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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.

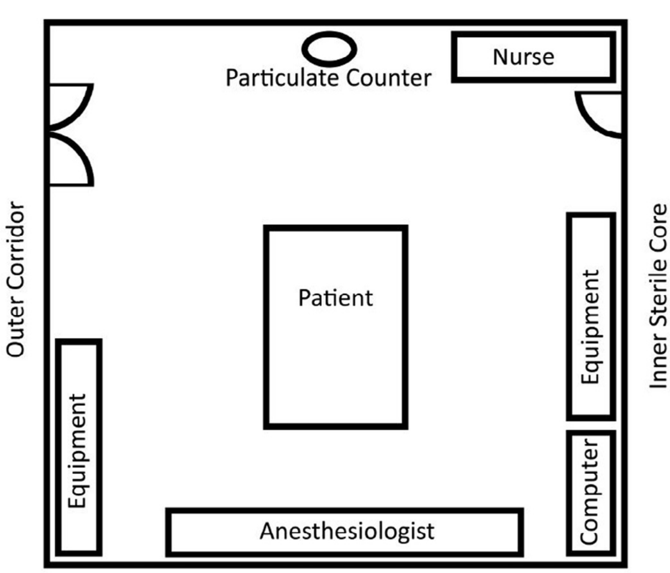

Fig 1. Operating room diagram and placement of particulate counter. This schematic represents the operating room where the APC measurements were performed and demonstrates the approximate placement of the particle counter within the operating room. Note: Not to scale.

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