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Major Article

# Operating room PathTrac analysis of current intraoperative *Staphylococcus aureus* transmission dynamics

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***Background:*** Operating room (OR) reservoir *Staphylococcus aureus* isolates have been linked to 50% of surgical site infections. We aimed to assess *S aureus* transmission dynamics in today's ORs to further guide health care–associated infection prevention.

***Methods:*** Forty OR case-pairs were randomly selected for observation in a 5-month prospective cohort study. Case-pair *S aureus* transmission dynamics were mapped using OR PathTrac.

***Results:*** *S aureus* pathogens were isolated from ≥1 OR reservoirs in 45.7% (37 of 81) of surgical cases, and epidemiologically related transmission events were confirmed in 22.5% (9 of 40) of case-pairs. Patient skin sites and provider hands provided comparable risk of OR *S aureus* exposure (19 of 481 patient vs 35 of 1,173 provider hands, relative risk [RR], 1.32; 95% confidence interval [CI], 0.77-2.29; $P = .32$). Environmental contamination at case 2 start was higher than at case 1 start (case 2 start 32 of 152 sites with >20 colony-forming units vs case 1 start 7 of 163 sites with >20 colony-forming units; RR, 4.90; 95% CI, 2.23-10.77; $P < .0001$). The stopcock contamination rate was not significantly different than our prior study in 2008 (19 of 164 2008 vs 8 of 77 2018; RR, 1.12; 95% CI, 0.51-2.43; $P = .78$). All epidemiologically related transmission events involved the between-case mode of transmission and phenotype H.

***Conclusions:*** Current OR *S aureus* exposure threats reliably include patient skin sites and provider hands. Perioperative *S aureus* preventive measures should extend from patient decolonization to include improved hand decontamination efforts.



Health care–associated infections (HAIs) are a significant issue associated with increased patient morbidity, mortality, and health care costs.[1-4] HAIs continue to affect approximately 3.2% of hospitalized patients and up to 7% of patients undergoing surgery, despite advances in surgical procedures, disinfection agents, and adherence to surgical care improvement project measures.[5-7] The persistent nature of HAIs is due in part to the evolution of bacterial pathogens in which some organisms, such as *S aureus*, have acquired resistance and virulence traits that make infections more difficult to treat when they develop.[8,9] In response, the Centers for Disease Control and Prevention has advised the health care community to address 3 major goals moving forward including (1) prevention of infections for patients undergoing surgery, (2) prevention of bacterial spread, and (3) improved antibiotic stewardship.[10,11]

The perioperative environment is a high-risk arena for *S aureus* transmission and subsequent infection development.[12-15] In fact, 50% of surgical site infections have been linked to bacterial pathogens present in the operating room (OR) at the time of surgery.[13] Organisms linked to postoperative infections include more pathogenic strain characteristics such as multilocus sequence type 5, which is a sequence type associated with USA100 that is a common cause of hospital-acquired *S aureus* infections.[15] Evidence shows that the spread of USA100 is driven at least in part by increased strength of

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biofilm formation and resistance to desiccation tolerance, calling attention to the need for targeted attenuation of the spread of these more pathogenic strain characteristics.[12-15]

Provider hands, patient skin sites, and environmental surfaces are confirmed sources of perioperative bacterial *S aureus* transmission.[12,16] Open lumen intravenous (IV) stopcock sets are devices in direct continuity with the patient's intravascular space that have been shown to be contaminated with 1 or more bacterial pathogens in up to 32% of surgical cases.[17] Stopcock contamination has been directly linked by whole cell genome and pulsed-field gel electrophoresis to postoperative infection development and repeatedly associated with increased patient mortality.[16,17]

The Society for Healthcare Epidemiology of America recently published expert guidance to address these issues. Recommendations included, but were not limited to, improved provider hand hygiene, consideration of double gloving during induction of anesthesia, use of closed, disinfectable injection ports, hub disinfection prior to injection, capping of syringe tips, proper laryngoscope blade and handle disinfection, and regular monitoring and evaluation of infection control practices.[18] The primary goal for all such practices is to reduce within and between-patient transmission of causative organisms of infection, including, but not limited to, bacterial pathogens. In this study, we used OR PathTrac (RDB Bioinformatics, Omaha, NE), an evidence-based monitor of OR bacterial transmission,[13-15] to assess the present day need to reduce bacterial transmission, and thus infection.

## METHODS

### *Design*

A prospective cohort study with random selection of patients was conducted at a tertiary care medical center over a 5 month study period (September 5, 2017 to February 12, 2018). Institutional review board approval (201705826, An Investigation of Novel Technology to Bring Genomic Analysis to the Patient Bedside to Systematically Track and Report on ESKAPE Bacterial Transmission in Today's OR Environments) with a requirement for informed, written, patient consent was obtained. A total of 2 patients declined participation. Providers received advanced notice of study participation and could decline participation at any time. A total of 9 providers refused to participate, 5 surgeons and 4 certified-registered nurse anesthetists. Culture results were de-identified. The trial protocol is available at clinicaltrials.gov (NCT03605498).

### *Inclusion and exclusion criteria*

Inclusion was based on OR environments involving adult patients (≥18) undergoing gynecology/oncology, colorectal, open vascular, orthopedic total joint, and cardiovascular procedures requiring peripheral IV and/or central venous catheter placement, providing informed, written consent. Exclusion criteria included age <18 years, no IV catheter (peripheral or central), incarcerated patients, or lack of informed, written consent. All intraoperative providers were considered eligible for participation.

### *Patient recruitment and randomization*

Patient enrollment occurred on 48 separate days across the 5-month study period. Thirty-four OR environments were screened for patients meeting inclusion criteria each day. The 34 available rooms were randomly assorted via a computer-generated list. The research assistant worked the list from the top down to find the first OR meeting inclusion criteria. Informed patient consent was then obtained.

### *Observational unit*

Case pairs (2 patients undergoing sequential care in the same OR) were used so that within and between-case epidemiologically related *S aureus* transmission events could be detected.

### *Baseline OR infection control practices*

Infection control practices in the ORs included routine and terminal environmental cleaning with quaternary ammonium compounds (Virex II 256, Diversey, Charlotte, NC) and surface disinfection wipes (PDI Healthcare, Super Sani-Cloth, Germicidal Disposable Wipes, Orangeburg, NY). Disinfection wipes were placed on anesthesia machines or carts for provider use. All providers had access to alcohol dispensers containing 62% isopropyl alcohol and located on the wall and anesthesia carts, and gloves were immediately available for use. Open lumen IV stopcocks were used with ethanol wipes available in the anesthesia carts. Decolonization efforts for orthopedic surgery were standardized to include preoperative use of nasal mupirocin and chlorhexidine gluconate, whereas colorectal, cardiovascular, and gynecology/oncology decolonization approaches varied.

### *General overview*

OR PathTrac incorporates an innovative information technology platform with an ordered, kit-based reservoir collection process to map and report on epidemiologically related, perioperative ESKAPE (*Enterococcus*, *S aureus*, *Klebsiella*, *Acinetobacter*, *Pseudomonas*, and *Enterobacter* spp.) transmission events. Automated reports identify perioperative reservoirs in need of greater attention in a given context, providing fidelity measurements of existing infection control measures to provide the impetus for proactive, evidence-based improvement strategies. More pathogenic strain characteristics are identified and mapped in order that they can be proactively addressed in a given health care setting.[13]

In this study, OR PathTrac was used to characterize *S aureus* transmission events occurring in 81 OR environments (40 case-pairs 2 surgical cases occurring sequentially in the same OR) to monitor and evaluate current intraoperative infection control practices pertaining to provider hand hygiene, patient decolonization, environmental cleaning, and intravascular catheter disinfection. Anesthesia, nursing, surgical, and technical provider hands and environmental sites were monitored using collection kits.[13-15] The specific culture sites observed included baseline and case-end swabs of circulating nurse (circulating nurse desk [CND]), anesthesia (adjustable pressure limiting [APL] valve and agent dial of the anesthesia machine), and surgical (equipment tray) environments, anesthesia, nursing, surgical staff and assistant hands throughout care (before, during, and after), patient nasopharyngeal, axillary, and groin/rectal (for colorectal surgery only) skin sites, and the internal lumens of stopcock sets from the primary (used for induction) IV tubing. The temporal association provided by the ordered collection process (Fig 1) was used by the information technology platform to identify, order, and map epidemiologically related *S aureus* isolates according to the definitions provided in the next section.

The primary endpoint of this study was the epidemiology of intraoperative *S aureus* transmission dynamics.

### *Definitions*

- Transmission dynamics: frequency of reservoir isolation and the overall incidence, reservoirs of origin, mode(s), portal of entry, and strain characteristics for epidemiologically related transmission events.

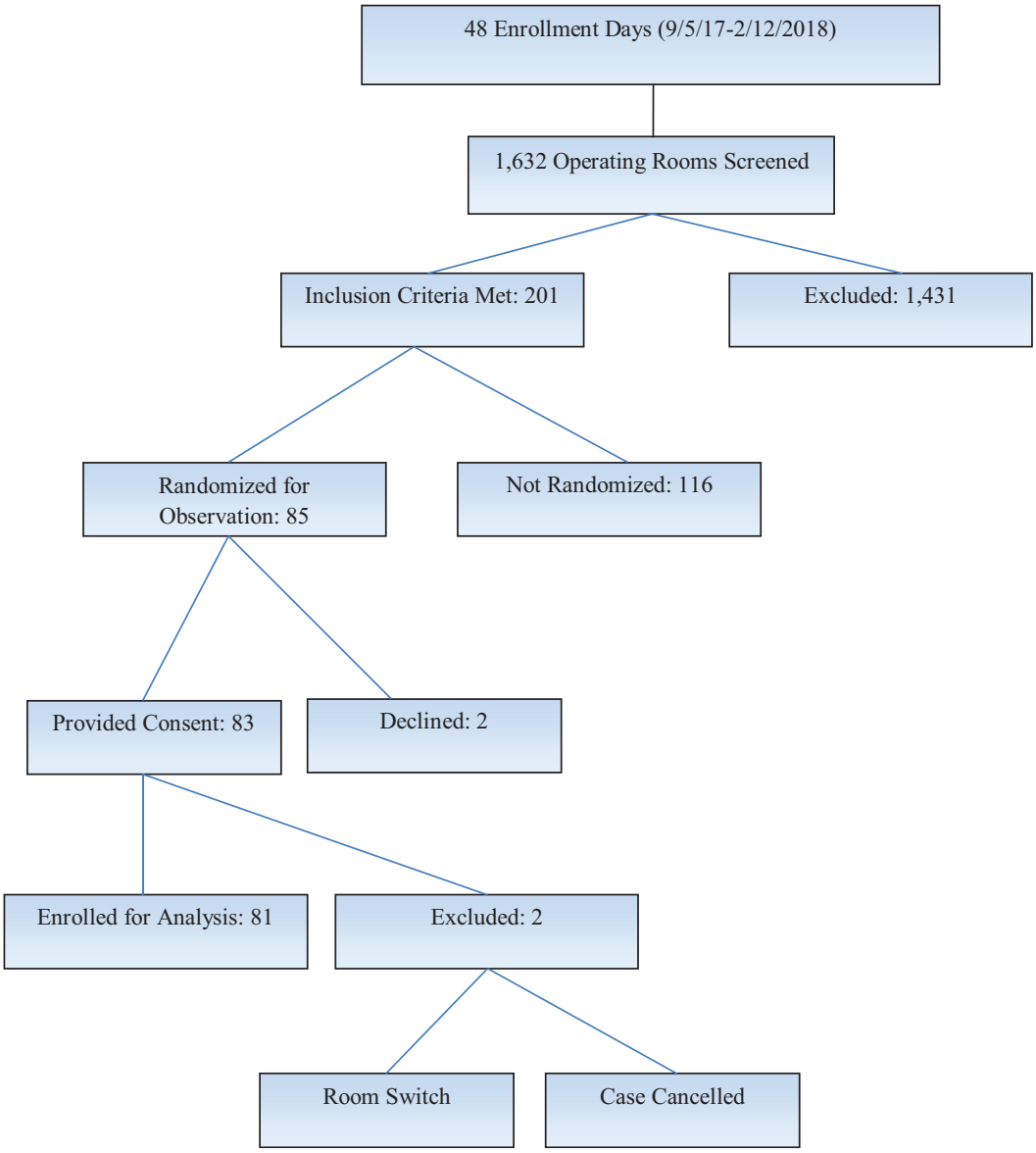


**Fig 1.** Operating room PathTrac systematic reservoir collection. *APL*, adjustable pressure limiting.

- Epidemiologically related *S aureus* transmission: 2 or more isolates obtained from 2 or more distinct reservoirs within an observational unit that were temporally associated and identical according to colony morphology, simple rapid tests, biotype, and antibiotic susceptibility.[12,16]
- Transmission event: 1 or more isolates present in a measured reservoir at case end that were not present at case start.
- Mode: within or between-case transmission within an observational unit.
- Portal of entry: stopcock contamination.
- Strain characteristics: biotype by analytical profile indexing. Prior work identified *S aureus* phenotypes P and H as hypertransmissible *S aureus* strain characteristics in the intraoperative environment.[12]

*Sample collection technique*

(1) APL valve complex and agent dial of the anesthesia machine: For case 1, 2 sites on the anesthesia machine (APL valve complex and agent dial) were decontaminated (Virex II 256, Diversey, Charlotte, NC) and cultured aseptically using sterile swabs (ESwab, Copan Diagnostic Inc, Corona, CA) to cover the entire surface area before anesthesia provider entry. A repeat culture was obtained at the end of the case. For case 2, the APL valve complex was cultured without prior decontamination as described for case 1.

(2) CND: A 10 × 10 cm area of the CND was identified a priori and repeatedly sampled for each case-pair using the earlier described technique for baseline and case-end samples.

(3) Instrument tray: Instrument trays were opened at case start by the circulating nurse and a 10 × 10 cm area identified a priori cultured sterilely using the earlier described swab technique. Cultures were repeated at case end.

(4) IV stopcock culture: As bacterial cultures obtained from stopcock sets immediately on removal from the packaging (at case start) were previously shown to be invariably negative,[17] only case-end samples were obtained. A sterile nasopharyngeal swab (ESwab) moistened with sterile transport medium was inserted into the internal surfaces of each injection port of the

3-way stopcocks for the primary IV tubing set and rotated 360° 10 times to culture.

(5) Anesthesia provider hand cultures: A previously validated glove juice technique was used to measure the transient flora of provider hands at case start and at case end. This technique has been shown to track transmission of multiple bacterial pathogens from provider hands, including *S aureus*.[12,16] The sterility of glove juice solution was confirmed.

(6) Patient cultures: A sterile nasal swab (ESwab) was inserted gently into the internal surface of each nostril and rotated 10 times to culture. In addition, a sterile swab was inserted gently into the axilla (armpit) and groin/rectum (only for colorectal surgery) of each patient bilaterally and rotated 10 times to culture. Cultures were obtained at case start and at case end.

### *Microbial culture conditions*

All blood agar plates were incubated at 35°C for 48 hours, and microorganisms were quantified according to colonies per surface area sampled and identified according to standard laboratory methods as described in the following paragraphs.

### *Bacterial identification*

Recovered organisms were identified by standard clinical microbiology techniques supplemented by Kirby-Bauer disk diffusion and analytical profile indexing for gram-positive organisms. Methicillin-resistant *Staphylococcus aureus* (MRSA) isolates were confirmed by agar dilution minimal inhibitory concentration.[19]

### *Systematic-phenotypic analysis*

Temporal association: Two *S aureus* isolates obtained from 2 or more distinct reservoirs within a study unit were considered temporally associated because they were more likely to be related than independent given that the probability of *S aureus* isolation from any 1 tested site previously ranged from 3% (hand and environmental samples) to 16% (patient nasopharynx and/or axilla).[12] Therefore, the probability of isolating *S aureus* from 2 distinct reservoirs within the platform of temporal association, probability of A x B, was considered to range from 0.09%-3%, whereas the probability of being related to a common reservoir was considered to range from 97%-99.91%.[12]

Analytical profile indexing: Bacterial organisms were identified, and isotypes specified using the commercially available bioMerieux API identification system (Marcy l'Etoile, France), resulting in a 7-9 digit identification number. This number was then cross-referenced using the Analytical Profile Index database to obtain the final organism biotype.[12]

Antibiotic susceptibility: We used disk diffusion antibiotic susceptibility testing analysis as previously described.[12] Bacterial sensitivity was recorded and subsequently analyzed as sensitive or resistant (including intermediate resistance).[19] MRSA isolates were also confirmed by agar dilution minimal inhibitory concentration.[19]

OR PathTrac analysis: All results were entered into the OR PathTrac program to characterize epidemiologically related *S aureus* transmission maps and the overall magnitude of reservoir contamination.[13-15,20]

### *Demographic information*

First case, OR number, sex, American Society of Anesthesiologists health classification status >2, aged >50 years, procedure (orthopedic, gynecology/oncology, vascular, colorectal, and cardiovascular surgery), duration ≥2 hours, general anesthesia, and dirty or infected surgical classification were collected for each case within an observational unit.

### *Statistical analysis*

The primary endpoint of this study was the epidemiology of intraoperative *S aureus* transmission dynamics according to frequency of reservoir isolation and the overall incidence, reservoirs of origin, mode(s), portal of entry, and strain characteristics for epidemiologically related transmission events. The Fisher exact tests were used for analyses of contingency tables including assessment of associations between each of the earlier listed demographic variables and OR exposure to 1 or more positive reservoirs.

One endpoint of multivariable analysis was OR *S aureus* exposure. The unit of analysis was the patient; with each patient having 1 surgical case, that effectively meant the surgical case. Logistic regression was used to evaluate variables that were significant ($P < .05$) in the univariate analyses: general anesthesia, case 1, duration >2 hours, orthopedic surgery, gynecology/oncology surgery, aged >50 years, and ORs 2 and 18.

The second endpoint was epidemiologically related *S aureus* transmission events. The unit of analysis was a case-pair involving the first and second case of the day in an observed OR environment. Again, logistic regression was used. Variables significant in the univariate analyses and included in the analysis were: colorectal and orthopedic surgery, anesthesia duration of >2 hours, OR 2, and dirty or infected site.

The final endpoint was whether MRSA was associated with the phenotype H strain characteristic.[12] Logistic regression analysis was performed with phenotype H as the independent variable while controlling for the covariates significantly associated with MRSA ($P < .05$): OR 1, OR 18, orthopedic surgery, and general anesthesia.

To assess the overall magnitude of reservoir contamination, we considered a dirty surface to be one in which there were >20 colony-forming units (CFU) based on prior work.[21] We compared the proportion of sites with >20 CFU at case 1 start to case 1 end and to case 2 start using the $\chi^2$ test. The mean incidence of stopcock contamination among ports sampled during the study period was compared to the reported incidence of stopcock contamination reported during a similar season in 2008.[22]

Statistical analyses were performed using STATA 15.1 (StatCorp, College Station, TX). All *P* values are 2-sided.

### *Power*

This study was powered to detect a previously reported rate of *S aureus* transmission of 39%.[12] As such, we planned to enroll 40 case-pairs (80 patients) to capture and report on 32 possible *S aureus* transmission events (80 cases x 0.39 = 31.2 possible transmission events) in which 2 or more *S aureus* isolates were obtained from 2 or more distinct reservoirs within a case-pair. We anticipated that approximately 30% (9.4 of 31.2) of possible transmission events would be confirmed with additional testing or an estimated 10 confirmed events across 40 case-pairs, a 25% and clinically relevant rate of detection requiring active intervention. Because the sample size was chosen based on incidence, and yet there are included multiple multivariable analyses, an alpha level of $P < .005$ was defined as statistically significant.[23]

## RESULTS

Patient enrollment is shown in Figure 2. A total of 1,632 OR environments were screened with 201 meeting inclusion criteria and 85 randomly selected for observation. Eighty-three provided consent with 81 included in the final analysis. One OR was cancelled unexpectedly, and another patient was placed into a different OR, thus violating inclusion criteria. The 81 cases included were 40 case-pairs

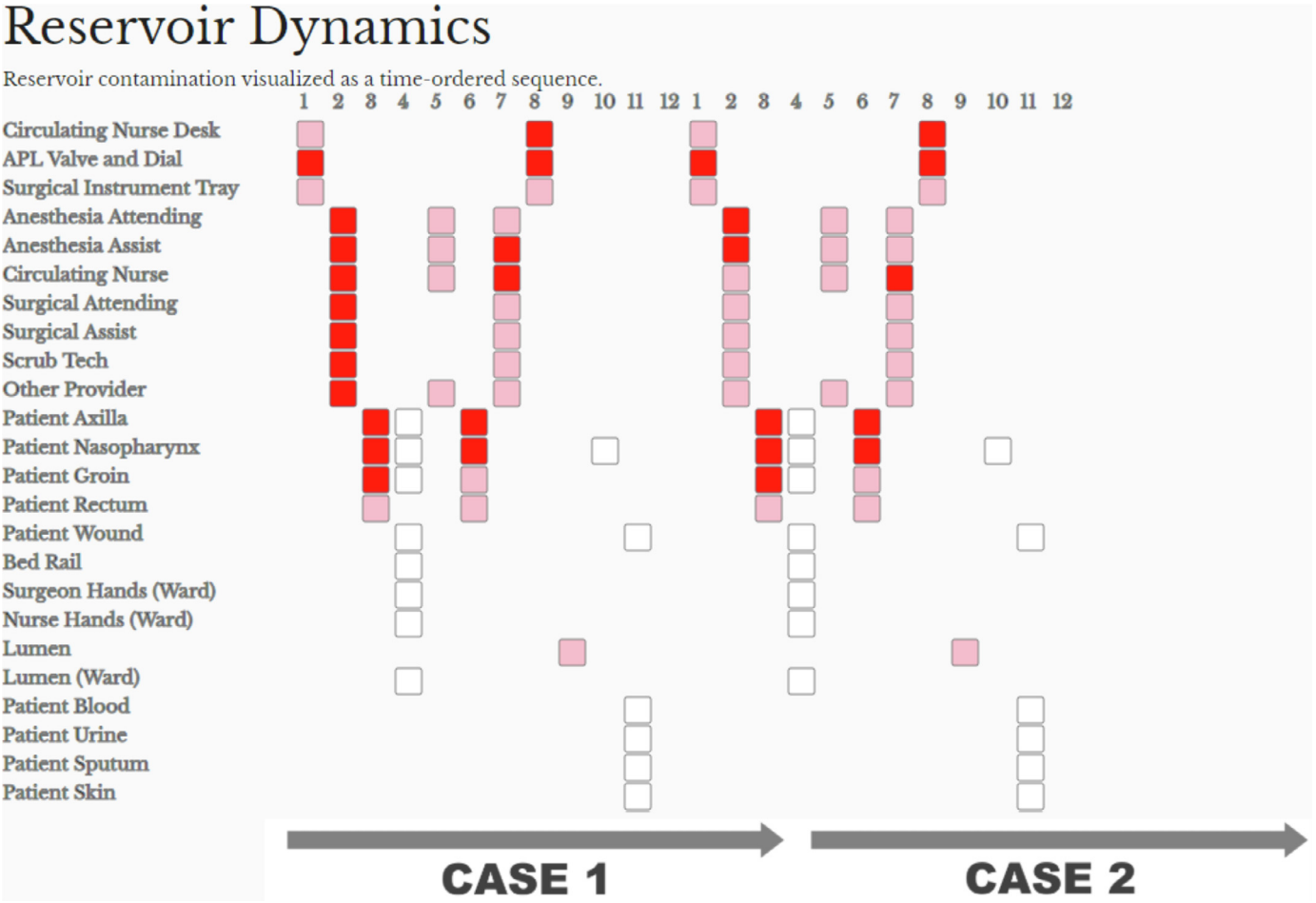


**Fig 2.** Patient enrollment.

plus 1 patient without a pair. Patient demographics stratified by OR *S aureus* reservoir exposure are shown in Table 1.

*S aureus* isolates were detected in at least 1 OR reservoir in 45.7% (37 of 81) of surgical cases. A total of 481 patients, 1,173 provider hands, and 475 environmental sites were evaluated. Twenty-four different providers were involved in the 35 isolates collected from provider hands. One surgeon accounted for 4 isolate exposures on different dates from September 2017 to January 2018. An anesthesia attending and circulating nurse each had 2 exposures on the same date, different cases. Some hands brought more than 1 *S aureus* exposure to the OR (ie, different strain characteristics).

Patient skin sites and provider hands provided comparable risk of overall OR *S aureus* (19 of 481 patient vs 35 of 1,173 provider hands; relative risk [RR], 1.32; 95% confidence interval [CI], 0.77-2.29; $P = .37$). Approximately 88% (28 of 32) of the hand reservoir sites were considered dirty. Patient skin sites were associated with significantly greater risk of OR *S aureus* exposure as compared to the environment (19 of 481 patient vs 4 of 475 environment; RR, 4.69; 95% CI, 1.61-13.69; $P = .002$), whereas provider hands were not significantly different (35 of 1,173 provider hands vs 4 of 475 environment; RR, 3.54; 95% CI, 1.27-9.91; $P = .007$).

The odds of 1 or more OR reservoirs being positive with *S aureus* during a surgical case was modeled using logistic regression (Table 2). The sole significant variable was being the first case of the pair (odds ratio, 6.96; $P < .001$).

*S aureus* epidemiologically related transmission events were confirmed in 22.5% (9 of 40) of case pairs and in 11% (9 of 81) of cases overall. This involved 4 epidemiologically related transmissions and 5 transmission events. Epidemiologically related transmissions and/or events were identified during 9.5% (2 of 21) of gynecology/oncology, 4.3% (2 of 46) orthopedic, and 50% (5 of 10) of colorectal procedures. The 4 cases in OR 2 all had transmission events as compared with 5 of 77 in the other ORs ($P < .001$).

The patient's nasopharynx and surgical attending, surgical assistant, and circulating nurse hands were all implicated as reservoirs of origin. All transmission stories involved the between-case mode of transmission. All *S aureus* transmission stories and events involved the phenotype H strain characteristic. OR exposure to MRSA was significantly predicted by the phenotype H strain (odds ratio, 55.15; 95% CI, 9.80-310.45; $P < .0001$) (Table 3).

Stopcock contamination (portal of entry) occurred in 12% (5 of 39) and 9% (3 of 33) of collected samples for case 1 and case 2, respectively. The rate of stopcock contamination was similar to that in 2008 (19 of 164 2008 vs 8 of 77 2018; RR, 1.12; 95% CI, 0.51-2.43; $P = .78$).

A total of 156 and 163 environmental samples (anesthesia, circulating nurse, and surgical) were obtained for case 1 end and case 1 start, respectively. The number of reservoirs with bacterial CFU >20 were higher at case 1 end as compared to case 1 start (case 1 end 60 of 156, vs case 1 start 7 of 163; RR, 8.96; 95% CI, 4.22-18.99; $P < .0001$). A total of 152 and 163 environmental samples were obtained for case 2 start and case 1 start, respectively. The number of samples with CFU >20 were higher at case 2 start as compared to case 1 start (32 of 152 case 2 start vs 7 of 163 case 1 start; RR, 4.90; 95% CI, 2.23-10.77; $P < .0001$).

**Table 1**
Operating room, procedural, and patient demographic factors stratified by operating room exposure to 1 or more reservoirs positive for *Staphylococcus aureus*

| Total N = 81 operating rooms (40 case-pairs) | *Staphylococcus aureus* exposure N (%) |
|---|---|
| Operating room factors | |
| Room | |
| A (N = 8) | 6 (75) |
| B (N = 4) | 4 (100) |
| C (N = 16) | 9 (56) |
| D (N = 14) | 5 (36) |
| E (N = 13) | 7 (54) |
| F (N = 2) | 1 (50) |
| G (N = 2) | 1 (50) |
| H (N = 4) | 1 (25) |
| I (N = 4) | 2 (50) |
| J (N = 14) | 1 (8) |
| Total rooms | 37 |
| First case (N = 41) | 26 (63) |
| Procedural | |
| Duration ≥2 hours (N = 71) | 28 (36) |
| General anesthesia (N = 40) | 23 (58) |
| Type of surgery | |
| Gynecology/oncology (N = 21) | 14 (67) |
| Orthopedic (N = 46) | 15 (33) |
| Open vascular (N = 2) | 0 (0) |
| Colorectal (N = 10) | 7 (70) |
| Cardiovascular (n = 2) | 1 (50) |
| Dirty or infected (N = 4) | 2 (50) |
| Patient | |
| Age >50 years (N = 60) | 23 (38) |
| ASA health classification status >2 (N = 27) | 12 (44) |
| Sex female (N = 50) | 21 (42) |

*ASA*, American Society of Anesthesiologists.

**Table 2**
Risk factors for operating room *Staphylococcus aureus* exposure

| *Staphylococcus aureus* OR exposure | Odds ratio | *P* value | 95% Confidence interval |
|---|---|---|---|
| Operating room | | | |
| OR 2 | 1 | | |
| OR 18 | 0.09 | .024 | 0.01-0.71 |
| Case 1 | 6.96 | .001 | 2.20-22.07 |
| Age >50 years | 0.58 | .50 | 0.12-2.86 |
| Anesthesia duration ≥2 hours | 0.11 | .073 | 0.01-1.23 |
| Procedure | | | |
| Orthopedic | 1.75 | .61 | 0.21-14.48 |
| Gynecology/oncology | 2.08 | .45 | 0.31-13.81 |
| General anesthesia | 1.07 | .93 | 0.21-5.38 |

*OR*, operating room.

## DISCUSSION

We monitored and evaluated intraoperative *S aureus* transmission dynamics over a 5-month study period. A high magnitude of *S aureus* OR exposure and transmission events indicate a suboptimal state of current intraoperative infection control practices and should provide the impetus for implementation of improvement strategies as recommended by recent perioperative infection control expert guidance.[18]

As half of postoperative *S aureus* surgical site infections have been linked by nucleotide variant analysis to *S aureus* isolates present in the OR at the time of the surgery, OR *S aureus* exposure is an important consideration.[13] In this study, we found that nearly half of all observational units were exposed to *S aureus* despite the majority of cases involving orthopedic procedures with standardized decolonization practices. Therefore, infection control efforts extending beyond patient decolonization efforts are indicated.

Patient skin sites introduced no greater risk of overall OR *S aureus* exposure than provider hands, and the majority of provider hand reservoirs we dirty throughout patient care. Therefore, optimization of intraoperative hand hygiene compliance is indicated. Future work should identify a practical level of observed hand hygiene compliance that correlates well with low levels of *S aureus* transmission, providing the data transparency, process measures, and the feedback necessary to improve hand hygiene performance.[18]

We extended our investigation to all intraoperative providers and associated environments to ascertain a less anesthesia-centric view of *S aureus* transmission dynamics.[22] Attending and resident surgical physicians and circulating nurses were identified as sources of transmission events indicating that intraoperative hand hygiene improvement strategies should be extended to all intraoperative providers. Indeed, surgical providers interact with patients in the intraoperative arena outside of the boundary of the surgical scrub.

Consistent with prior work, intraoperative *S aureus* transmission occurred frequently with 22.5% and 11% of case-pairs and cases, respectively, affected by 1 or more events.[12-16] As the most frequent mode of *S aureus* transmission was patient-to-patient with provider hands a confirmed vector, the attenuation of intraoperative *S aureus* transmission via hand hygiene improvement strategies would be in alignment with Centers for Disease Control and Prevention recommendations to reduce between-patient bacterial transmission.[10,11] Prior work evaluating knowledge, attitudes, and beliefs of anesthesia providers regarding the importance of hand hygiene should be extended to other intraoperative providers to augment such efforts to prevent environmental and subsequent between-patient contamination.[24,25]

The CND desk is an environmental surface with the potential to serve as an *S aureus* relay station between surgeons, nurses, and

**Table 3**
Intraoperative *Staphylococcus aureus* transmission dynamics

| Transmission stories | Reservoir(s) of origin | Mode of transmission | Transmission location(s) | Strain characteristic |
|---|---|---|---|---|
| 14520-14526 | Surgical attending hand start case 1 | Between | Circulating nurse hand end case 2 | MSSA (phenotype H) |
| 14481-14490 | Patient nose case 1 | Between | Anesthesia machine valve and dial end of case 2 | MRSA (phenotype H) |
| 14539-14543 | Circulating nurse hand end case 1 | Between | Circulating nurse hand start case 2 | MRSA (phenotype H) |
| 14520-14526 | Surgical assistant case 1 start | Between | Circulating nurse hand before/during case 2 | MSSA (phenotype H) |
| **Transmission events** | *Reservoir(s) of origin* | *Mode of transmission* | *Transmission location(s)* | *Strain characteristic* |
| 14481 | N/A | N/A | Anesthesia machine valve and dial end case 1 | MSSA (other phenotype) |
| 14481 | N/A | N/A | Patient nose end case | MRSA (phenotype H) |
| 14515 | N/A | N/A | Anesthesia machine valve and dial end case 1 | MRSA (phenotype H) |
| 14519 | N/A | N/A | Patient axilla end case 1 | MSSA (phenotype H) |
| 14536 | N/A | N/A | Anesthesia attending hand end case 1 | MRSA (phenotype H) |
| 14539 | N/A | N/A | Circulating nurse hand end case 1 | MSSA (phenotype H) |

*MRSA*, methicillin-resistant *Staphylococcus aureus*; *MSSA*, methicillin-susceptible *Staphylococcus aureus*; *N/A*, not available.

patients during patient preparation prior to the skin incision[24] and to serve as a vector for aerosolized particles and subsequent patient and/or equipment contamination.[17] The fact that the CND is not included in routine, between-case cleaning procedures indicates a need for improved OR environmental surveillance to assess the efficacy of cleaning and to identify high-risk, emerging environmental targets.[18] Future investigations should examine the impact of strategic targeting of high-risk environmental sites with ultraviolet C therapy via use of OR PathTrac,[13,26] anesthesia machine covers,[27] and germicidal light[28] on OR *S aureus* exposure, transmission, and subsequent infection development.

We identified 2 key risk factors for OR exposure to *S aureus*, the first case of the day and the particular OR. The ability of a strong biofilm-forming and desiccation-tolerant pathogen such as *S aureus* to aerosolize[29] and to settle on environmental surfaces over a 24-hour period ± breakdowns in basic infection control measures, such as OR terminal cleaning, could affect risk of transmission, including an association with the first case of the day. ORs with increased risk of *S aureus* exposure despite adjustment for potentially confounding variables, combined with the absence of predictors for *S aureus* transmission, further support the rationale that behavioral breakdowns can result in increased aerosolization and/or the development of institutional reservoirs that further propagate high-risk transmission. Therefore, a multifaceted approach augmented by proactive optimization of behavioral efforts through surveillance is indicated to address this complex issue, including addressing hyper-transmissible and resistant *S aureus* strain characteristics such as phenotype H.[12]

The overall magnitude of OR contamination was previously characterized by measuring multiple sites within the anesthesia work area.[21] In this study, these findings were extended to an assessment of 62 reservoirs per observational unit. Similar to earlier work, we found a significant increase in environmental contamination from case start to case end.[17] Here, we show a significant increase from case 1 to case 2, indicating residual contamination of multiple environmental sites after the first case. This is an important finding, as residual contamination of the environment is a potent patient-to-patient transmission vehicle in the OR.[16,17] This also likely explains in part why case 1 is a significant predictor for OR *S aureus* exposure. Future work should evaluate disinfection practices and positioning of surgical trays and equipment within or outside of the laminar flow curtain, with or without various air purification systems, and the impact of the development of routine air quality assessment and standardization.[30]

Stopcock contamination has been previously identified as a significant issue in need of new design and better handling. The average frequency of stopcock contamination detected in this study was comparable to that from 2008,[22] suggesting that little to no improvement has been achieved over the last decade at the studied institution. Considering that reduction in stopcock contamination has been associated with reduced infection in a well-designed and executed study, and that stopcock contamination has been repeatedly associated with increased patient mortality, this remains a significant patient safety issue.[16-17,22,31]

## CONCLUSIONS

Threats to OR *S aureus* exposure are reliably not only patient skin sites but also provider hands. Perioperative infection control efforts targeting *S aureus* should be extended from patient decolonization to include hand decontamination improvement strategies involving all intraoperative providers. A multimodal solution is indicated to maximally attenuate high-risk OR *S aureus* exposure and transmission, including attenuation of *S aureus* phenotype H, a hand-derived strain characteristic.

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