Molecular epidemiology of microbial contamination in the operating room environment: Is there a risk for infection?

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Background. Modern operating rooms are considered to be aseptic environments. The use of surgical mask, frequent air exchanges, and architectural barriers are used to reduce airborne microbial populations. Breaks in surgical technique, host contamination, or hematogenous seeding are suggested as causal factors in these infections. This study implicates contamination of the operating room air as an additional etiology of infection.

Methods. To investigate the potential sources of perioperative contamination, an innovative in situ air-sampling analysis was conducted during an 18-month period involving 70 separate vascular surgical procedures. Air-sample cultures were obtained from multiple points within the operating room, ranging from 0.5 to 4 m from the surgical wound. Selected microbial clonality was determined by pulse-field gel electrophoresis. In a separate series of studies microbial nasopharyngeal shedding was evaluated under controlled environmental conditions in the presence and absence of a surgical mask.

Results. Coagulase-negative staphylococci were recovered from 86% of air samples, 51% from within 0.5 m of the surgical wound, whereas Staphylococcus aureus was recovered from 64% of air samples, 39% within 0.5 m from the wound. Anterior nares swabs were obtained from 11 members of the vascular team, clonality was observed between 8 strains of S epidermidis, and 2 strains of S aureus were recovered from selected team members and air-samples collected throughout the operating room environment. Miscellaneous Gram-negative isolates were recovered less frequently (<33%); however, 7 isolates expressed multiple patterns of antimicrobial resistance. The traditional surgical mask demonstrated limited effectiveness at curtailing microbial shedding, especially during symptomatic periods of rhinorrhea.

Conclusions. Gram-positive staphylococcal isolates were frequently isolated from air samples obtained throughout the operating room, including areas adjacent to the operative field. Nasopharyngeal shedding from person participating in the operation was identified as the source of many of these airborne contaminants. Failure of the traditional surgical mask to prevent microbial shedding is likely associated with an increased risk of perioperative contamination of biomedical implants, especially in procedures lasting longer than 90 minutes. (Surgery 2005;138:573-82.)

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IT IS ESTIMATED that of the nearly 30 million operations performed each year in the United States, 500,000 to 750,000 result in a surgical site infection for a rate approaching 2.5 per 100 operations, resulting in increased patient morbidity and mortality, 3.7 million extra hospital days, and a cost to the US healthcare system of $1.6 billion in excess hospital charges each year.[1-3] *Staphylococcus aureus* and the coagulase-negative staphylococci (CNS) are the major pathogens associated with infection of implantable biomedical devices.[4] The etiologic source of these infections has been suggested to be the patient's own endogenous skin or nasal flora, hematologic seeding after implantation of the device, or some break in perioperative aseptic

Cascade Impactor Placement in Vascular Operating Room
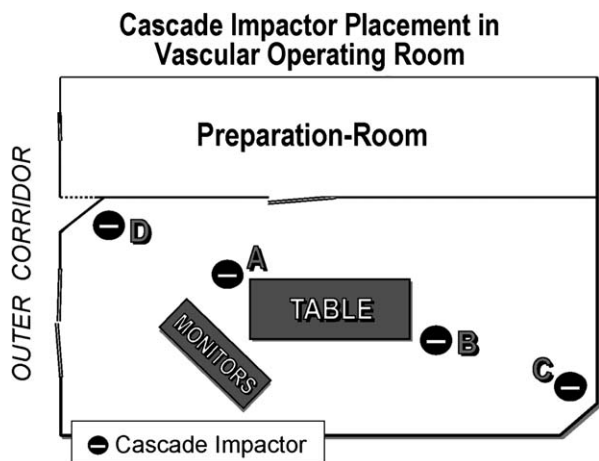
Fig 1. Schematic of vascular operating room with positioning of cascade impactor noted as *A, B, C,* and *D.*

Fig 2. Schematic of air-sampling device with 0.45-μm microbial filter; filter is aseptically removed from air-sampling device and placed on surface of agar plate and incubated for 48 hours for microbial recovery.

technique.[4-7] Because of their sequestered location in the hospital, multiple air exchanges (>15 per hour), and requirement that personnel entering the operating room wear a face mask, operating rooms are viewed as having a reduced microbial burden compared with other patient care areas. We have previously demonstrated that during the intraoperative interval, selected microbial populations can be recovered from the operating room air.[8]

Although there is no specific consensual standard for airborne microbial contamination within the operating room, the risk is perceived to increase as airborne microbial counts exceed 36 to 150 colony-forming units (cfu) per m^3 of sampled air.[9]

Recent studies have suggested that skin and nasal shedding by members of the surgical team might be a selected risk factor for perioperative contamination and subsequent infection.[10-13] Those studies have been facilitated by the use of molecular epidemiologic tools such as pulse-field gel electrophoresis (PFGE), allowing investigators to identify clonality patterns of transmission and sources of selected surgical site infections. The following investigation was undertaken to identify the potential sources and mechanism of contaminating microbial aerosols during the perioperative interval.

MATERIAL AND METHODS

The study protocol was reviewed and approved by the Medical College of Wisconsin-Froedtert Memorial Lutheran Hospital Institutional Review Board. Informed consent was obtained from members of the vascular surgical service before obtaining nasal cultures and from volunteers participating in the surgical mask study. During an 18-month period, i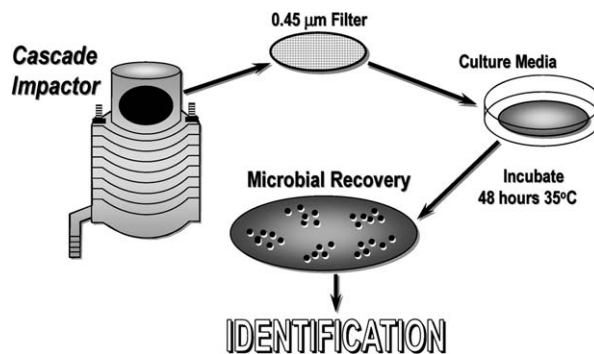ntraoperative airborne cultures were obtained during 70 separate vascular reconstructive procedures by using an innovative sampling device, a personal cascade impactor. Four devices were positioned within the vascular operating room suite (Fig 1). Two air-samplers were positioned 4 to 5 m from the surgical field, and 2 devices were positioned on intravenous poles, 0.5 to 1 m from the surgical field. Environmental conditions (temperature, humidity, and air changes) within the operating room were not altered during the study interval. The sampling devices were attached to an external pump, which was turned on at the start of each operation and turned off after wound closure. Before each sampling interval, the impactor devices and pumps were calibrated to an airflow rate of 2 L per minute, and the mean sampling time was 4.3 hours. After each surgical procedure, the impactor was conveyed to a sterile hood, where a 0.45-μm filter was removed and placed aseptically on the surface of trypticase soy agar, supplemented with 5% sheep blood and incubated at 35°C for 48 hours. The sampling process is demonstrated in Fig 2. Individual colonies recovered from each impactor were identified by standard methods, and antimicrobial susceptibility studies were performed on selected microbial populations.[14] After each sampling interval, the devices were completely disassembled, and all components were immersed in 70% alcohol for 10 minutes. After sterilization, a new 0.45-μm microbiologic filter was aseptically positioned in place, and the device was reassembled.

Nasal cultures were obtained from 11 individuals members of the vascular surgical team. Cultures were taken from the distal 1 cm of the anterior nares with a circular motion by using a sterile polyester fiber–tipped swab moistened with saline. The swabs were placed in 5 mL of trypticase soy broth and vortexed for 10 seconds, followed
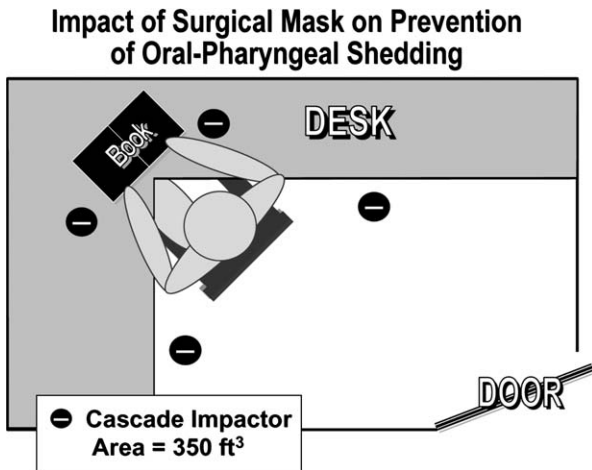
Impact of Surgical Mask on Prevention of Oral-Pharyngeal Shedding

Fig 3. Position of volunteer in environmentally controlled chamber with 4 impactor devices positioned around subject for airborne microbial recovery.

by plating on trypticase soy agar with 5% sheep blood. Plates were incubated for 48 hours at 35°C. Colonial morphology consistent with the staphylococci was Gram-stained and tested for catalase and coagulase activity. Selected strains of CNS were further differentiated to identify isolates of *S epidermidis.*

Selected Gram-positive isolates were evaluated by the PFGE method described by Smith and Cantor[15] with some modification. Briefly, cells were suspended in buffer (0.01 mol/L Tris-HCL pH 7.6, 1 mol/L NaCl) to an optical density (OD_{600}) of 0.16 to 0.25 and mixed with equal portion of 2.4% low melting point agarose made up in the same buffer. Cells suspended in agarose buffer were lysed at 37°C overnight in lysis buffer (0.006 mol/L Tris-Hcl, 1 mol/L NaCl, 0.1 mol/L ethylenediaminetetraacetic acid pH 7.6, 0.2% sodium desoxycholate, 0.5% N-lauryl sarcosine) with 1 mg/mL lysozyme hydrochloride and 50 μg/mL lysostaphin. The cells were digested overnight with *Sma*I enzyme, and fragments were separated electrophoretically (60 V, 14°C, with pulse times of 3 and 25 seconds for 24 hours). PFGE bands were interpreted as follows: major types differing by 3 or more bands were determined to be unrelated, whereas subtypes differing by fewer than 3 bands were considered as related or identical.[16]

To study the impact of the surgical mask on microbial shedding, 30 volunteers wearing surgical scrub suits, disposable sterile gowns, hair covers, shoe covers, and sterile gloves were positioned within a 350-ft^3 environmental chamber with 4 air-sampling devices (Fig 3). Environmental conditions (temperature, humidity, and air exchanges)

within the chamber mimicked those found in the operating room. The subjects were asked to spend 3 hours in the chamber on 2 different days. On day 1, the volunteer sat at a table and alternated reading aloud and silently for 15-minute intervals for a total of 180 minutes. At the end of 90 minutes, 2 impactor devices were removed, and the filters were processed for culture. The subject continued the exercise for an additional 90 minutes, at which time the final 2 sampling devices were taken to the laboratory for culture. On day 2, the experiment was repeated, except this time the volunteer wore a standard surgical tie-back mask. Before volunteers entered the chamber, the surgical mask was checked to ensure that it was tied properly, covering the bridge of the nose and extending under the chin. It was noted at the time of sampling that 8 volunteers were experiencing rhinorrhea ("cold-like" symptoms). Rather than exclude these subjects from the study, the results were analyzed as an independent group. Microbial recovery was expressed as cfu/m^3 of sampled air.

RESULTS

The percent intraoperative recovery of airborne microbial populations is demonstrated in Fig 4. Selected strains of CNS were recovered from 60 of 70 (85.7%) vascular reconstructive procedures, and in 36 (51.4%) of these operations CNS were recovered within 0.5 to 1 m from the surgical wound. One third of all CNS were identified as *S epidermidis* (N = 32). At least 1 isolate of *S aureus* was recovered from 42 of 70 (60%) vascular procedures. A higher incidence of recovery was actually observed from airborne samples collected adjacent to the operative field (27 of 70 vascular procedures; 38.5%) compared with the more peripheral areas of the room (18 of 70 procedures; 25.7%). Additional Gram-positive commensal bacteria, including *Micrococcus* spp, *Corynebacterium* spp, and *Bacillus* ssp, were recovered at varying frequency from samples collected within 1 m of the operative field and in the periphery of the room (4 to 5 m from the operative field). The quantitative recovery of *S aureus* and *S epidermidis* from sampled operating room air ranged from 12.5 to 41.5 cfu/m^3 and 19.6 to 58.6 cfu/m^3 of sampled room air, respectively.

Several Gram-negative bacteria were recovered during the perioperative sampling period (23 of 70 operations, 32.8%) including *Stenotrophomonas maltophilia, Burkholderia cepacia, Aeromonas* species, and 3 miscellaneous pseudomonal species (Fig 4). At least 3 of these isolates, *Stenotrophomonas, Burkholderia,* and *Aeromonas* were identified as originating
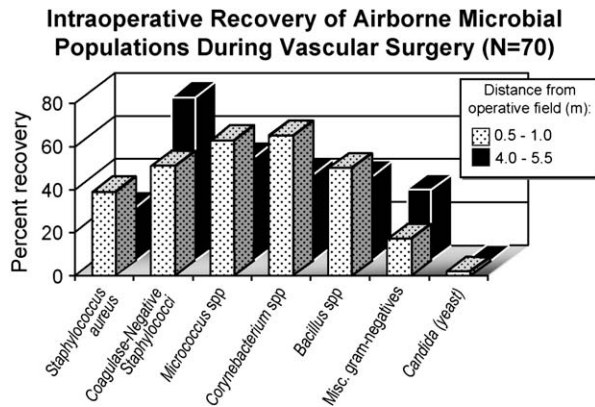
Fig 4. Percent intraoperative recovery of airborne microbial populations during 70 reconstructive vascular procedures.

Fig 5. PFGE of clonally related strains of *S epidermidis* and *S aureus* recovered from members of the vascular surgical team and perioperative airborne sampling. *Lanes 3a/3b* and *4a/9a*, *S epidermidis* clonality; *lanes 7a/7b* and *1a/1b/1c/1d*, *S aureus* clonality.

from a utility sink, entering the operating room as an aerosol when the faucet was turned on. Seven of these strains expressed multiple patterns of antimicrobial resistance, encompassing several drug groups such as the aminoglycosides, β-lactams, and fluoroquinolones. Yeasts were recovered at a relatively low frequency (2 of 70 surgeries; 2.8%) compared with Gram-positive and Gram-negative microbial recovery. The quantitative recovery of ;miscellaneous Gram-negative bacteria, such as *Burkholderia* and *Stenotrophomonas*, from operating room air ranged from 8.4 to 29.6 cfu/m^3 of sampled room air. Before the perioperative studies, overnight qualitative and quantitative sampling was conducted in the same operating room to establish baseline (control) values when the room was empty. The predominant microbial populations recovered included *Micrococcus* species, *Bacillus* species, and *Corynebacterium* species in less than 30% of samples, regardless of impactor positioning. The baseline (control) quantitative microbial recovery ranged from 2.9 to 3.8 cfu/m^3 of sampled room air.

Anterior nares cultures of the 11 operating room personnel recovered a total of 15 CNS isolates and 4 isolates of *S aureus*. In total, 13 unique staphylococcal clones were recovered in culture of the anterior nares, 10 unique clones of S *epidermidis* and 3 unique clones of *S aureus*. Four members of the surgical team actually harbored identical strains of *S epidermidis*, whereas 3 team members, a nurse and 2 surgeons, harbored an identical strain of methicillin-sensitive *S aureus*. A comparison of *S aureus* and *S epidermidis* isolates recovered during perioperative operating room air sampling revealed 8 distinct clones of *S epidermidis* and 2 clones of *S aureus* that presented with identical or similar bands
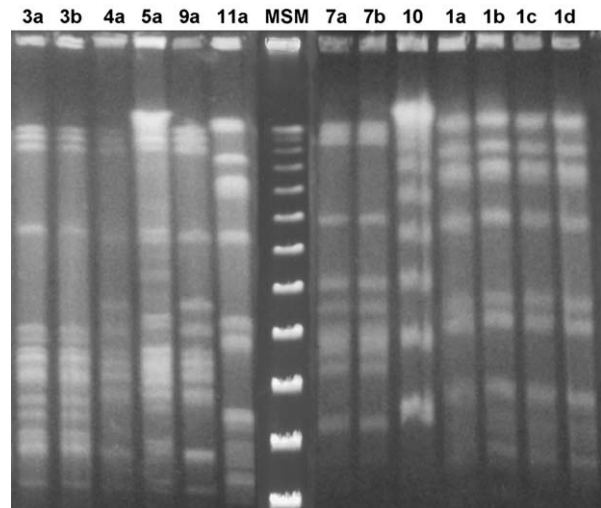
to strains recovered from nasal cultures of members of the vascular surgical team. The PFGE in Fig 5 demonstrates the clonality that was observed between staphylococcal isolates recovered from nasal cultures and organisms recovered during perioperative airborne sampling. Lane 3a is from a nasal isolate (vascular staff surgeon) of *S epidermidis*, and lane 3b was obtained from an impactor that was positioned less than 1 m from the operative field. The PFGE pattern observed in lane 4a (operating room staff nurse nasal culture) is identical to that of a strain of *S epidermidis* recovered from an impactor positioned in the outer edge of the room (lane 9a). Lanes 5a and 11a were both recovered from air-sampling devices positioned within 1 m of the surgical field, but they expressed no clonality with strains recovered from members of the vascular team. Lane 7a demonstrates the PFGE banding pattern from an *S aureus* isolate recovered from a vascular surgeon, and lane 7b represents the identical strain recovered from air collected 4 to 5 m from the operative field. Lanes labeled 1a through 1d represent complete clonality between a nasal isolate of *S aureus* (vascular fellow; 1a) and 3 other isolates (1b to 1d) recovered from impactor devices positioned 0.5 to 5 m from the operative field.

Figure 6 documents the impact of the standard tie-back surgical mask to prevent microbial shedding. In the presence of no mask, the mean nasopharyngeal shedding was measured to be 12.5 cfu/m^3 at 90 minutes, whereas microbial shedding was measured to be 5.6 cfu/m^3 when a surgical mask

Impact of Surgical Masks on Prevention of Microbial Nasopharyngeal Shedding in Healthy (N = 22) Individuals and Subjects with Symptoms of Rhinorrhea (N = 8)
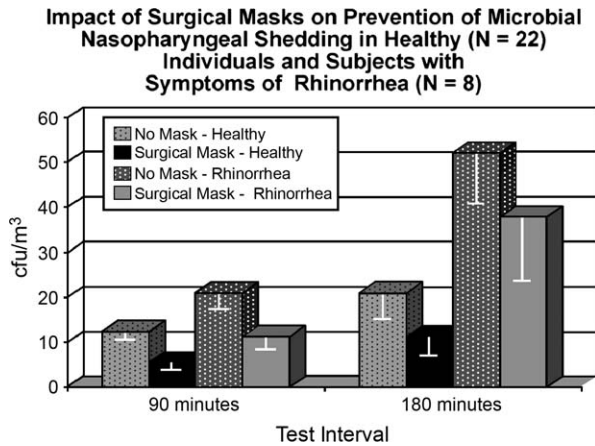

Fig 6. Impact of the standard tie-back surgical mask on prevention of microbial nasopharyngeal shedding in healthy volunteers (N = 22) and subjects with symptoms of rhinorrhea (N = 8).

was worn during the same time interval ($P < .05$). As the study time was extended, mean microbial shedding increased to 21.8 cfu/m^3 at 180 minutes in the no mask group compared with 12.3 cfu/m^3 when a surgical mask was worn for 3 hours ($P = .07$). These findings document that the standard surgical mask was effective at reducing nasopharyngeal shedding; however, the actual cfu/m^3 value in the "mask" group at 3 hours was more than double (2.1-fold increase) the counts obtained at 90 minutes. In a subset of volunteers who exhibited symptoms of rhinorrhea, the colony counts per m^3 of sampled air were significantly elevated in both study groups. At 90 minutes, mean nasopharyngeal shedding in subjects with rhinorrhea wearing no mask was 24.3 cfu/m^3 compared with 11.2 cfu/m^3 ($P < .05$) in the surgical mask group. At 3 hours, mean microbial shedding increased 2.3-fold to 53.8 cfu/m^3 in the no mask group compared with a 3.4-fold increase or 37.8 cfu/m^3 in volunteers wearing the standard surgical mask ($P < .58$). Although a significant difference was observed in mean microbial shedding in mask versus the non-mask groups at 90 minutes, no significance difference was observed in mean microbial counts at 3 hours between groups.

DISCUSSION

The airborne transmission of an infectious agent as the etiologic event in the development of postoperative surgical site infection has been largely ignored in favor of a more traditional pathway involving direct contact contamination, a break in aseptic practice, or possibly the involvement of the patient's own flora in postoperative

wound sepsis. Although it is technically easier to measure microbial contamination in water or on the hands of healthcare practitioners, there is increasing evidence that airborne transmission of microbial populations might play a greater role in postoperative infections, especially those involving biomedical devices. The possibility that airborne transmission of bacteria might occur within the healthcare environment has significant clinical implications for infection control practices within the operating room environment.

It has been reported that normal skin flora of patients or healthcare workers causes more than half of all surgical site infections after clean surgical procedures.[10,17,18] The importance of airborne transmission as a mechanism for microbial contamination and infection is a considerable source of debate and controversy.[19-23] The present study documents that during the perioperative period, under optimal environment conditions and air exchanges (>15 per hour) a myriad of microbial populations can be recovered from sampling points throughout the operating room, including areas adjacent to the surgical field. Results from other studies with settling plates or short duration, large volume air-sampling devices are often difficult to interpret because there is no universal consensus for acceptable levels of microbial contamination in the operating room.[9] However, an analysis of the potential risk would need to be tempered by the type of procedures performed within the specific operating room environment. Our findings revealed that during 70 reconstructive vascular procedures, CNS and *S aureus* were recovered from 85.7% (60 of 70) and 60% (42 of 70) of respective vascular procedures. Many of these isolates were recovered from within 1 m of the operative field. The major microbial pathogens associated with acute-onset and late-onset prosthetic vascular graft infections are decidedly Gram-positive; therefore the high incidence of *S aureus* and *S epidermidis* recovery in the present study from areas adjacent to the operative field suggests that airborne microbial populations might be a specific risk factor in selected surgical procedures, such as implantation of biomedical devices. Although the 4 strains of *S aureus* recovered from the 3 members of the vascular surgical team were methicillin-sensitive, the CNS expressed a wide range of antimicrobial resistance, such as methicillin and quinolone resistance.

The clonal linkage between airborne bacteria and microbial shedding by members of the vascular surgical team clearly suggests that the risk of infection is not limited to the patient's own endogenous skin flora. In a recent communication,

an outbreak of 7 surgical site infections was attributed to a single healthcare professional who, while caring for these patients, experienced symptoms of chronic sinusitis, shedding methicillin-resistant *S aureus* (MRSA). PFGE of isolates recovered from patient wound cultures and nasal cultures obtained from the practitioner documented all strains to be epidemiologically related.[13] In another published study, the spread of coagulase-negative bacteria was investigated prospectively in 20 cardiac surgical procedures (coronary artery bypass and valve replacement). Cultures were obtained from both the patients (nasal, presternal skin, groin, and incisional wound) and the operating room personnel (nose, forehead, forearm, and groin) before scrubbing. Wound contamination by CNS was observed in 12 of 20 (60%) surgical procedures. Furthermore, the authors demonstrated by molecular typing (PFGE) that flora shed from members of the surgical team could be recovered from the wound bed closure.[10] A study conducted in patients receiving total hip arthroplasty documented by polymerase chain reaction that wound contamination occurs frequently in both standard and ultra-clean laminar flow operating rooms.[24] Therefore, on the basis of molecular studies it would appear that the operative team members make a significant contribution to the airborne Gram-positive microbial burden within the operating room.

There are 3 probable mechanisms for Gram-positive airborne contamination within the operating room: (1) barrier failure of the surgical mask worn by members of the operative team as a result of venting over the bridge and sides of the mask, (2) direct room contamination by non-masked personnel, and (3) the patient's own flora. Previous studies have suggested that a synergy exists between microbial shedding and concomitant upper respiratory tract infection caused by viral etiology. Coughing and sneezing have been shown to be associated with airborne dispersion of *S aureus* and *S epidermidis* in volunteers infected with rhinovirus.[12,24] It is obvious that failure of the traditional surgical mask to prevent microbial shedding is exacerbated in surgical personnel with rhinorrhea or flu-like symptoms. Our study documented that the barrier properties of the standard tie-back surgical mask appear to be most effective during the first 90 minutes compared with a longer interval of use. Furthermore, our studies would also suggest that there was a 2-fold to 3-fold difference in microbial nasopharyngeal shedding in healthy volunteers with masks compared with masked subjects experiencing symptoms of rhinorrhea.

The secondary finding that Gram-negative bacteria, representing multidrug-resistant strain, were present in the room air during the perioperative period is also problematic, especially in light of the source of this contamination. Selected Gram-negative bacteria such as *Stenotrophomonas* and *Burkholderia* are significant pathogens associated with healthcare-associated infections involving vascular-access devices or ventilator-associated pneumonia in high-risk patient populations.[26] The origin of these 2 contaminants would suggest that environmental factors distant to the operating room, while unexpected, might also influence patient morbidity.

To date, there have been no infections detected in any of the 70 patients in whom perioperative airborne samples were conducted. Although the study was designed primarily to evaluate the etiology and prevalence of selected microbial aerosols by using an innovative sampling technique, the methodology could be used in a larger operative series to correlate airborne microbial recovery with wound contamination or surgical site infection. However, the present study did reveal that perioperative airborne contamination in the operating room involves both Gram-positive and Gram-negative bacteria, that many of the Gram-positive strains recovered from the operating room air are clonally related to nasopharyngeal flora, colonizing selected members of the surgical team, and that barrier failure of the surgical mask likely exacerbates the nosocomial airborne bioburden in the operating room environment.

What implications can we draw from these findings? First, the presence of *S aureus* in the nares of members of the surgical team should not necessarily trigger the immediate use of mupirocin. Current studies suggest that mupirocin should only be used to decolonize healthcare professionals who are directly or indirectly implicated as possible point-sources in a nosocomial outbreak. Widespread and indiscriminate use of this agent has been associated with resistance and, therefore, reduced therapeutic efficacy. Second, it is obvious that the barrier properties of the traditional surgical mask break down rapidly, enhancing perioperative nasal shedding. At a minimum, we should consider changing our surgical mask at an appropriate interval (60 to 90 minutes), especially if members of the surgical team are symptomatic for rhinorrhea. Finally, because no patient nares were cultured during the study, it is unknown what, if any, percentage of the patient's own intrinsic flora was recovered during perioperative air sampling. However, the PFGE findings strongly

suggest that intraoperative microbial shedding originating from the surgical team comprises a component of the potential contaminating flora present in the operating room air. This is potentially problematic, especially during implantation of a biomedical device, because even casual contamination might pose a significant risk for infection in selective patient populations. Therefore, strategies that would limit extraneous exposure of these devices to operating room air before insertion should be considered by members of the surgical team.

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DISCUSSION

Dr Mark A. Malangoni (Cleveland, Ohio). This study has frightening implications. You conclude that operating room personnel regularly shed bacteria from their nasal passages into the operating room air on the basis of a very sophisticated system for sampling of the operating room air. The analysis of the recovered species strongly links these contaminants to the operating room personnel, in particular the operative surgeon. Now, these observations are not new. William Beck, Harold Laufman, and others studied this same phenomenon more than 30 years ago. However, the technique of linking the personnel to the source of the bacteria is much more sophisticated than existed at that time.

Fortunately, none of these patients in the 70 operations that were done developed an infection, as I understand it. One has to ask the obvious question: why not?

You mentioned how ventilation systems are constructed. Just to recount briefly, the air enters over the patient on the operating room table, and then the air

flow patterns are such that the air goes away from the patient and away from the operating table to the sides of the room and toward the floor where the return air systems exist. So haven't you just demonstrated that this modern system works? I don't mean to be nihilistic about this sophisticated study, but no patient got infected.

So what you have demonstrated is that these contaminants are really present away from the operating room table. I would have been more convinced if you would obtain a way to sample directly over the patient. I am sure you can't put one of these cascade samplers over the patient, but there must be some other way to sample the patient.

Are you convinced that the operating room personnel were the clear source of the contamination, or could they have been contaminated by being in that operating room day after day and hence picked up bacteria that were present in the overall environment?

I was interested why you thought that more CNS and Gram-negative bacteria were recovered farther from the patient. You mentioned that aerosolization was implicated with the Gram-negative bacteria, but did the same hold for CNS? I wouldn't have expected that.

Also I think I would have been more convinced if you would have a control group where you could actually sample in an operating room that didn't have personnel in it, so we knew what the background contamination was.

I also have some comments about the surgical masks. We are all aware that these masks are designed so that the exhaled air exits from the side vents, away from the patient. In this case you would expect that the sampling location that was behind the test person in the operating room environment would recover bacteria. So was there a difference between the air sampled in the sampling systems alongside the test person and those that were farther away?

Last, what recommendations do you have for the surgeon who has an upper respiratory infection and rhinorrhea? Should they wear a different type of mask? Would you recommend that they just don't operate that day?

Dr Edmiston. First of all, many of the Gram-negative bacteria that were recovered, such as *Burkholderia cepacia* or *Stenotrophomonas maltophilia,* are ubiquitous to the hospital environment, quite often recovered from tap water, nebulizers, water baths, etc. In the case of this study we were able to identify a utility sink in an adjacent room as the source of aerosol contamination in the operating room. The Gram-positive bacteria are less likely to be associated with a point water source, but rather they originate from members of the operative team.

In terms of your comment on clinical relevance, this question comes up quite frequently. First of all, we must recognize that the primary pathogens associated with device-related infection are decidedly Gram-positive, most often involving the staphylococci. Second, although some of these infections such as acute-onset vacular graft infections often present within 7 to 21 days, late-onset vascular graft infections occur weeks, months, or even years postimplantation. It is our opinion that these organisms gain access to the prosthetic device at the time of insertion, in part because of nasopharyngeal shedding, contaminating the wound bed perioperatively.

This study, much like the study we presented last year in Chicago, was not designed as an infection study but rather to investigate the potential sources of microbial aerosols that could in fact contaminate the operative field. Our use of a standard molecular methodology to characterize the point source of many of these aerosols represents the present trend in studying the molecular epidemiology of surgical infections. Several articles, which are cited in this manuscript, reveal the obvious value of using such methodology to track and identify potential nosocomial sources of infection. A recent case report by Faibis and colleagues[13] documented by PFGE 7 surgical site infections involving MRSA in 2 surgical wards that were clonally related to a strain of MRSA carried by a healthcare worker with chronic sinusitis. The investigation clearly documented that the 7 patients contracted the infection during the perioperative period through airborne contamination.

The question often raised is, Are laminar flow (clean) rooms better than the usual operating room in which multiple air changes occur in a 60-minute period? The data would suggest not. Two recent publications, one from a Scandinavian and the other from an Italian investigator, have demonstrated that the "barrier of air" strategy cannot prevent intraoperative contamination, especially in regard to nasopharyngeal shedding. The laminar flow environment does not truly exist in the operating room, because the "barrier of air" is continuously broken by the monitors, lights, and by the movements of the operative team in and out of the field. We tried to position our collection devices in areas that covered both the operative field and peripheral areas of the room. In this manner we felt confident that the microbial populations that were captured were representative of what was in the room air during the perioperative period.

Although the mask study clearly demonstrates the failure of the traditional surgical mask to inhibit nasopharyngeal shedding, especially after 90 minutes, this sampling involved one individual at a time. Imagine the microbial burden created in the fully staffed operating room. During our operating room sampling study there were between 5 to 8 team members per operation, stationary or moving throughout the room, all shedding microorganisms from the nasopharyngeal or exposed skin surfaces, creating a potential source of intraoperative contamination. Unfortunately, there is no consensual agreement as to what would be a threshold aerosolized microbial burden in the operating room. The Europeans have attempted to address this issue, suggesting that a microbial burden of 35 to 180 cfu/m^3 of room air represents a risk for infection; this is, however, based on 20- to 30-year-old data and does not

take into consideration the widespread implantation of biomedical devices in today's surgical practice. I think as a bottom line we need better surgical masks, especially masks that maintain their barrier properties over time. In Lisbon, Portugal, surgeons are encouraged not to operate if they have a cold. Would that work in this country? Probably not.

Finally, if the wound bed is being continually assaulted with these contaminating aerosols, which for selected patients represents a significant risk, then maybe the use of antiseptic-impregnated devices such as suture material, mesh, or other prosthetic devices might by virtue of innovative technology play an adjunctive role in reducing the overall risk of surgical site infections.

Dr Thomas A. Stellato (Cleveland, Ohio). This is really a tremendous and intriguing study. Getting back to the question about the masks, can you express your opinion about the idea of perhaps changing your mask? The masks seem to break down at 3 hours. Should you put on a new mask at 2 hours or use a double mask, especially if you have an upper respiratory infection?

Do you have any thoughts about whether the air exchanges actually do make a difference? Could you look at that?

Finally, I have always been amazed by the fact that there is always one person in the operating room who never wears a mask, and that is the patient. Can you give me your thoughts about that?

Dr Edmiston. If I could make a single recommendation based on our findings and one that I believe that most practitioners would readily accept, that would be to change your mask after 90 minutes. If you have rhinorrhea, consider the microbial burden that you are contributing to room air and possibly even the wound bed. Imagine yourself leaning over the wound positioning a vascular prostheses or even a mesh. It doesn't take a great deal of imagination to consider the potential consequences.

Air exchanges, do they make a difference? There were some wonderful papers published in the late 60s and early 70s, the early days of total joint procedures, some from the Mayo experience, clearly showing that increasing the number of air exchanges per hour does make a difference. I also believe it makes a difference but only up to a certain point. There is, no doubt, room for improvements in both surgical mask design and efficacy; reducing the risk of intraoperative device contamination should be viewed as a priority.

Dr Joseph F. Buell (Cincinnati, Ohio). Vancomycin-resistant enterococcus was demonstrated in a study we performed at the University of Chicago, which is an infection transferred by topical vectors. Our patients who had liver transplant were infected during their stay in the intensive care unit. These were surface contaminations that were confirmed in a prospective study. So the question I pose is, Are there ways to rid the intensive care unit of topical infections?

MRSA has been a considerable problem. England had a large outbreak of MRSA. What was done was culturing of all asymptomatic individual surgeons, and when found, they were prevented from operating until they were treated and cleared of MRSA.

In England, if you are doing laparoscopy, you do not need to be masked. The only time that you need to be masked in an operating theater is when you are doing an open surgical case. When they stopped the MRSA-contaminated surgeons or individuals in the operating room from operating, they cleared their MRSA infections. Is that something that we need to consider, or should we not even contemplate this?

Dr Edmiston. In the interest of time, let me direct you to some of the works of Drs Sherertz,[22] Bassetti,[25] and Bischoff,[12] who have clearly shown that an intimate relationship exists between nasopharyngeal microbial shedding and viral (*Rhinovirus*) infection of the upper airway. It is apparent that the symptoms (coughing and sneezing) associated with rhinovirus infection exacerbate the airborne dispersion of both coagulase-negative and coagulase-positive staphylococci. As we observed from our face mask study, microbial shedding was significantly increased (>3-fold at 3 hours) in the rhinorrhea group compared with healthy individuals.

Your comment concerning mupirocin was well-taken; however, studies have shown that if you use this agent indiscriminately and attempt to decolonize everyone, then resistance to the drug increases significantly, reducing its potential value in the future. The most effective application of this compound is to only use it to decolonize documented carriers of MRSA who are directly involved in an outbreak or management of high-risk patient populations. However, some surgical specialties (cardiothoracic, orthopedic, and vascular) have proposed using it to decolonize high-risk patients before operation.

Dr. C. Max Schmidt (Indianapolis, Ind). Have you thought about doing surgical site cultures and perhaps surgical site cultures as a function of duration of operation? With this information you might be able to correlate your findings of what is aerosolized close to the surgical site with the bacteria that are actually in the surgical site itself. If you haven't done this, has anybody done this in a similar study format?

Dr Edmiston. If you look at the literature, you will find studies that suggest wound contamination rates varying from 15% to 100% at the time of closure. Actually what you are describing was done by a group of orthopedic surgeons in England, where by using the polymerase chain reaction technique they attempted to correlate wound contamination with eventual infection. It was quite an exquisite approach, and although their findings were somewhat mixed, it is a study that should be repeated in a larger sample. However, if you look at the current infection rates for selected biomedical implantable devices (2.5% to 3.7%), it would take a rather large series of patients to give you meaningful results.

In essence what we have attempted to do in presenting this study is to raise the awareness among our surgical colleagues of the potential risk for intraoperative

contamination through a mechanism of microbial shedding from members of the surgical team. In those patients who might be receiving a biomedical implant, the risk is much more problematic. Although we have often viewed in the past the patients' own flora as a mitigating factor associated with most surgical site infections, the present findings would suggest that members of the operative team make a significant contribution to the microbial burden present in operating room air.

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