate (CFU/m^2/h) | | | | | | | | | |
| | | Orthopedic Procedures | | | | | Pediatric Procedures | | | | | Orthopedic Procedures | | | | | Pediatric Procedures | | | | |
Period	Source	No.	Mean	SD	Min	Max	No.	Mean	SD	Min	Max	No.	Mean	SD	Min	Max	No.	Mean	SD	Min	Max
Spring	Bacteria	28	17.1	16.3	0.0	76.1	19	18.0	21.2	0.0	70.1	27	283.0	190.3	0.0	629.1	20	264.8	286.5	0.0	1,048.5
	Fungi	28	0.2	0.5	0.0	2.1	19	0.7	1.6	0.0	4.7	27	17.9	31.2	0.0	107.2	16	0.0	0.0	0.0	0.0
Fall	Bacteria	5	34.6	31.9	0.0	80.0	4	49.8	63.2	0.0	131.6	35	812.0	557.2	56.5	2,038.1	28	716.7	415.5	0.0	1,952.4
	Fungi	7	0.0	0.0	0.0	0.0	4	0.0	0.0	0.0	0.0	35	29.2	53.2	0.0	226.0	28	10.0	37.1	0.0	160.0

NOTE. CFU, colony-forming units; SD, standard deviation; Min, minimum; Max, maximum.

TABLE 3. Analysis of Bacterial Load Using Air Samplers[a]

Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Sampling period[b]	0.26	0.13	0.20	0.41	0.41	−0.28
Temperature in the OR		−0.07	1.04	1.55[c]	1.53[c]	1.48[c]
Humidity in the OR		−0.01	0.63	0.95[c]	0.94[c]	0.91[c]
OR1[d]			13.35	19.43[c]	19.24[c]	18.28[c]
OR2[d]			2.37	3.99	3.94	3.44
OR3[d]			1.99	2.34	2.36	2.30
No. of door openings				0.05	0.05	0.05
No. of people					−0.03	−0.05
Traffic level[e]						1.42[f]
Constant	2.11[f]	7.93	−102.06	−155.08[c]	−152.50[c]	−148.48[c]
Sample size	51	51	51	51	51	51
Adjusted R^2	−0.0166	−0.0494	−0.0223	−0.0214	−0.0454	0.1080
Probability > F[g]	0.6687	0.8856	0.5618	0.5526	0.6654	0.1272

NOTE. CFU, colony-forming units; OR, operating room.
[a]All values are shown the log of CFU/m^3.
[b]Month: 0, March; 1, September.
[c]$P < .10$, where P is the probability of observation when null hypothesis of no difference is true.
[d]OR: 0, orthopedic; 1, pediatric.
[e]Traffic level at location: low, 0; high, 1.
[f]$P < .01$, where P is the probability of observation when null hypothesis of no difference is true.
[g]F test for the overall significance of the specified model.

traffic was significant in model 6 (Table 3), the model itself did not yield statistically significant results. The lack of significant differences in the air sampling data may have several explanations. The first is that we used 2 types of air samplers and that we had fewer air samplers than we did settle plates, so the sample size was much smaller for air samples. Also, living particles may become inactive through contact with the air sampler,[25] which offsets the air sampling device advantage (compared to settle plates) of exposing a known volume of air to the sampling medium.

The major findings of this study are that higher-traffic areas in the OR have a higher microbial load than lower-traffic areas (see model 6 in Tables 3 and 4) and that the number of door openings did not have a significant impact on microbial load. While door openings were not identified as a significant factor on its own, proximity to a door still influenced bacterial count, which was embedded into the classification of "high traffic versus low traffic" (Table 1). Importantly, in both model 5 and model 6, the number of people in the room may have increased the bacterial count (Table 4). All hierarchical regression models of the settle-plate CFU identified the sampling period as significant (Table 4), which supported prior research[5] that SSI rates vary according to the season.

The finding that high-traffic areas have higher microbial loads as measured by the settle plates indicates that it is important to control the traffic in the OR and move it away from the surgical field. This finding supports prior research that the measurements of microbial load near the wound are the most important.[27,28] It also suggests that intraoperative asepsis methods that would keep traffic away from the surgical field would contribute to reducing microbial load near the wound and consequently to fewer SSI. The a priori video analysis used to create Figure 1 identified that certain areas of the OR attract traffic, such as areas near the OR doors,

TABLE 4.   Analysis of Bacterial Load Using Settle Plates[a]

Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Sampling period[b]	1.32[c]	1.10[c]	1.05[d]	1.09[d]	0.96[d]	0.86[d]
Temperature in the OR		−0.08	−0.40	−0.20	−0.33	−0.33
Humidity in the OR		−0.01	−0.20	−0.07	−0.18	−0.18
OR1[e]			−3.87	−1.31	−4.47	−4.70
OR2[e]			−0.44	0.33	−0.67	−0.67
OR3[e]			−0.49	−0.24	−1.13	−1.13
No. of door openings				0.01	−0.01	−0.01
No. of people					0.37[f]	0.37[f]
Traffic level[g]						0.90[d]
Constant	4.89[c]	11.12[f]	42.47	22.10	34.54	33.86
Sample size	100	100	100	100	100	100
Adjusted R[2]	0.1674	0.1686	0.1546	0.1484	0.1708	0.2057
Probability > F[h]	.0000	0.0001	0.0013	0.0024	0.0013	0.0004

NOTE. OR, operating room; CFU, colony-forming units.
[a]All values are shown in log of $CFU/m^2/hour$.
[b]Month: 0, March; 1, September.
[c]$P < .01$, where P is the probability of observation when null hypothesis of no difference is true.
[d]$P < .05$, where P is the probability of observation when null hypothesis of no difference is true.
[e]OR: 0, orthopedic; 1, pediatric.
[f]$P < 0.10$, where P is the probability of observation when null hypothesis of no difference is true.
[g]Traffic level at location: low, 0; high, 1.
[h]F test for the overall significance of the specified model.

telephone, computer work stations, and cabinet storage. Extensive traffic was also observed between the anesthesia area and the door, as well as circulating nurse movements around the room and through the door. Therefore, to the extent possible, these high traffic areas should be situated near each other and away from the surgical field.

High-traffic areas by role in the OR could be related to the type of movements that staff engage in within the OR. For example, it would be important to enable the circulating nurse, whose role leads to high foot traffic, to have a workstation area situated away from the surgical field and to have the phone and storage cabinets adjacent to the workstation. For the anesthesia team, who may enter and leave during the procedure, it would be helpful to have a pathway that does not cross the surgical field and, instead, remains behind the head of the patient. This adjustment could include having a door dedicated to the anesthesia team. Each of these suggestions requires further research into understanding how the OR design parameters interact with staff responsibilities to affect staff movement.

It is also important to consider the causes for movement, possibly sorting necessary task movements from controllable movements caused by lack of communication or lack of materials and supplies, which are both causes of increased traffic flow in the OR.[18] To this effect, the location of supplies can greatly influence traffic levels because the location of the supply cabinets, workstations and functional areas (eg, back table) are all attractors of movement at different points in the procedure. Our results suggest that OR and workflow design could reduce contamination by limiting the spread of microbes to the surgical field.

Other drivers of OR traffic movement are visual and auditory constraints. Staff may have to move to observe activity in and around the surgical field. This need to move could also be true for students and other observers, so better views could possibly be provided by strategically mounted cameras and projection systems. To hear voice prompts, staff may need to approach the surgical field more often when there is excess noise in the OR. Improving OR acoustics would reduce the need for such movement.

While the number of people in the OR did not contribute significantly to microbial load in the model, further research should be conducted. It would be useful to investigate which areas in the OR will allow observation without interfering with the procedure and without increasing the amount of traffic in the OR. Nevertheless, limiting the movement of people present in the OR should be prioritized over limiting the number of people in the OR. There results of our study showed no significant difference in the bacteria count between the ORs. Because orthopedic surgeons take special precautions to prevent microbial contamination, it was expected that microbial load in the orthopedic procedures would be lower. Lastly, the nonsignificance of the number of door openings also suggests that the amount of traffic is more important than door openings. To further address these factors, future research could investigate correlation between traffic level, number of people in the room, and the number of door openings.

The significance of the sampling period was also not expected. Although the outside bacterial counts are expected to increase during the summer and fall because of humidity and temperature, it was expected that the environmental

controls inside the OR would mitigate the effects of weather. A post hoc analysis showed no difference in the temperature during the 2 sampling periods, but a significant difference in the range of the humidity measurements were detected, with the September humidity measurements being much more extreme than the March measurements.

This study included only a limited number of sampling locations in the OR. A sampling plan that took more samples and ensured that samples were taken from every part of the OR would provide more information about the distribution of microbes throughout the OR. This improvement would allow better estimates of how door placement and cabinet placement affect the microbial load.

Also, it is not possible to determine the specific contribution to microbial load in the OR from colonized OR staff in our study, and this factor is beyond the scope of our experiments. However, several studies have demonstrated that OR staff can be linked to contamination of the environment with airborne bacteria due to skin shedding and that this has led to SSIs. A recent comprehensive review of this topic was undertaken by the Association of periOperative Registered Nurses.[29]

While OR sampling was limited to orthopedic and pediatric procedures, conclusions drawn from this research are applicable to other types of operative procedures. By understanding the level and reasons for intraoperative movement (regardless of procedure type), informed workflow design could potentially reduce the amount of movement, which would ultimately reduce microbial loads, and thereby lessen SSI risk.

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REFERENCES

1. de Lissovoy G, Fraeman K, Hutchins V, Murphy D, Song D, Vaughn B. Surgical site infection: incidence and impact on hospital utilization and treatment costs. *Am J Infect Control* 2009;37:387–397.
2. 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.
3. Andersson A, Bergh I, Karlsson J, Eriksson B, 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.
4. Benenson S, Moses A, Cohen M, 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.
5. Anthony C, Peterson R, Polgreen L, Sewell D, Polgreen P. 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.
6. Birgand G, Saliou P, Lucet J. Influence of staff behavior on infectious risk in operating rooms: What is the evidence? *Infect Control Hosp Epidemiol* 2015;36:93–106.
7. Friberg B, Friberg S, Burman L. Correlation between surface and air counts of particles carrying aerobic bacteria in operating rooms with turbulent ventilation: an experimental study. *J Hosp Infect* 1999;42:61–68.
8. Tjade O, Gabor I. Evaluation of airborne operating room bacteria with a Biap slit sampler. *J Hygiene* 1980;84:37–40.
9. Castella A, Charrier L, Legami V, 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. Ritter M. Operating room environment. *Clin Orthop Relat Res* 1999;369:103–109.
11. Yinnon A, 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.
12. Borer A, Gilad J, Meydan N, et al. Impact of active monitoring of infection control practices on deep sternal infection after open heart surgery. *Ann Thorac Surg* 2001;72:515–520.
13. Crolla R, van der Laan L, Veen E, Hendriks Y, van Schendel C, Kluytmans J. Reduction of surgical site infections after implementation of a bundle of care. *PLoS One* 2012;7:e44599.
14. Van der Slegt J, van der Laan L, Veen E, 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:e71566.
15. Beldi G, Bisch-Knaden S, Banz V, Mühlemann K, Candinas D. Impact of intraoperative behavior on surgical site infections. *Am J Surg* 2009;198:157–162.
16. Tammelin A, Blomfeldt A. Comparison of two single-use scrub suits in terms of effect on air-borne bacteria in the operating room. *J Hosp Infect* 2017;95:324–326.
17. Mangram A, Horan T, Pearson M, Silver L, Jarvis W. CDC guideline for prevention of surgical site infection. *Infect Control Hosp Epidemiol* 1999;20:247–278.
18. Uçkay I, Harbarth S, Peter R, Lew D, Hoffmeyer P, Pittet D. Preventing surgical site infections. *Expert Rev Anti Infect Ther* 2010;8:657–670.
19. Gosden PE, MacGowan AP, Bannister GC. Importance of air quality and related factors in the prevention of infection in orthopedic implant surgery. *J Hosp Infect* 1998;39:173–180.
20. Alfonso-Sanchez J, Martinez I, Martin-Moreno J, et al. Analyzing the risk factors influencing surgical site infections: the site of environmental factors. *Can J Surg* 2017;60:155–161.
21. Wan G, Chung F, Tang C. Long-term surveillance of air quality in medical center operating rooms. *Am J Infect Control* 2011; 39:302–308.
22. 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.

23. Armellino D. Optimal infection control practices in the OR environment. *AORN J* 2016;104:516–522.

24. Loison G, Troughton R, Raymond F, et al. Dress code and traffic flow in the operating room: a multicentre study of staff discipline during surgical procedures. *J Hosp Infect* 2017. doi: 10.1016/j.jhin.2017.03.026.

25. Pasquarella C, Pitzurra O, Savino A. The index of microbial air contamination. *J Hosp Infect* 2000;46:241–256.

26. Wooldridge J. *Introductory Econometrics: A Modern Approach*. 5th ed. Mason, OH: South-Western College Publishing; 2013.

27. 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.

28. Napoli C, Marcotrigiano V, Montagna M. Air sampling procedures to evaluate microbial contamination: a comparison between active and passive methods in operating theatres. *BMC Public Health* 2012;12:594–599.

29. Spruce L. Surgical head coverings: a literature review. *AORN J* 2017;106:306–316.