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Major Article

Assessment of operating room airflow using air particle counts and direct observation of door openings

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Background: The role of the operating room (OR) environment has been thought to contribute to surgical site infection rates. The quality of OR air, disruption of airflow, and other factors may increase contamination risks. We measured air particulate counts (APCs) to determine if they increased in relation to traffic, door opening, and other common activities.

Methods: During 1 week, we recorded APCs in 5-minute intervals and movement of health care workers. Trained observers recorded information about traffic, door openings, job title of the opener, and the reason for opening.

Results: At least 1 OR door was open during 47% of all readings. There were 13.4 door openings per hour during cases. Door opening rates ranged from 0.19-0.28 per minute. During this time, a total of 660 air measurements were obtained. The mean APCs were 9,238 particles (95% confidence interval [CI], 5,494-12,982) at baseline and 14,292 particles (95% CI, 12,382-16,201) during surgery. Overall APCs increased 13% when either door was opened ($P < .15$). Larger particles that correlated to bacterial size were elevated significantly ($P < .001$) on door opening.

Conclusions: We observed numerous instances of verbal communication and equipment movement. Improving efficiency of communication and equipment can aid in reduction of traffic. Further study is needed to examine links between microbiologic sampling, outcome data, and particulate matter to enable study of risk factors and effects of personnel movement.

BACKGROUND

Despite resources contributed to the prevention of surgical site infections (SSIs), they remain costly complications from the associated morbidity, mortality, and costs. They also impact more patient-centered measures, including quality of life and satisfaction. The approaches to prevention have primarily focused on patient-level factors, including the use of skin cleansing, perioperative antibiotics when indicated, patient warming, and so forth. Recent studies suggest that many-pronged interventions are important and likely necessary for improvement in this complicated environment.

The role of the operating room (OR) environment has been considered important and is thought to contribute to SSI rates; however, data on its risk attribution has been difficult to quantify.[1] Quality of OR air, disruption because of traffic and door openings, laminar airflow, and other factors may alter pressure relationships and affect risks for contamination. In fact, data show that the number of colony forming units increases as OR door openings increase.[1] Hence, monitoring of air quality in the OR is a frequent strategy to assess risks and factors for contamination.[2] Although there is no consensus on the best method, correlation exists between air particle counts (APCs) and microbial contamination and has been suggested as a surrogate to monitor contamination.[3-6] A recent large multicenter study has demonstrated a correlation between APCs and microbial contamination of OR air.[7] Furthermore, studies show that decreasing door openings and likely APCs lead to decreased SSIs when included in a bundle of interventions.[8,9] Because of the increasing interest in improving patient safety and surgical outcomes, understanding factors that lead to high airborne particulate levels in the

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OR is crucial. Furthermore, such data are lacking in the setting of reconstructive procedures that use implants. We measured the APCs in a building of a large academic center with ORs to determine the relationships to traffic, door openings, and other commonly experienced activities. The ultimate goal was to integrate the findings into interventions to enhance OR safety and decrease the risk of contamination that increases risk of SSI. We focused on the typical practice of plastic and reconstructive surgery.

MATERIALS AND METHODS

Johns Hopkins Hospital is a 1,192-bed academic medical center with an active surgical service with 40 inpatient ORs between 2 separate buildings. Plastic surgery performs approximately 3,900 cases annually, primarily in several ORs situated in a building that opened in 1997. Routine and standard perioperative and infection prevention practices are in place. The air pressure in the ORs is positive to the core areas, and pressure relationships are measured routinely by facilities personnel.

Over the course of 1 week when typical clean and nonemergent cases were performed in the OR, we systematically and routinely recorded APCs and movement of health care workers. APCs were counted using a Climet Innovation Particulate Counter (Climet Instruments, Redlands, CA) after the facility department validated performance characteristics within the OR suite. Baseline recordings were obtained from empty room checks. Study recordings were obtained from a single location within the room every 5 minutes, for 7 separate cases. Each recording consisted of 3 sample readings spaced approximately 1 minute apart, ensuring consistent readings every 1-2 minutes throughout the entire observation period. Because the particle counter was not automated, the extended 5-minute observation set led to a cycle that was nearly continuous and also allowed observers to record the supplementary qualitative and quantitative information.

The location of the APC counter (Fig 1) had been determined by preliminary assessment of the magnitude of changes in particle counts in various positions within the room when considering both door openings and subsequent intra-OR traffic. These considerations were balanced with assumed clinical impact of APCs in various room locations, presuming counts nearer the operating table were more likely to impact risk of contamination and patient outcomes. Reference and baseline samples were also taken in the sterile core, outer corridor, and surgical wing front desk using established institutional protocols for quality control checks temporally just prior to the beginning of the observational study. The readings in these reference samples were found to be within expected, acceptable ranges. Hospital facility technicians verified the airflow exchanges and pressure readings to ensure they were within working standards.

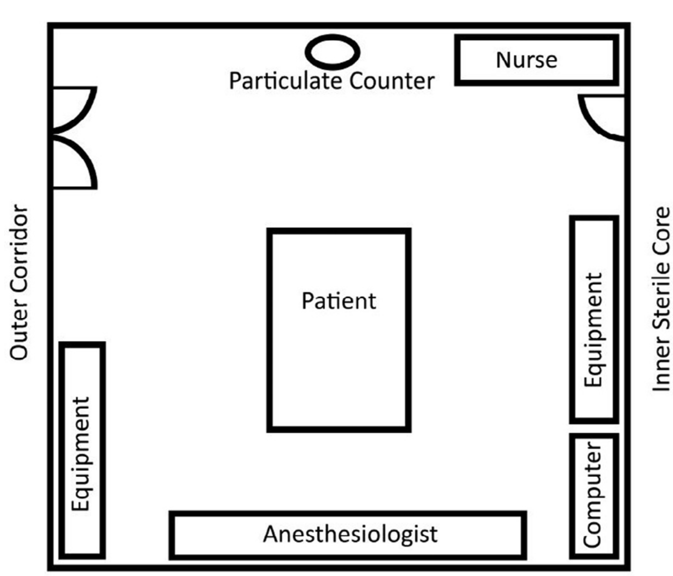

Fig 1. Operating room diagram and placement of particulate counter. This schematic represents the operating room where the APC measurements were performed and demonstrates the approximate placement of the particle counter within the operating room. Note: Not to scale.

Supplemental baseline data were collected in the morning before any activity, and between and after cases as well. Trained observers stood in a standard area to observe and record information about traffic and activity. Specifically, observers recorded when the operating door was opened, job title of the person opening the door, and the reason for opening the door. Information was documented in 5-minute time intervals. Reasons for opening the doors were, when possible, classified as necessary for the case, unknown, or unnecessary.

Door opening rates were divided into 3 groups (1) pre or early case: the first 30 minutes of the case; (2) late or post case: the last 30 minutes of the case; and (3) intermediate: activity in any intervening time. These time frames were chosen to replicate common clinical timings within the plastic surgery practice, including increased activity with patient entry, anesthesia induction, and surgical start (pre or early case); ongoing surgical intervention (intermediate case); and closing, dressing of wounds, emergence, and exit from room (late or post case). When the average opening number data was examined related to time, natural breakpoints in door opening were not present that might contradict the presumed standard clinical breakpoints. This assumed that starting or completing the case might be associated with increased equipment or personnel needs (modifiable or not).

Data were analyzed using Stata IC 12.1 (StataCorp, College Station, TX). APC data were analyzed with parametric statistics and compared using Student *t* tests and analyses of variance. Normal logarithmic transformations were used for APC groups for linear regression modeling. Categorical and ordinal data were analyzed using χ^2 analysis or Fisher exact test. Mean APCs for each 5-minute recording group (3 sample set) were analyzed with Gaussian smoothing techniques with a 95% confidence interval (CI) for visual presentation. Statistical significance was defined a priori at $\alpha = 0.05$.

RESULTS

Over a 5-day period, the activity around a total of 7 cases was observed while the air quality was monitored. A total of 660 air quality measurements were obtained overall with 58 reference period readings and 602 measurements while patients were present in the OR. The average APCs were 9,238 (95% CI, 5,494-12,982) in the baseline period and 14,292 (95% CI, 12,382-16,201) while surgery was occurring. Overall APCs increased 13% when either door was opened; however, the increase was not statistically significant ($P < .152$). When analyzed by particle size, however, particle groups >0.5 μ did have significant elevation from baseline ($P < .001$). Particles of this size are known to include bacteria, fungi, and other organisms that could be pathogens in wounds.[10] The magnitude of APC increase did not significantly differ based on whether the door to the sterile core or door to the outer corridor was opened ($P = .599$); however, larger particles, including groups of 1, 5, 10, and 25 μ, did increase significantly when the outer door was opened compared with the inner door opening ($P < .001$).

Particulate counts rose steadily over the course of the day on 3 days and dropped on 2 other days. APCs were lower between cases than during cases ($P < .057$). APCs were generally higher and more varied during the first 2 days of cases than later in the week. Figures 2

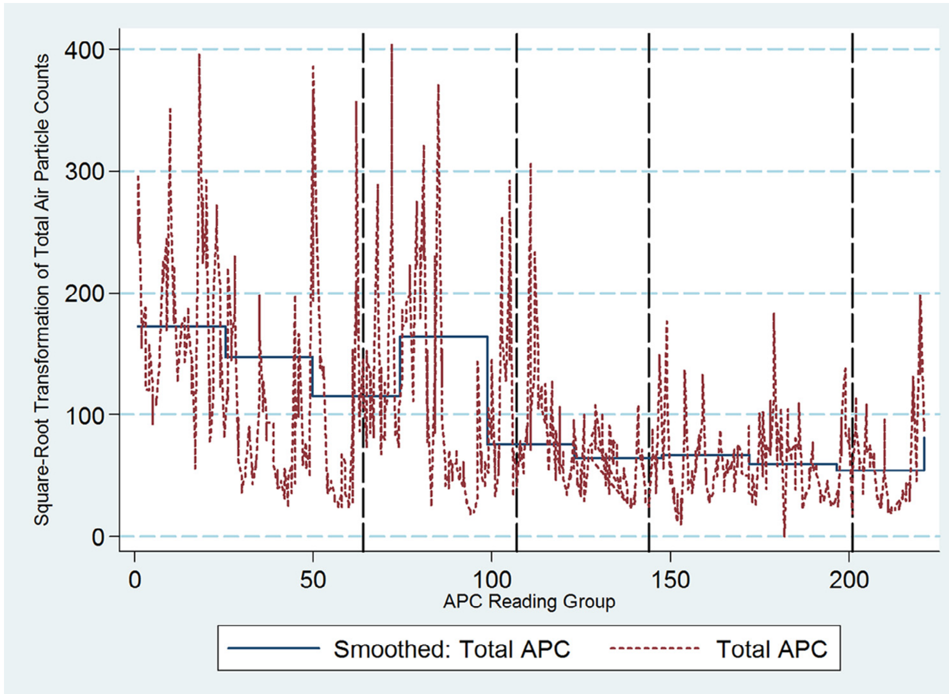

Fig 2. Particle counts over the course of the cases. Total particle counts are recorded along the Y-axis and displayed for each 5-minute interval. The set of particle count readings represents an overall count for all cases recorded. Y-axis is displayed using square root transformation of total air particulate count (APC) for better visualization of temporal trends. Vertical lines denote each day of observation. Smoothing using stepped moving average in Gaussian distribution over 10 observation groups is displayed in the black horizontal line. The X-axis represents sequential APC 5-minute reading group across all cases.

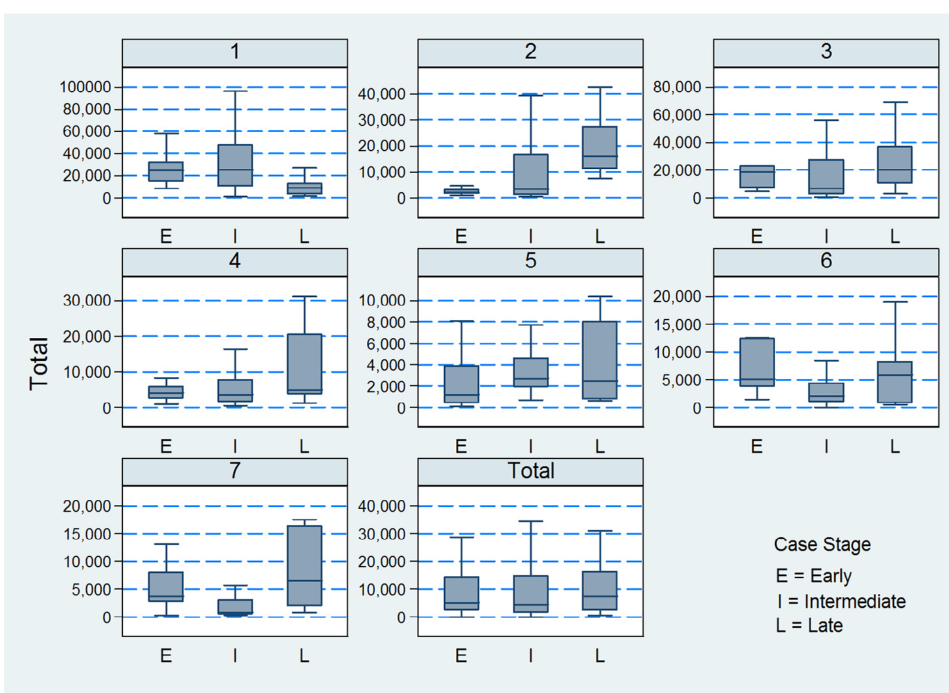

Fig 3. Summary comparison of air particulate counts for individual cases and interoperative time frames. Summary air particulate count (APC) divided by state in the case (Early, Intermediate, or Late). Each panel represents a separate case labeled 1-7. The overall summary counts are seen in the panel labeled "total." Comparison is APC for each case broken by interoperative timeframe. Early = first 30 minutes; Late = last 30 minutes; Intermediate = time period between early case and late case stages. Defined using anecdotal clinical breakpoints for surgery types.

and 3 demonstrate temporal trends in APCs over the observation days and cases. There was wide variation, particularly in smaller particle groups that tend to be more susceptible to smaller variations in flow and room pressure.

Overall, one or both OR doors were open during 47% (309/660) of all readings. Both doors were open concurrently in 7% (45/660) of readings. Extrapolating based on the timing of the cases, there were on average 13.4 door openings per hour during the cases. Door

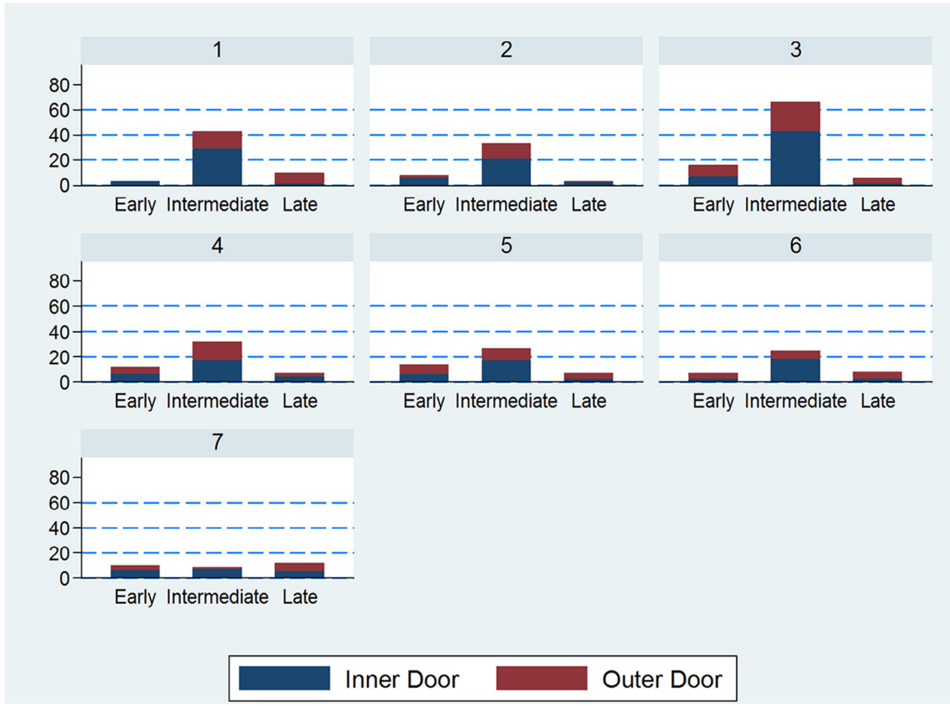

Fig 4. Door openings by case stage. Distribution of the number of door openings in each case by interoperative timeframe. The number of door openings is shown on the Y-axis and the period is displayed on the X-axis. Each panel represents a separate case. Early case = first 30 minutes; Late case = last 30 minutes; Intermediate = period between early case and late case stages. Defined using anecdotal clinical breakpoints for surgery types.

opening rates per minute ranged from 0.185-0.278 and were not significantly different among the cases ($P = .109$). Door opening rates during cases did not differ significantly for the 3 defined time periods of the case pre or early, late or post, and intermediate ($P = .108$). The average of the door opening number did not correlate with the presumed standard clinical breakpoints (Fig 4).

The number of personnel entering or exiting for each door opening was also evaluated. We found the mean number of personnel per door opening, regardless of inner or outer door, to be 2.3 individuals per door opening (95% CI, 2.1-2.5). Mean personnel movement was found to be 2.6 (95% CI, 2.4-2.8) for the inner door and 2.5 (95% CI, 2.2-2.8) for the outer door. When both doors were found open, the mean number of personnel entering or exiting was 4.3 (95% CI, 3.7-4.9). Linear regression using log-transformed APCs found the number of people entering during each opening was not associated with recorded APCs ($P = .906$). This was also true for small particle counts ($P = .869$) and large particle counts ($P = .474$).

We evaluated reasons behind door openings to examine opportunities for modifiable behavior and to attempt to define a baseline acceptable rate of opening viewed as necessary to standard practice. During the study period, a total of 311 occurrences of personnel entering or exiting the room were observed. Overall, during the 7 cases, the median number of entrances or exits was 39 (95% CI, 30-66; range, 28-73). The most common reasons for opening either door during the case were to obtain case equipment (30%; 95% CI, 25%-34%), case status updates (12%; 95% CI, 9%-15%), and work-related or social conversations (8%; 95% CI, 5%-11%). Table 1 demonstrates the full range of reasons and frequency of occurrence of each.

Circulating nurses were responsible for a third of all door openings (Table 2). Individuals expected to be scrubbed most of the time accounted for 25% of door openings (scrub technicians, resident surgeons, attending surgeons, or students). The anesthesiology team accounted for 12% of door openings. Other staff (nurses working in

Table 1
Reasons operating room doors were opened during procedures

Reason	Inner door, n	%	Outer door, n	%	Total, n	%
Equipment for case	77	35.7	30	20.1	107	30.1
Status update	22	10.2	20	13.4	42	11.8
Scrub in or out	2	0.9	35	23.5	37	10.4
Unknown	18	8.3	20	13.4	38	10.7
Multiple	26	12.0	10	6.7	36	10.1
Work conversation	19	8.9	5	3.4	24	6.7
First entry for case	10	4.6	12	8.1	22	6.2
Break	19	8.8	2	1.3	21	5.9
Equipment for other case	11	5.1	3	2.0	14	3.9
Shift change	5	2.3	4	2.7	9	2.5
Equipment personnel	1	0.5	4	2.7	5	1.4
Social conversation	3	1.4	1	0.7	4	1.1
Instruments for case	2	0.9	1	0.7	3	0.8
Specimens to laboratory	1	0.5	2	1.3	3	0.8

Table 2
Personnel opening doors during OR procedures

Staff	Inner door, n	%	Outer door, n	%	Total, n	%
Circulating RN	96	44.4	24	16.1	120	32.9
Multiple persons	27	12.5	15	10.1	42	11.5
Scrub technician	18	8.3	15	10.1	33	9.0
Resident (surgeon)	14	6.5	15	10.1	29	8.0
CRNA	6	2.8	19	12.8	25	6.9
Attending surgeon	5	2.3	16	10.7	21	5.8
Anesthesiologist	6	2.8	14	9.4	20	5.5
Nurse (other)	14	6.5	3	2.0	17	4.7
Researcher	10	4.6	3	2.0	13	3.6
OR staff	8	3.7	3	2.0	11	3.0
Unknown or missing	6	2.8	16	10.7	22	6.0
Medical student	1	0.5	4	2.7	5	1.4
Vendor	3	1.4	1	0.7	4	1.1
Equipment staff	2	0.9	1	0.7	3	0.8
Anesthesiologist (resident)	0	0.0	0	0.0	0	0.0

OR, operating room; *RN*, Registered Nurse.

other rooms, researchers, OR administrators, vendors, or equipment staff) together accounted for 11% of door openings. Groups of mixed staff types entered together approximately 11% of the time. Only 6% of door openings were not attributed to an occupation.

DISCUSSION

The focus on improving patient outcomes by improving process in the ORs is thought to enhance patient safety. We studied processes in the ORs where clean nonemergent operations were being performed and found a high rate of door openings. Other investigators have noted this finding; however, it has not been studied in a modern OR.[1] Still, our results were similar to findings of Lynch et al in an observational study of several surgical disciplines.[11] In their study, the team recorded 3,071 door opening over 28 cases, with 30%-50% of openings during the preincision period. Our study differs in that we found most openings were in the middle of the case; however, the distribution across time periods was not statistically significant. Other investigators have found that the OR doors are commonly opened 60-135 times per case in clean procedures, such as cardiac surgery and joint arthroplasty.[12,13] We found a range of 28-73 door openings during each of our reconstructive surgery cases. Young and O'Regan also found that the door was open 10.7% of each hour on average across all observed cases.[12] Similarly, we noted 13.4 door openings per hour, which, depending on the duration of opening, could account for 15 minutes per hour (25%). Because our study did not analyze duration of opening, a true estimate of that measurement could not be obtained. A door could be open for as little as a few seconds for personnel exchange, or as much as a few minutes for transfer of equipment or entry of the patient bed. It is worth noting, however, that a door was open nearly half of the time during which the observations took place. Even after the start of the procedure, door openings were noted for status updates and numerous scrub-ins by other staff.

Scaltriti et al examined the link between microbiologic and dust contamination to define the risk factors affecting air quality in the ORs.[3] Frequency of door openings was negatively associated with over threshold values of both fine and larger dust particles. In our study, we found larger particles to have a stronger association with door openings than smaller particles. We also found that smaller particles persisted in the air longer after door openings, causing particulate levels for those groups to remain higher until several more minutes after the door had been closed. Even in a new modern building with state of the art ventilation systems, the impact of traffic on APCs was not compensated for highlighting the need for better process engineering in the OR and increased awareness of excess traffic among health care personnel.

It is not surprising that the circulating nurses contributed to most openings because their duties do require entry and exit and they are the most common personnel in this setting. Other personnel, such as surgeons and staff, attributed for about a quarter of entries and exits. Although it is common for surgeons to enter and exit to perform different parts of the surgeries, the need for residents remains unknown. At teaching hospitals in particular, residents or other medical students may be participating in the surgery for education and do not have a direct role in the patient care. Because of the nature of our study, we did not address which surgeons or anesthesiologists were directly providing care and which were ancillary.

Because the facility is also a research center, there are often times when researchers are in the ORs. In our study, this only accounted for approximately 3% of the total openings, and we do not think this was likely to have influenced overall outcomes. Vendors and other staff types included a mix of normal OR staff that are present day-to-day in the OR areas whether in an academic or community health care setting. External vendors in particular are common in the OR areas. Although they may not be present for every case, they are likely to be involved in the typical surgical case and therefore do factor into the traffic into the OR.

We noted numerous instances of verbal communication for status updates, clinical discussion, or other social visit reasons. Pada and Perl noted when summarizing their data that >21% of door openings are for social reasons or communications and 38% of the time no reason was recorded.[1] Our findings here again mirrored these data where information requests accounted for most door openings in the study. These instances do not require entry into the room, given the presence of intercom or other technologies that permit someone in the room to communicate with the outer door. Although in our setting the occurrence of social visits was relatively low, it still factored into the flow during 1 case. Certainly, in recent years, the airline industry has taken to utilization of intercom technology to communicate from the cabin to the flight deck. For security reasons, most communication during flight is done without the flight deck door open. Furthermore, many health care institutions have implemented technology to allow communication between providers so that they do not need to go in and out of patient rooms as often. Similarly, we feel that short or routine communications that occur during the surgical procedure could also benefit from such technology, and this would decrease unnecessary door openings.

It follows that a number of entries and exits from the room for equipment could be reduced by bundling the equipment needed together, using telephones to determine the status of cases, and eliminating unnecessary personal or social conversations. There were instances where several openings over a short amount of time for equipment could have potentially been consolidated into a single trip, therefore limiting the number of door openings. Two separate studies looked at the impact of a bundle of interventions, including perioperative antibiotics, hair removal before surgery, perioperative normothermia, and discipline in the OR (limiting the number of OR door openings), to prevent SSI.[8,9] Crolla et al found that when studying patients undergoing colorectal surgery, the most improvement in SSI rates occurred when door openings were restricted. The largest effect was observed once compliance with OR door openings reached 80%. The adjusted odds ratio for developing an SSI was 36% lower at the end of the study period.[8] When Van der Slegt et al implemented this program in patients undergoing vascular surgery, the SSI rate was 51% lower at the end of the study period.[9] These data point to the larger concern that the culture in the OR supports activities that may have deleterious effects on patient outcomes and that there is new evidence supporting a reverse in processes decreases adverse patient outcome. Hence, the expectation that we need to improve processes during room changeover and patient arrival during the procedure should be embraced as important to improving patient outcomes.

Parikh et al noted that monitoring of OR traffic with staff knowledge in itself did not have a significant reduction in OR traffic.[14] Their 2-phase study showed no decrease in the numbers of door openings or traffic. In our study, personnel were aware of the monitor; however, they were not aware of the reason for collecting the data. Nevertheless, having an observer in the OR did not yield changes of practice. Engagement of the staff, feedback of data, and developing personal accountability and other quality improvement techniques are needed to implement sustainable change regarding door openings and traffic in these high-risk settings.

Our study, although provocative, has several limitations. First, we performed our study over a single week in the OR. We have no reason to suspect that there was less activity than normal, but there could be variations in volumes that affect the results. Second, our study was small, which may have contributed to some of the variation over time we identified. Additionally, we only used 1 particle counter for the study. This limited the analysis of airflow patterns where multiple counters could account for variation in airflow system design.

We did ensure the correct room pressure (ie, OR positive to the exterior hall), but we were unable to measure variations of the room pressure for our study. Third, no direct correlation between particulate matter and microbiologic contamination was explored. Several studies have questioned the relationship between APCs and microbiologic contamination.[15,16] We did not use microbiologic cultures to assess actual contamination as in other studies. Only assessing APCs, though frequently used as a surrogate for contamination, did not allow for study of organisms present in the OR. Fourth, we did not link the cases observed to surgical outcomes of the patient, which is the ultimate question to be answered. Because our study was small and limited to environmental factors for process improvement, patient-level factors were not included in the analysis. Finally, our study included a relatively small sample of cases (n = 7) in a single OR. Results of this homogenous setting limit generalization to multiuse ORs or differing configurations of OR architecture.

To enhance the quality of data and fill in gaps, further studies should examine links between microbiologic sampling, outcome data, and particulate matter in multiple settings to enable concrete study of risk factors and effects of personnel movement on surgical outcomes. Linking surgical APCs, microbiologic contamination, and outcome data will help demonstrate the true attributable risk of air quality to SSI. Additionally, studies across surgical disciplines or in multiuse ORs should be conducted to analyze the effects of different types of procedures and traffic patterns on APCs and microbiologic counts. Finally, additional studies that implement OR discipline and limit traffic and door openings are needed to demonstrate and refine the findings of previous investigators.

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