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Major Article

Wearing long sleeves while prepping a patient in the operating room decreases airborne contaminants

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Background: The use of long sleeves by nonscrubbed personnel in the operating room has been called into question. We hypothesized that wearing long sleeves and gloves, compared with having bare arms without gloves, while applying the skin preparation solution would decrease particulate and microbial contamination.
Methods: A mock patient skin prep was performed in 3 different operating rooms. A long-sleeved gown and gloves, or bare arms, were used to perform the procedure. Particle counters were used to assess airborne particulate contamination, and active and passive microbial assessment was achieved through air samplers and settle plate analysis. Data were compared with Student's *t*-test or Mann-Whitney U, and $P < .05$ was considered to be significant.
Results: Operating room B demonstrated decreased 5.0- μm particle sizes with the use of sleeves, while operating rooms A and C showed decreased total microbes only with the use of sleeves. Despite there being no difference in the average number of total microbes for all operating rooms assessed, the use of sleeves specifically appeared to decrease the shed of *Micrococcus*.
Conclusion: The use of long sleeves and gloves while applying the skin preparation solution decreased particulate and microbial shedding in several of the operating rooms tested. Although long sleeves may not be necessary for all operating room personnel, they may decrease airborne contamination while the skin prep is applied, which may lead to decreased surgical site infections.

Wearing surgical scrubs in the operating room has been standard since the middle of the 20th century. Multiple studies have evaluated the type of fabric used for scrubs, as well as whether the cuffs and ankles should be tucked in, whether boots should be worn, and where the scrubs should be laundered.[1–4] However, the use of only certain articles of surgical clothing, such as sterile gloves and impervious surgical gowns, has been shown to reduce surgical site infections.[5–9] In fact, the most beneficial factor in the modern operating room has been the development of appropriate and effective ventilation strategies, which help cleanse the air and reduce bacterial load.[10,11]

Although much attention has been devoted traditionally to the immediate bedside surgical team, concerns regarding overall operating room cleanliness have shifted the focus to other care members within the clean space. Previous studies have revealed that simple movements by operating room personnel can generate a fairly large number of airborne particles.[12] In 2004, the Association of periOperative Registered Nurses (AORN) began to recommend that long sleeves be worn by these personnel under the premise that the long sleeves would capture epithelial skin cells, which tend to carry bacteria.[13] They thought that this practice might reduce surgical site infections. Furthermore, the current policy recommendation from AORN is that the individuals who apply antibacterial skin prep immediately prior to surgery do so wearing long sleeves and gloves.[14] These "sleeves" are typically warm-up jackets or nonsterile gowns.

Studies with clothed and unclothed individuals in the operating room suggested that clothed individuals may actually disperse more bacteria.[15] The theory surrounds the notion that the friction

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of the clothes increases skin cell and bacterial dispersal. Given the conflicting data in the literature regarding the effectiveness of wearing long sleeves while performing skin preparation before surgery, we elected to review several environmental quality indicators. We hypothesized that wearing a long-sleeved gown and gloves during skin prep would decrease airborne contaminants, compared with standard scrubs with bare arms exposed.

METHODS

Study design

An experimental study was performed to assess the utility of long-sleeved gowns and gloves in reducing the particle and bacterial load over the operating room table during standard preoperative skin prep. Two experimental groups were studied: "Sleeves," in which the prepping individual wore a long-sleeved sterile gown with sterile gloves; and "Bare Arms," in which the prepping individual did not wear a long-sleeved gown or gloves. Particle contamination as well as bacterial load were assessed (see below).

Location

In order to better translate the results of this study across multiple institutions, one operating room at each of 3 hospitals was used for experimentation. Two operating rooms were within academic medical centers (A and B), and one was an outpatient surgery center (C). All had high-efficiency particulate air (HEPA) filtration systems and measured 638, 554, and 415 square feet, respectively. All rooms were maintained at approximately 25 air changes per hour for the study. Studies took place from February to July of 2017.

Personnel

The study team consisted of a surgeon, a microbiologist, 2 engineers specializing in heating, ventilation, and air conditioning, and an industrial air hygienist. The surgeon, microbiologist, one engineer, and the air hygienist were present in the room during the studies. The surgeon was responsible for performing the mock prep procedure; the microbiologist and engineer deployed and monitored the surface air samplers and settle plates to collect bacterial data; and the air hygienist monitored the particle counter for particle assessment. The microbiologist, engineer, and air hygienist approached the operating room table only to tend to their equipment, and then backed slowly away to the periphery of the room. The additional engineer was outside of the operating room and insured that the room temperatures and air velocities were consistent throughout the procedures and between sites. Study personnel wore standard, hospital-issued, clean scrubs, masks, head covers, and shoe covers.

Mock prep of patient

A mock skin prep procedure was designed to cover the area of the operating room table, in the location where a normal adult patient's abdomen would be during surgery (Fig 1). An actual patient was not utilized, so that instrumentation could be in the sterile field, and to avoid contamination of the sterile field with the patient's native flora. Additionally, we wanted to ensure that we measured only the flora of the prepping person. The mock skin prep lasted 11 minutes, to allow adequate capture of environmental contaminants. During that time, the prepping surgeon (TAM) held a chlorhexidine skin prep stick and moved his hands back and forth over the patient in a fashion similar to what would be done for a routine skin prep for surgery. The mock skin prep encompassed the whole prep zone (Fig 1). In each of 3 operating rooms, a total of 4 experiments were performed. In 2 of these experiments, the prepping surgeon wore a sterile gown and gloves that were provided by the institution (Sleeves). In the other 2 experiments, only the scrubs were worn, without a jacket, gown, arm covers, or gloves ("Bare Arms"). Experiments were alternated—Sleeves, Bare Arms, Sleeves, Bare Arms—at each institution. A total of 6 experiments with Sleeves, and 6 with Bare Arms were performed for the entire study.

Particles

Particle contamination was measured using a Climet Model CJ-750T 75 LPM particle counter. The particle counter was placed

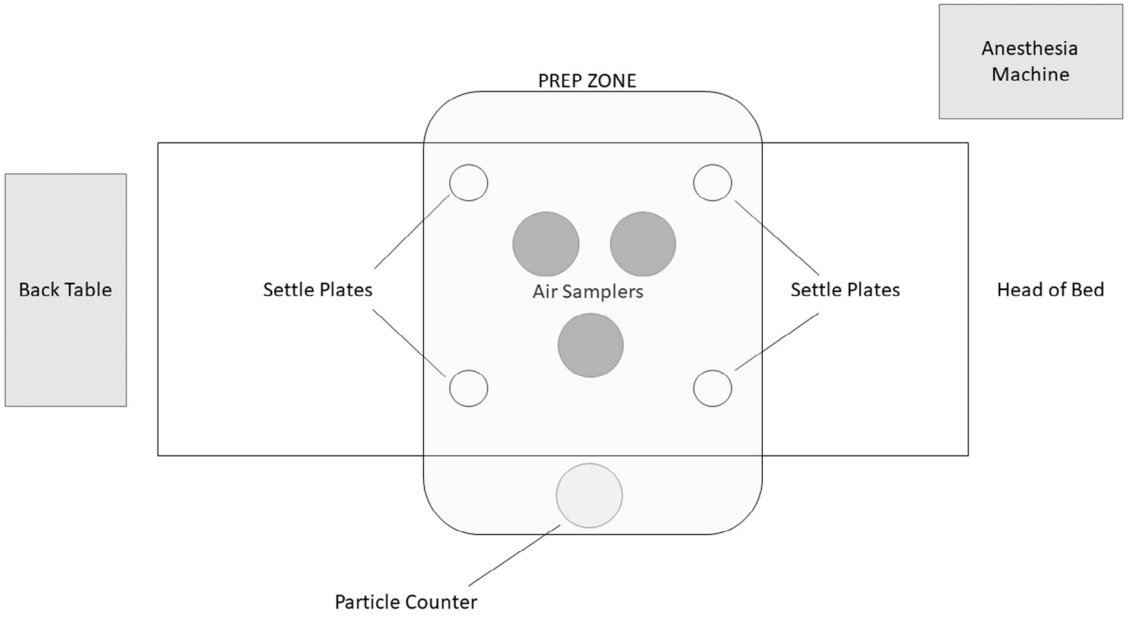

Fig 1. Instrument setup in the operating room for assessing airborne contaminants while prepping patients prior to surgery.

directly to the right of the patient bed (Fig 1) and sampled total particles continuously for each minute during the 11-minute prep experiment. Given that 2 experiments were performed for Sleeves and Bare Arms at each of the 3 hospitals (total of 6 experiments for Sleeves and 6 experiments for Bare Arms), this provided 66 particle data points for Sleeves, and 66 for Bare Arms. Particle sizes recorded were 0.3, 0.5, 1.0, and 5.0 microns in particles per cubic meter.

Bacteria

Active bacterial assessment was achieved through the use of Bioscience viable surface air samplers (SAS180). These devices were placed in triplicate in the center of the prep zone (Fig 1). The samplers were factory calibrated and set to collect 1000 liters of air over a 5.5-minute period of time. Petri plates with Blood Agar media were used in the samplers and were changed once during each run of the experiment (6 experiments for Sleeves and 6 for Bare Arms yields 36 total agar plates for Sleeves, and 36 for Bare Arms). The viable microbial samples were sent under chain of custody to a third-party microbiology laboratory (Aerobiology) for qualitative and quantitative analysis of bacteria. This laboratory has been accredited by the American Industrial Hygiene Association and served as a third-party vendor for bacterial analysis. Bacterial genuses were identified by this vendor and were quantified as colony-forming units per cubic meter.

Passive microbial assessment was achieved by placing 4 blood agar settle plates around the sterile field and allowing them to collect microbes and debris that dropped throughout the 11-minute prep period (n = 4 per experiment, times 6 experiments for Sleeves; and 6 experiments for Bare Arms yields n = 24 total settle plates for Sleeves, and 24 for Bare Arms). Settle plates were analyzed by the team's microbiologist and quantified as colony-forming units per plate (CFU/plate).

Statistics

All statistical analysis was done using GraphPad Prism 7 (GraphPad Software, La Jolla, CA). Data were assessed for normalcy by the Shapiro-Wilk and the KS normality tests and reported as the mean with SEM (parametric), or median with interquartile range (nonparametric). Data were compared using the Student's *t*-test (parametric) or Mann-Whitney U test (nonparametric). *P*-values less than .05 were considered statistically significant.

RESULTS

Particles

No significant differences were noted in particle sizes when Sleeves or Bare Arms were assessed in operating rooms A or C. However, in operating room B, a significantly lower amount of the larger 5.0-μm particles was seen when Sleeves were used (Sleeves: 5.0-μm particles totaled 514 [interquartile range {IQR} 533] vs. Bare Arms at 780 particles [IQR 367], $P < .05$). When particle counts from all 3 hospital operating rooms were averaged, the significant difference at this 5.0-μm particle size persisted (Sleeves at 347 [IQR 290] vs. Bare Arms at 507 [IQR 340], $P < .05$, Fig 2).

Bacteria

Total airborne bacteria in each of the operating rooms were assessed. Operating rooms A and C had significantly lower airborne bacteria collected by active assessment when Sleeves were worn (operating room A: Sleeves, 10.0 ± 0.98; Bare Arms, 22.75 ± 3.27, $P < .05$; operating room C: Sleeves, 44.33 ± 8.04; Bare Arms, 98.92 ± 18.66, $P < .05$). Operating room B yielded no significant difference when sleeves were worn, compared with bare arms. When all airborne bacteria were averaged from the 3 operating rooms, no difference was found in bacterial count between Sleeves and Bare Arms (Fig 3).

Although no significant differences were found in actively assessed bacteria when the 3 hospital operating rooms were averaged, a significant difference was found in identified bacterial genus. Coagulase negative *Staphylococcus*, *Micrococcus*, and *Corynebacterium* were identified most commonly on each plate. However, only *Micrococcus* was seen significantly less when sleeves were worn, compared to when the arms were bare (Table 1). Assessing bacteria by passive settle plate analysis yielded no differences between the Sleeve and Bare Arm groups in any of the operating rooms tested (Fig 4). When settle plate CFUs were averaged for all 3 operating rooms, groups showed no differences.

DISCUSSION

Nonscrubbed operating room personnel were previously told to be "bare below the elbows," and were not allowed to wear long-sleeve jackets, watches, jewelry, or other accessories, as these items were viewed as a possible sources of infection spread.[5] However, in 2004, the fear of operating room personnel shedding skin squamous cells prompted AORN to reconsider this strategy. In the 2004 guidelines, AORN began recommending that long sleeves be worn by all nonscrubbed personnel, suggesting that long sleeves capture skin squames and decrease bacterial contamination.[16] Because of these claims, the recommendation was made that those charged with applying the skin preparation solution to the patient immediately before surgery wear long sleeves and gloves.[14] The rationale for this practice was that it would decrease skin cell and microbial flora at the surgical site. Despite these recommendations, strong scientific evidence to justify or refute these practices is lacking. Herein, we saw that large-particle counts and airborne bacteria were significantly decreased when a long-sleeved gown and gloves were worn during skin prep.

Previous reports assessing types of scrubs worn in the operating room have evaluated the material, as well as whether boots are worn, and whether the scrubs are tucked in, cover the arms, and have tight-fitting cuffs at the arms and ankles. In this study, a 50% reduction in airborne CFUs was identified when the scrubs were tucked in and the cuffs were tight. However, the rate of wound contamination did not differ between the 2 groups, and surgical site infections were not reported.[17]

The concern regarding prepping a patient for surgery with bare arms was that skin squamous cells or bacterial flora from the person prepping could fall onto the patient, thereby causing a surgical site infection in the postoperative period. However, previous studies have also suggested that the friction of a long-sleeved garment promotes further shedding of skin cells. This claim was counter to traditional dogma, and was noted in a study in which bacterial dispersal rates were compared between naked and dressed subjects. Here, the addition of scrubs actually increased the dispersal of aerobic and anaerobic CFUs.[15] Therefore, the data on use of long sleeves for skin preparation remain inconsistent.

In our study, we saw decreased 5.0-μm particles when a sterile, sleeved gown was worn with sterile gloves to prep the patient. This phenomenon was seen at only one hospital, but it was a strong enough factor to outweigh the results from the other 2 facilities, so that when all operating rooms were combined, it remained significant. Given that the larger particles are more synonymous with skin squamous cells, these results suggest that the gowns in operating room B more effectively blocked the shed of skin cells onto

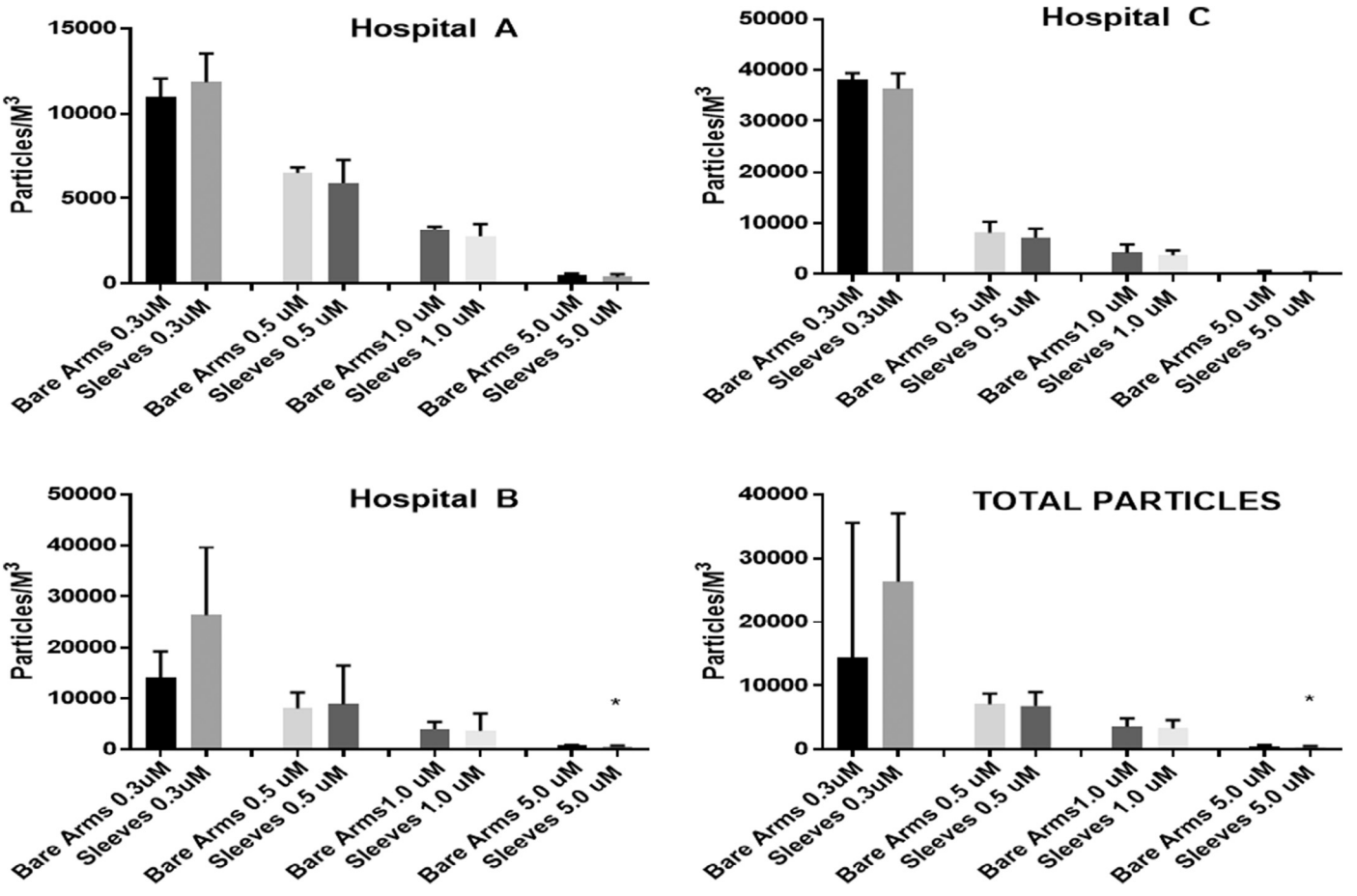

Fig 2. Particle counts in each of the 3 hospital operating rooms assessed individually and combined. *$P < .05$ versus Bare Arms.

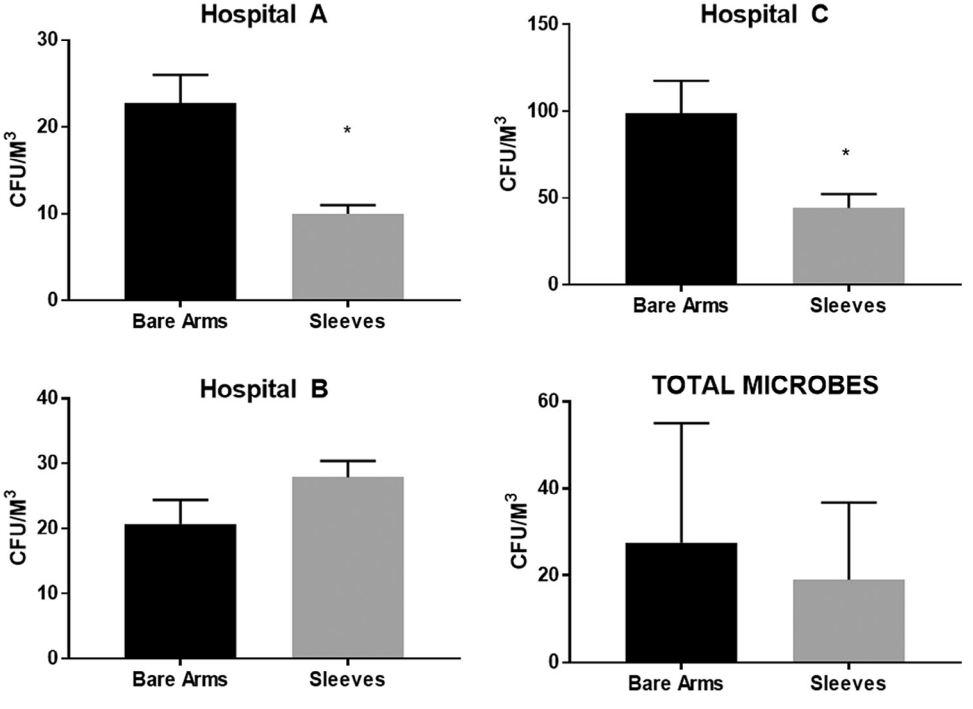

Fig 3. Airborne bacterial contaminants within each of the 3 hospital operating rooms acquired by active assessment. *$P < .05$ versus Bare Arms.

Table 1
Bacterial isoforms isolated from operating rooms

	Coag (−) Staph	Coag (+) Staph	Micrococcus *	Bacillus	Corynebacterium	Other gram (+) cocci	Gram (−) rods	Gram (+) rods	Yeast
Bare arms									
Minimum	1	0	0	0	0	1	0	0	1
25% percentile	3.25	0	6.5	0	0	1	0	0	1
Median	6.5	0	14	0	1.5	1	0.5	0	1
75% percentile	30.75	0	19	0	4	1	1	0	1
Maximum	203	6	142	2	17	1	1	0	1
Sleeves									
Minimum	0	0	2	0	0	1	0	0	1
25% percentile	5	0	4	0	0	1	0	0	1
Median	9	0	6	0	1	1	0	0	1
75% percentile	19.75	0	8	0	7	1	0	0	1.5
Maximum	66	1	17	2	17	1	0	1	2

*Significant difference between Bare Arms and Sleeves groups.

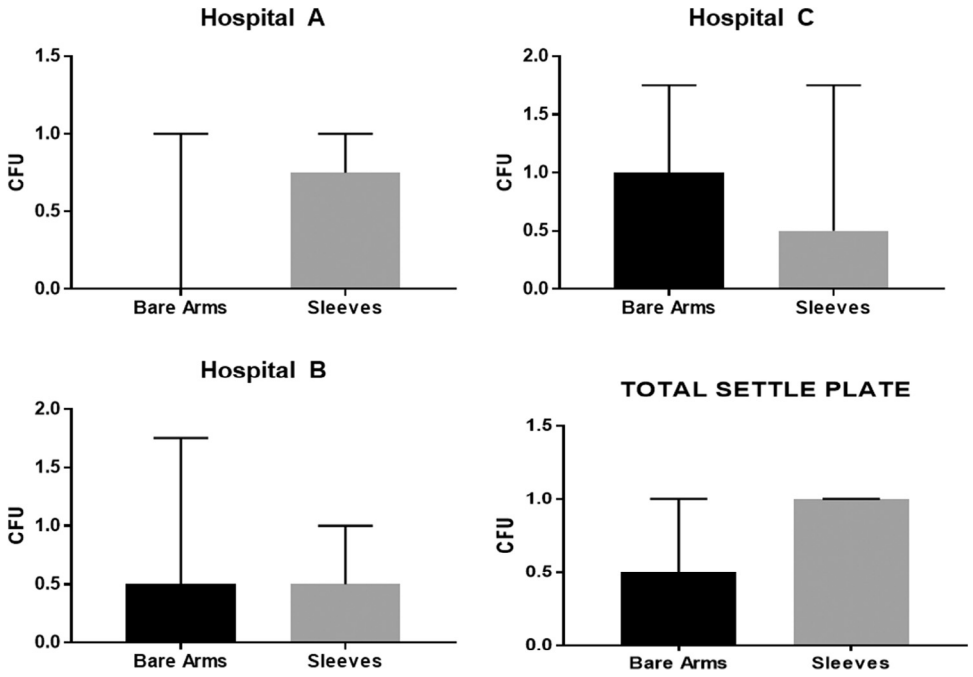

Fig 4. Airborne bacterial contaminants within each of the 3 hospital operating rooms acquired by passive settle plate assessment. *$P < .05$ versus Bare Arms.

the field. The other particles were smaller in nature, and likely could have passed through the small pores of the gowns more readily.

Total bacteria levels, as acquired by active assessment, were also lower when sterile gowns and gloves were used. This observation was seen at 2 of the 3 operating rooms assessed, but not at the third. The reason this finding did not occur in operating room B is unclear. Despite the lack of difference in the average number of total bacteria between Sleeves and Bare Arms, when acquired by active assessment, some differences were found in the genuses of bacteria identified. We noted that levels of *Micrococcus* were significantly decreased when sleeves were worn. In subanalysis, this phenomenon was seen at operating rooms A and C, but not B.

A 2017 prospective study suggested that the most common organisms in aerodigestive-related surgical site infections are *Escherichia coli*, *Klebsiella pneumoniae*, *Enterobacter cloacae*, *Pseudomonas aeruginosa*, *Bacteroides fragilis*, *Staphylococcus aureus,* and *Enterococcus faecalis*.[18] Additionally, other studies suggest that coagulase-negative *Staphlococcus* play import roles in device or implant infections.[19–21] Our analysis of operating room bacteria suggested that skin flora, including coagulase-negative *Staphlococcus*, *Micrococcus*, and *Corynebacterium*, were the most prominent bacteria in the room. Although *Staphlococcus* species have certainly shown pathogenicity, the other 2 are unlikely to result in surgical site infections. Additionally, although the different operating room environments could have contributed to the differences seen in our results, we did perform baseline testing at each site prior to the study and noted many of these same bacteria prior to experimentation. We felt that 3 sites were necessary to increase the generalizability of the results to other institutions.

Vigorous studies of the operating room environment designed to assess contamination risk and best practices have been limited. Many groups, including the Joint Commission, turn to AORN to set perioperative guidelines. Unfortunately, many of the studies used to justify policy lack vigorous scientific credibility, and many experts believe that additional studies are necessary to determine best practice.[22,23] To provide additional objective scientific data, our group has developed an assessment of various metrics, known as environmental quality indicators, within dynamic operating room environments, to address these issues.[10,24] These studies have used real operating rooms during a mock procedure, to assess bacterial and particulate load as a surrogate for assessing the risk of surgical site infections.

The results of these experiments suggest that wearing a gown with gloves while applying the sterile skin prep to patients before surgery may have some benefit. In our study, we saw decreased large particles and lower levels of bacteria when sleeves were worn. Although wearing a sleeved garment may not be indicated for all operating room personnel, it may hold some therapeutic benefit for those prepping the skin for surgery.

LIMITATIONS

This study has several limitations that should be noted. First, our experiments were performed during a mock procedure rather than during real operations with patients. We feel that performing these experiments during patient operations is unethical. However, the conditions of the mock procedure were very similar to that of a real skin preparation, and therefore, the data are likely generalizable to real surgery conditions.

An additional limiting factor to this study was that it was not blinded or randomized. Therefore, those involved in the experiments were aware that a sleeve versus bare arm study was being conducted, so bias may be a factor. A third limitation surrounds the length of each experiment. Most real skin preps take only a few minutes to perform. Therefore, the 11 minutes used in the experiment may be excessive. However, we wanted to ensure adequate capture of data points for the study. Given that the air samplers ran for 5.5 minutes, the 11-minute length was necessary to capture 2 replicates. Despite the aforementioned limitations, we feel that this study represents the best scientific attempt to assess the utility of wearing a sleeved gown while performing a sterile skin prep.

We also realize that numerous brands of gowns and gloves are available on the market. Some of these may perform better than others in reducing microbial and particulate airborne shedding and contamination. The analysis of specific brands of gowns and gloves was beyond the scope of this study and could be a topic of consideration in additional studies. Furthermore, the gowns and gloves worn during these experiments were sterile. It is unclear if wearing a nonsterile jacket or gown with nonsterile gloves would have affected the results.

CONCLUSIONS

The use of long sleeves by nonscrubbed personnel in an operating room is controversial. Policy has changed several times over the years surrounding the use of long-sleeved garments. Unfortunately, the scientific data to support either policy have been lacking. Through the use of specific environmental quality indicators, we determined that use of a sterile sleeved gown and gloves significantly decreased particle and microbial contamination at the area of skin prep. Although we cannot correlate our findings to surgical site infections, the use of long-sleeved gowns and gloves for the application of the presurgical skin prep should be considered. Furthermore, future studies surrounding the use of implementation science methodologies should be undertaken to more credibly relate the use of long-sleeved gowns to surgical site infections.

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References

1. Hubble MJ, Weale AE, Perez JV, Bowker KE, MacGowan AP, Bannister GC. Clothing in laminar-flow operating theatres. J Hosp Infect 1996;32:1-7.
2. Tammelin A, Blomfeldt AM. Comparison of two single-use scrub suits in terms of effect on air-borne bacteria in the operating room. J Hosp Infect 2017;95:324-6.
3. Nordstrom JM, Reynolds KA, Gerba CP. Comparison of bacteria on new, disposable, laundered, and unlaundered hospital scrubs. Am J Infect Control 2012;40:539-43.
4. Al-Benna S. Laundering of theatre scrubs at home. J Perioper Pract 2010;20:392-6.
5. Salassa TE, Swiontkowski MF. Surgical attire and the operating room: role in infection prevention. J Bone Joint Surg Am 2014;96:1485-92.
6. Moylan JA, Fitzpatrick KT, Davenport KE. Reducing wound infections. Improved gown and drape barrier performance. Arch Surg 1987;122:152-7.
7. Garibaldi RA, Maglio S, Lerer T, Becker D, Lyons R. Comparison of nonwoven and woven gown and drape fabric to prevent intraoperative wound contamination and postoperative infection. Am J Surg 1986;152:505-9.
8. Sanders R, Fortin P, Ross E, Helfet D. Outer gloves in orthopaedic procedures. Cloth compared with latex. J Bone Joint Surg Am 1990;72:914-7.
9. Sebold EJ, Jordan LR. Intraoperative glove perforation. A comparative analysis. Clin Orthop Relat Res 1993;297:242-4.
10. Gormley T, Markel TA, Jones H, Greeley D, Ostojic J, Clarke JH, et al. Cost-benefit analysis of different air change rates in an operating room environment. Am J Infect Control 2017; pii: S0196-6553:30911-2.
11. Bischoff P, Kubilay NZ, Allegranzi B, Egger M, Gastmeier P. Effect of laminar airflow ventilation on surgical site infections: a systematic review and meta-analysis. Lancet Infect Dis 2017;17:553-61.
12. Noguchi C, Koseki H, Horiuchi H, Yonekura A, Tomita M, Higuchi T, et al. Factors contributing to airborne particle dispersal in the operating room. BMC Surg 2017;17:78.
13. Andersen BM, Solheim N. Occlusive scrub suits in operating theaters during cataract surgery: effect on airborne contamination. Infect Control Hosp Epidemiol 2002;23:218-20.
14. AORN. Guidelines for surgical attire. In: Guidelines for perioperative practice. 2015. p. 97-120.
15. Benediktsdottir E, Hambraeus A. Dispersal of non-sporeforming anaerobic bacteria from the skin. J Hyg (Lond) 1982;88:487-500.
16. AORN Recommended Practices Committee. Recommended practices for surgical attire. AORN J 2005;81:413-20.
17. Tammelin A, Hambraeus A, Stahle E. Routes and sources of Staphylococcus aureus transmitted to the surgical wound during cardiothoracic surgery: possibility of preventing wound contamination by use of special scrub suits. Infect Control Hosp Epidemiol 2001;22:338-46.
18. Alexiou K, Drikos I, Terzopoulou M, Sikalias N, Ioannidis A, Economou N. A prospective randomised trial of isolated pathogens of surgical site infections (SSI). Ann Med Surg (Lond) 2017;21:25-9.
19. Dapunt U, Burkle C, Gunther F, Pepke W, Hemmer S, Akbar M. Surgical site infections following instrumented stabilization of the spine. Ther Clin Risk Manag 2017;13:1239-45.
20. Kozon I, Riahi S, Lundbye-Christensen S, Thogersen AM, Ejlertsen T, Aaen D, et al. Risk factors of cardiac device infection: glove contamination during device procedures. Am J Infect Control 2017;45:866-71.
21. Pineda M, Burnett AL. Penile prosthesis infections—a review of risk factors, prevention, and treatment. Sex Med Rev 2016;4:389-98.
22. Faulkner W, Memarzadeh F, Riskowski G, Kalbasi-Ashtari A, Ching-Zu Chang A. Effects of air exchange rate, particle size and injection place on particle concentrations within a reduced-scale room. Build Environ 2015;92:246-55.
23. Memarzadeh F, Olmsted RN, Bartley JM. Applications of ultraviolet germicidal irradiation disinfection in health care facilities: effective adjunct, but not stand-alone technology. Am J Infect Control 2010;38:S13-24.
24. Gormley T, Markel TA, Jones HW 3rd, Wagner J, Greeley D, Clarke JH, et al. Methodology for analyzing environmental quality indicators in a dynamic operating room environment. Am J Infect Control 2017;45:354-9.