Making Invisible Pathogens Visible: How To Prevent SSI's Before They Occur Webinar Toolkit

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Making the Invisible Visible:
How to Prevent SSIs Before They Occur

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Optimization of Perioperative Infection Control

Leapfrog Webinar
Randy W. Loftus, MD
Mayo Clinic

Learning Objectives

- **Objective 1:**
  - What does the current state of contamination in the perioperative arena look like in a post pandemic world? What is the impact on patient safety?
- **Objective 2:**
  - Identify breakdowns within current infection control processes and prevent SSIs before they occur. Demonstrate how mapping pathogen transmission pathways lead to optimizing current IP protocols in the OR including the Big Four.
- **Objective 3:**
  - Addressing breakdowns with clinical decision support software over time can provide actionable improvements, decreasing HAIs and increasing performance metrics.

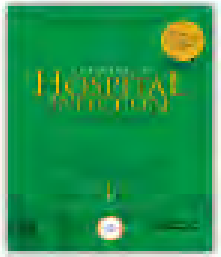
Problem

- **Surgical Site Infections**:
  - Affect **up to 11%** (5,281/50,000) of patients undergoing surgery, including 10% of patients undergoing low risk surgery.[1]
    - UK 2017-2022
    - Retrospective analysis of 50,000 patients open surgery
    - 3 studies in the US in the same timeframe-2 RCTs and a large postimplementation analysis: 6.9-8%[2-4]
  - Increases the risk of death and hospital duration 2-fold.[5]
  - Increases readmission and cost.[6]

1. Guest JF, Fuller GW, Griffiths B. Cohort study to characterize surgical site infections after open surgery in the UK's National Health Service. BMJ Open. 2023 Dec 18;13(12):e076735. doi: 10.1136/bmjopen-2023-076735. PMID: 38110388.
2. Koff et al. Infect Control Hosp Epidemiol. 2016 Aug;37(8):888-895. doi: 10.1017/ice.2016.106. Epub 2016 Jun 7. PMID: 27267310.
3. Loftus et. al. JAMA Netw Open. 2020 Mar 2;3(3):e201934. doi: 10.1001/jamanetworkopen.2020.1934. PMID: 32219407.
4. Wall et. al. J Clin Anesth. 2022 May;77:110632. doi: 10.1016/j.jclinane.2021.110632. Epub 2021 Dec 17. PMID: 34929497.Wall et al.
5. Vogel TR, Dombrovskiy VY, Lowry SF. Impact of infectious complications after elective surgery on hospital readmission and late deaths in the U.S. Medicare population. Surg Infect (Larchmt). 2012 Oct;13(5):307-11. doi: 10.1089/sur.2012.116. Epub 2012 Oct 19. PMID: 23082877.
6. . Dexter F, Epstein RH, Loftus RW. Quantifying and interpreting inequality of surgical site infections among operating rooms. Can J Anaesth. 2021 Jun;68(6):812-824. English. doi: 10.1007/s12630-021-01931-5. Epub 2021 Feb 5. PMID: 33547628.

Transmission, or Pathogen Movement
Anesthesia workspace reservoirs

Transmission of Staphylococcus aureus in the anaesthesia work area has greater risk of association with development of surgical site infection when resistant to the prophylactic antibiotic administered for surgery



R W Loftus [1], F Dexter [2], J R Brown [3]

Affiliations + expand

PMID: 36693592 PMCID: PMC10066826 DOI: 10.1016/j.jhin.2023.01.007

- The risk of development of SSI was **2%** (8/406) without *S. aureus* transmission, **11%** (9/84) with transmission of *S. aureus* isolates that were susceptible to the prophylactic antibiotic used, and **18%** (4/22) with transmission of prophylactic-antibiotic-resistant *S. aureus* isolate.

- The Cochrane-Armitage two-sided test for ordered association was P<0.0001.

- Treating these three groups as 0, 1 and 2, by exact logistic regression, the odds of SSI increased by **3.59** with each unit increase (95% confidence interval 1.92-6.64; P<0.0001).

How Can Transmission Cause Infection?

1. Intravascular injection (hematogenous seeding)

2. Contiguous spread:
    - Contaminating the patient's chest while placing ECG leads

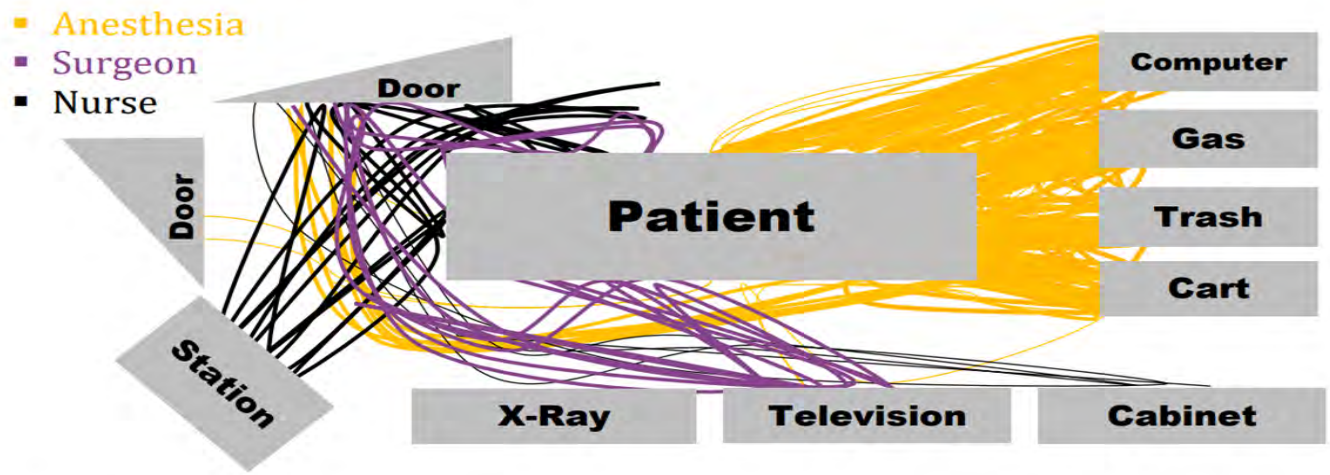
3. Direct contamination:
    - Dust from the boom
    - Sweat dripping from a surgeon's head
    - A surgeon/scrub tech touches a dirty environment, does an abbreviated scrub, and there is a break in their gloves during surgery?

4. Aerosolization: Any reservoir

Rubin R.H. Surgical wound infection: epidemiology, pathogenesis, diagnosis and 585 management. BMC Infect Dis. 2006;6:171.

The problem : Anesthesia Work Area

Patient-Environment-Provider Interactions → **Opportunity for Pathogen Transmission**



High task density: **150-300** Hand hygiene opportunities per hour [1]

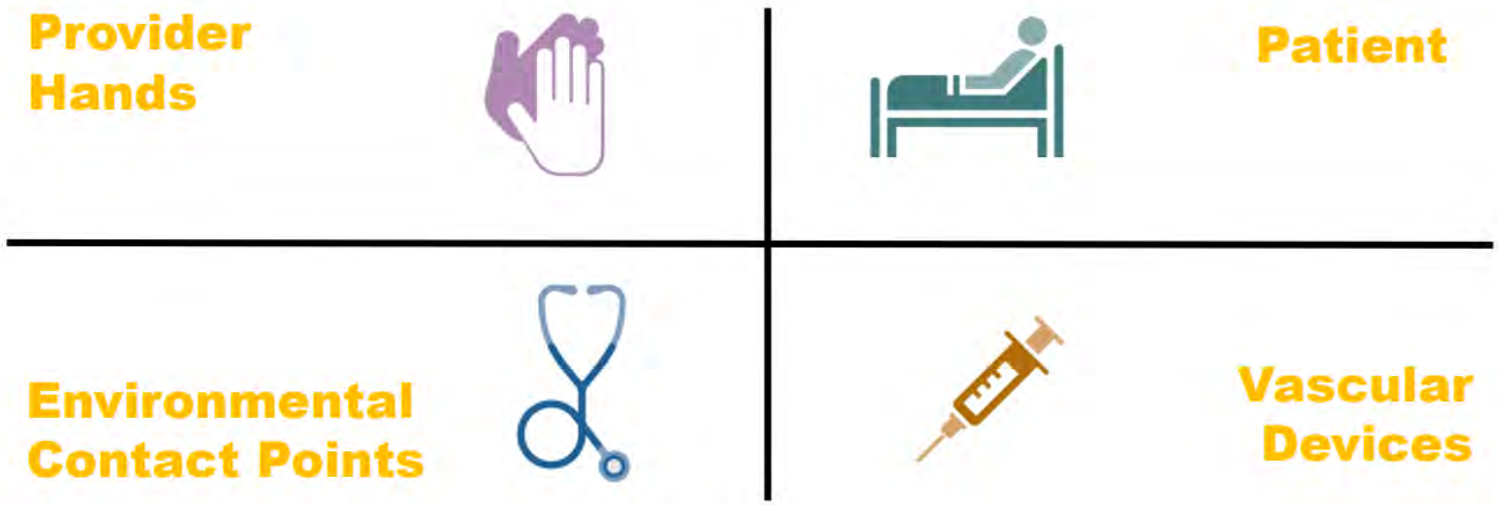
The image above is a simple map of potential transmission pathways that could occur during a high-risk procedure. The gold shows the anesthesia environment where there are up to 300 pathways per of movement by clinicians per hour during the vulnerable period a patient is being operated on, many of which involve access to the patient's blood stream. [1]

1. Sharma A, Fernandez PG, Rowlands JP, Koff MD, Loftus RW. Perioperative Infection Transmission: the Role of the Anesthesia Provider in Infection Control and Healthcare-Associated Infections. Curr Anesthesiol Rep. 2020 Jul 17:1-9. doi: 10.1007/s40140-020-00403-8. PMCID: PMC7366489.

Solution: Optimization of Basic Infection Control Measures

The big four [1]

The major risk factors for bacteria to spread within the operating room are:



1. Sharma, A., Fernandez, P.G., Rowlands, J.P. *et al.* Perioperative Infection Transmission: the Role of the Anesthesia Provider in Infection Control and Healthcare-Associated Infections. *Curr Anesthesiol Rep* **10,** 233–241 (2020). https://doi.org/10.1007/s40140-020-00403-8

Methodology for Optimization

Monitor perioperative bacterial transmission

Identify improvement targets

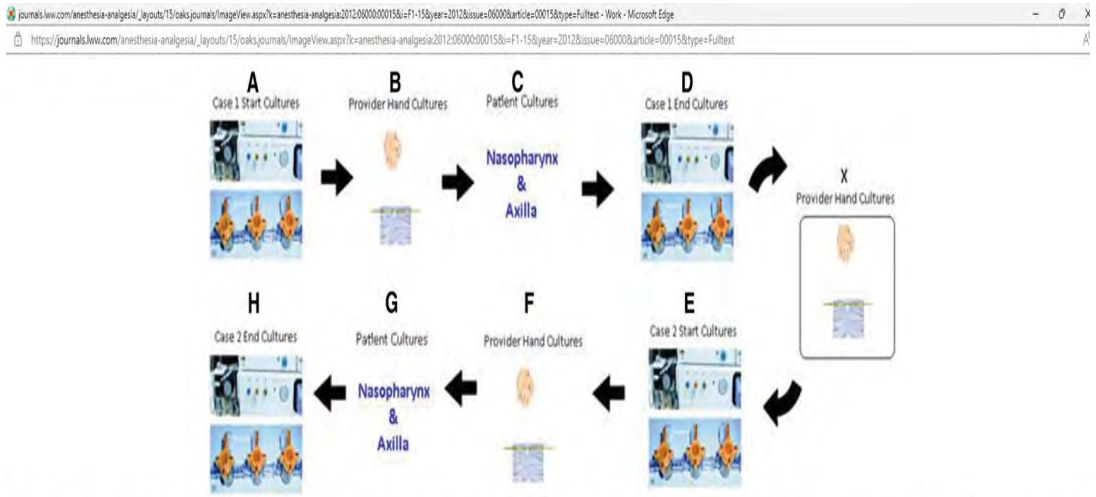
Provide feedback for system optimization

Reduce transmission and infections, improving patient safety, reducing cost

Loftus, Randy W. MD*; Brown, Jeremiah R. PhD, MS†; Koff, Matthew D. MD, MS*; Reddy, Sundara MD‡; Heard, Stephen O. MD§; Patel, Hetal M. BS, MLT*; Fernandez, Patrick G. MD*; Beach, Michael L. MD*; Corwin, Howard L. MD‖; Jensen, Jens T. MS*; Kispert, David BA*; Huysman, Bridget BA*; Dodds, Thomas M. MD*; Ruoff, Kathryn L. PhD¶; Yeager, Mark P. MD*. Multiple Reservoirs Contribute to Intraoperative Bacterial Transmission. Anesthesia & Analgesia 114(6):p 1236-1248, June 2012. | DOI: 10.1213/ANE.0b013e31824970a2

Reservoir Monitoring

Observational Unit: Case-Pair



Schematic of culture sampling sequence. Culture samples were collected sequentially (A→ H) from the operative environment (adjustable pressure limiting valve and agent dial), patient IV tubing, provider hands, and the patient nasopharynx/axilla. Provider hands were cultured at case start before patient care, intermittently throughout patient care, at case end, and upon provider return to the operating room after an absence during the case (X).

Collection Kits

OR PathTrac Kit Contents & Layout

There is a chipboard pad, a 3x5" OR data information card, and collection list in between the pre- and post-incision layers. Layers 1-3 are on top and layers 4-6 are underneath the chipboard divider (Fig. 6).

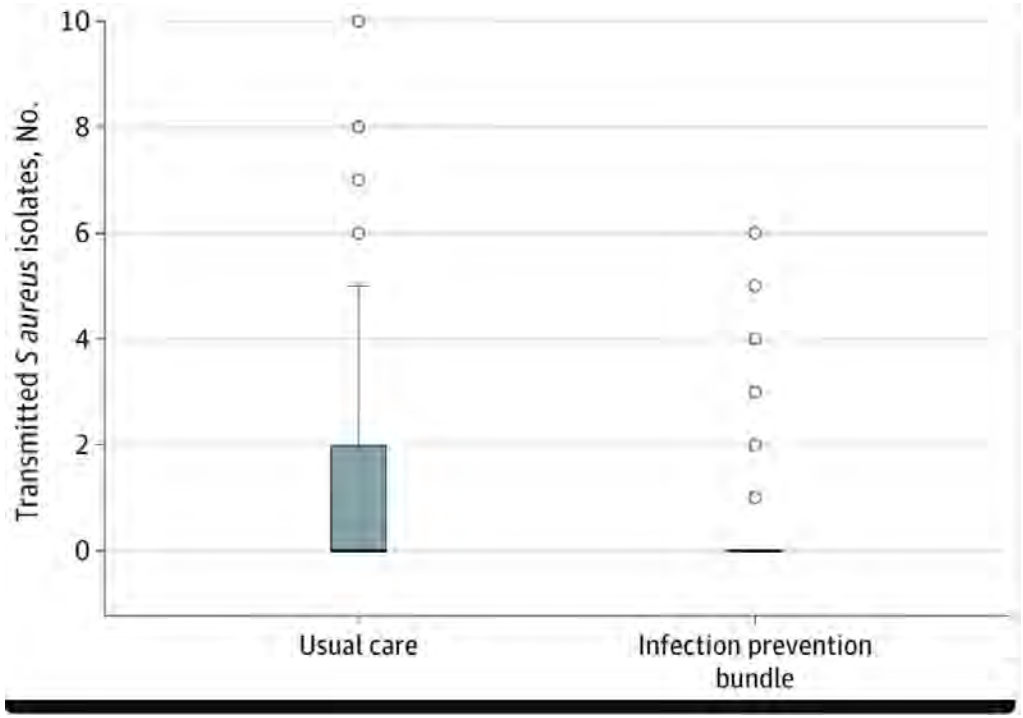
Figure 6. Layers 1-3 (left), chip board divider with information card and collection list (middle), layers 4-6 (right)

All samples should be collected while wearing gloves, a mask, and hair cap in the OR. All samples should be placed back into its layer bag once collection of that sample is completed. All swab samples must be immediately labeled after collection.

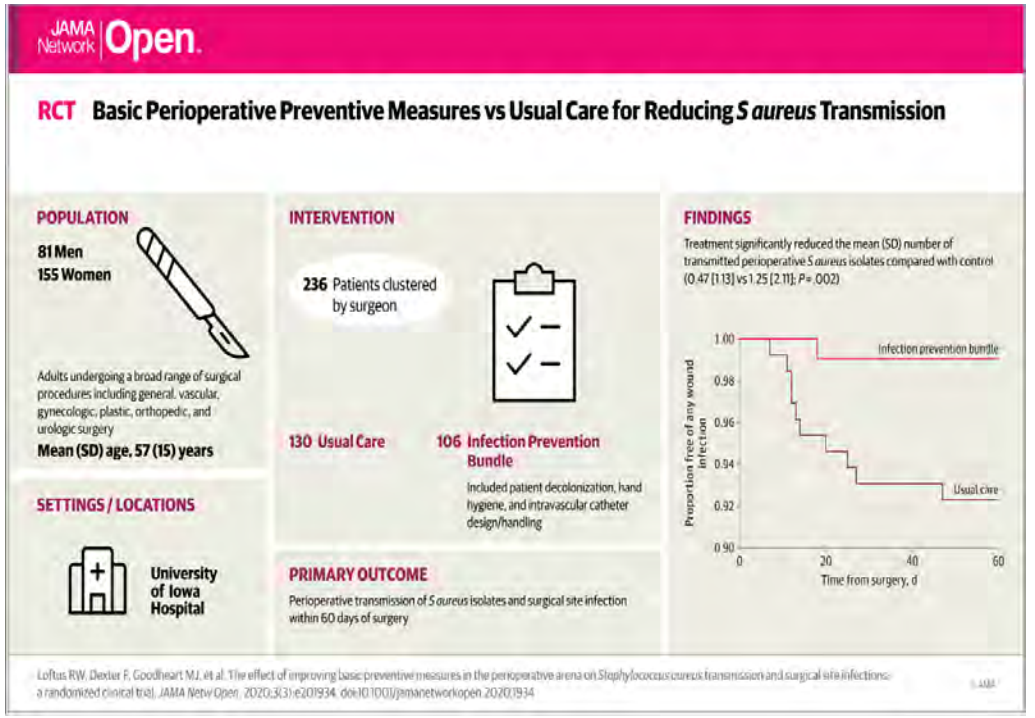
Robinson ADM, Dexter F, Renkor V, Reddy S, Loftus RW. Operating room PathTrac analysis of current intraoperative Staphylococcus aureus transmission dynamics. Am J Infect Control. 2019 Oct;47(10):1240-1247. doi: 10.1016/j.ajic.2019.03.028. Epub 2019 Apr 27. PMID: 31036398.

Efficacy

Transmission Reduced

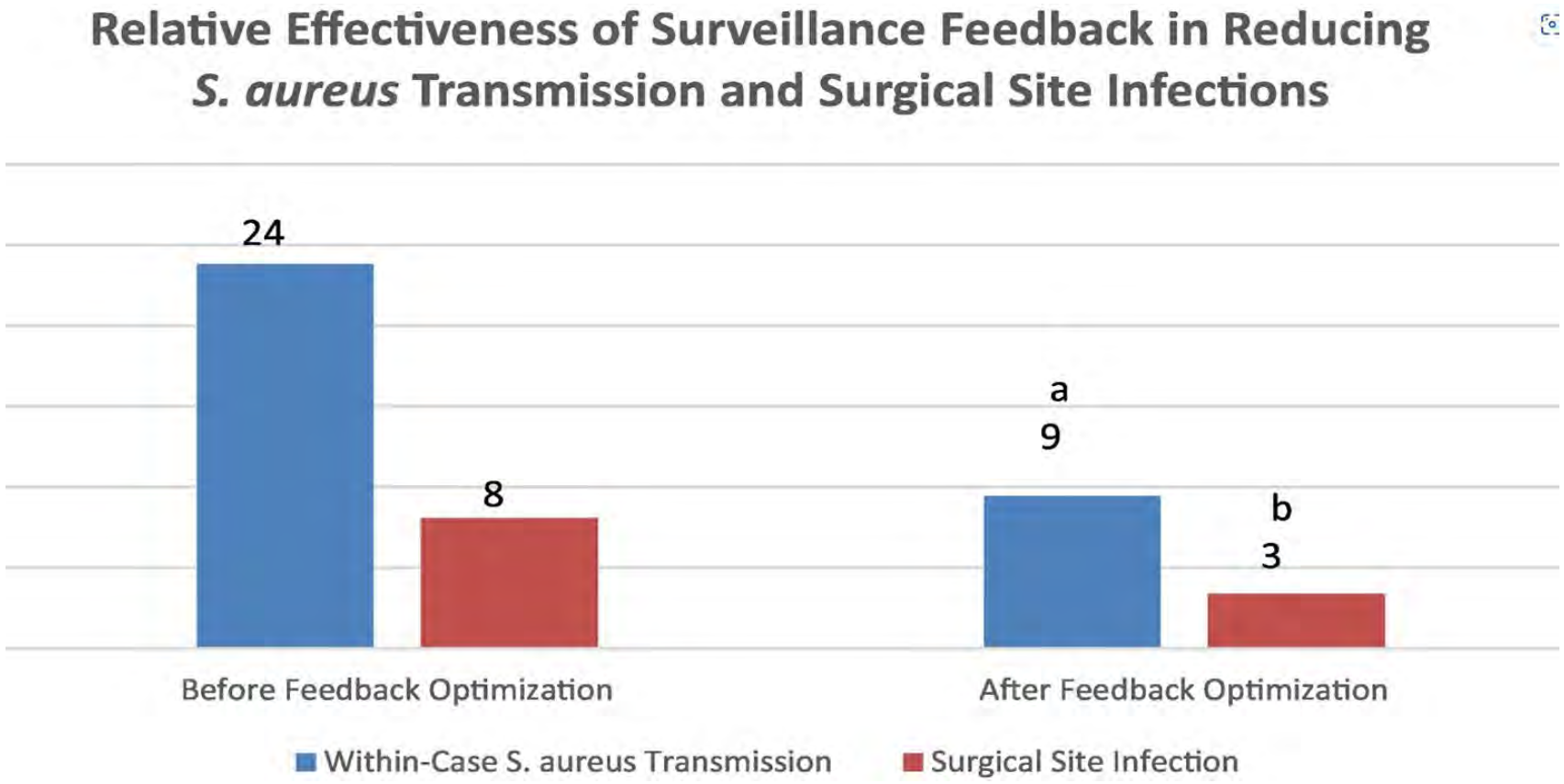


Surgical Site Infection Reduced



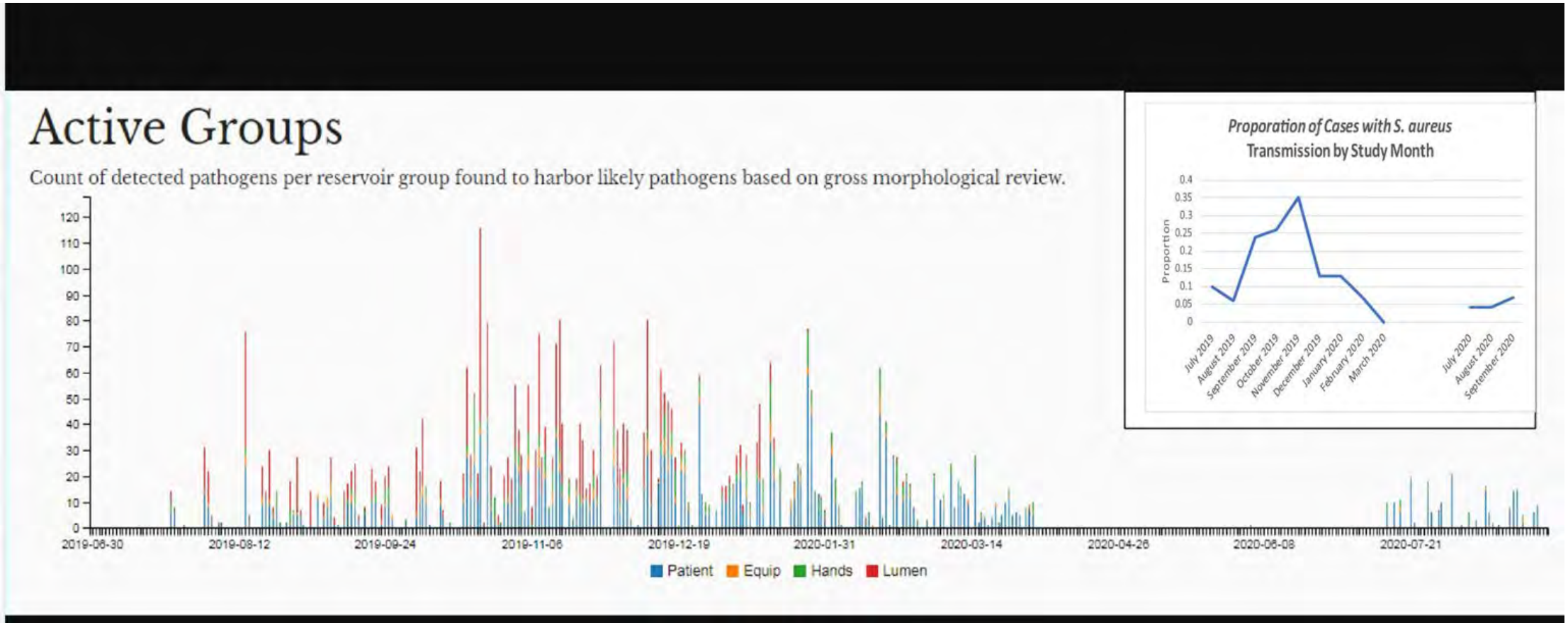
Loftus RW, Dexter F, Goodheart MJ, McDonald M, Keech J, Noiseux N, Pugely A, Sharp W, Sharafuddin M, Lawrence WT, Fisher M, McGonagill P, Shanklin J, Skeete D, Tracy C, Erickson B, Granchi T, Evans L, Schmidt E, Godding J, Brenneke R, Persons D, Herber A, Yeager M, Hadder B, Brown JR. The Effect of Improving Basic Preventive Measures in the Perioperative Arena on Staphylococcus aureus Transmission and Surgical Site Infections: A Randomized Clinical Trial. JAMA Netw Open. 2020 Mar 2;3(3):e201934. doi: 10.1001/jamanetworkopen.2020.1934. PMID: 32219407.

Effectiveness



Wall RT, Datta S, Dexter F, Ghyasi N, Robinson ADM, Persons D, Boling KA, McCloud CA, Krisanda EK, Gordon BM, Koff MD, Yeager MP, Brown J, Wong CA, Loftus RW. Effectiveness and feasibility of an evidence-based intraoperative infection control program targeting improved basic measures: a post-implementation prospective case-cohort study. J Clin Anesth. 2022 May;77:110632. doi: 10.1016/j.jclinane.2021.110632. Epub 2021 Dec 17. PMID: 34929497.

Effectiveness



Can J Anesth/J Can Anesth
https://doi.org/10.1007/s12630-024-02707-3

REPORTS OF ORIGINAL INVESTIGATIONS

A threshold of 100 or more colony-forming units on the anesthesia machine predicts bacterial pathogen detection: a retrospective laboratory-based analysis

Un seuil de 100 unités de formation de colonie ou plus sur l'appareil d'anesthésie prédit la détection d'agents pathogènes bactériens : une analyse rétrospective en laboratoire

Franklin Dexter, MD, PhD, FASA · Kaitlin M. Walker · Carmen Troncoso Brindeiro, PhD · Chase P. Loftus · Cornelie C. L. Banguid, MPH · Randy W. Loftus, MD

Received: 1 May 2023 / Revised: 7 November 2023 / Accepted: 8 November 2023

Table 1 Distinct samples, rooms, cases, reservoirs, days, and months among hospitals and pathogens

Hospitals or pathogens	Samples	Operating rooms	Cases	Reservoirs[a]	Days	Months/years[b]
Overall, all samples	31,783	105	2,616	40	385	53
Hospital 1	12,339	23	981	13	111	12
Hospital 2	8,804	42	685	40	209	41
Hospital 3	9,077	8	826	13	82	24
Hospitals 4 to 9	1,563	32	124	13	31	17
No pathogen detected[c]	24,182	99	2,615	39	385	53
Any pathogen detected[c]	7,601	98	2,170	34	377	53
Coagulase-negative *Staphylococcus*	5,047	96	1,906	33	374	53
Staphylococcus aureus, methicillin-sensitive	1,376	84	701	20	247	49
Gram-negatives except for *Pseudomonas*; includes *Klebsiella*, *Acinetobacter*, and *Enterobacter*	486	74	320	28	152	42
Enterococcus, vancomycin-sensitive	283	60	189	17	90	31
Staphylococcus aureus, methicillin-resistant	220	52	115	16	85	38
Pseudomonas	73	31	61	14	42	24
Micrococcus[d]	61	33	55	18	44	26
Bacillus	37	19	32	12	21	13
Other pathogenic *Staphylococcus*	8	5	6	8	6	2
Corynebacterium[d]	5	3	5	4	4	2
Enterococcus, vancomycin-resistant	4	3	4	4	4	3
Streptococcus	1	1	1	1	1	1

[a]The reservoirs are listed in Table 2

[b]"Months/years" means distinct months (e.g., January 2018 and January 2021 would be two months/years)

[c]The "no pathogen detected" and "any pathogen detected" rows have similar counts other than for the samples. The second column's entries of 24,182 and 7,601 samples sum to equal 31,783, the value in the first row, "overall, all samples." The third column's entries of 99 and 98 operating rooms, respectively, mean that the 24,182 samples with no pathogen detected were collected from among 99 of the 105 operating rooms (first row) and the 7,601 samples with any pathogen were collected from among 98 of the 105 rooms. The same counts of distinct items apply to the fourth through seventh columns of numbers. For example, both the "no pathogen detected" and "any pathogen detected" rows have 53 months/years. That means that all 53 months included at least one of the 24,182 samples with no pathogen detected and at least one of the

Dexter F, Walker KM, Brindeiro CT, Loftus CP, Banguid CCL, Loftus RW. A threshold of 100 or more colony-forming units on the anesthesia machine predicts bacterial pathogen detection: a retrospective laboratory-based analysis. Can J Anaesth. 2024 Feb 27. English. doi: 10.1007/s12630-024-02707-3. Epub ahead of print. PMID: 38413516.

Target Pathogen Distribution

Threshold for detecting environmental pathogens

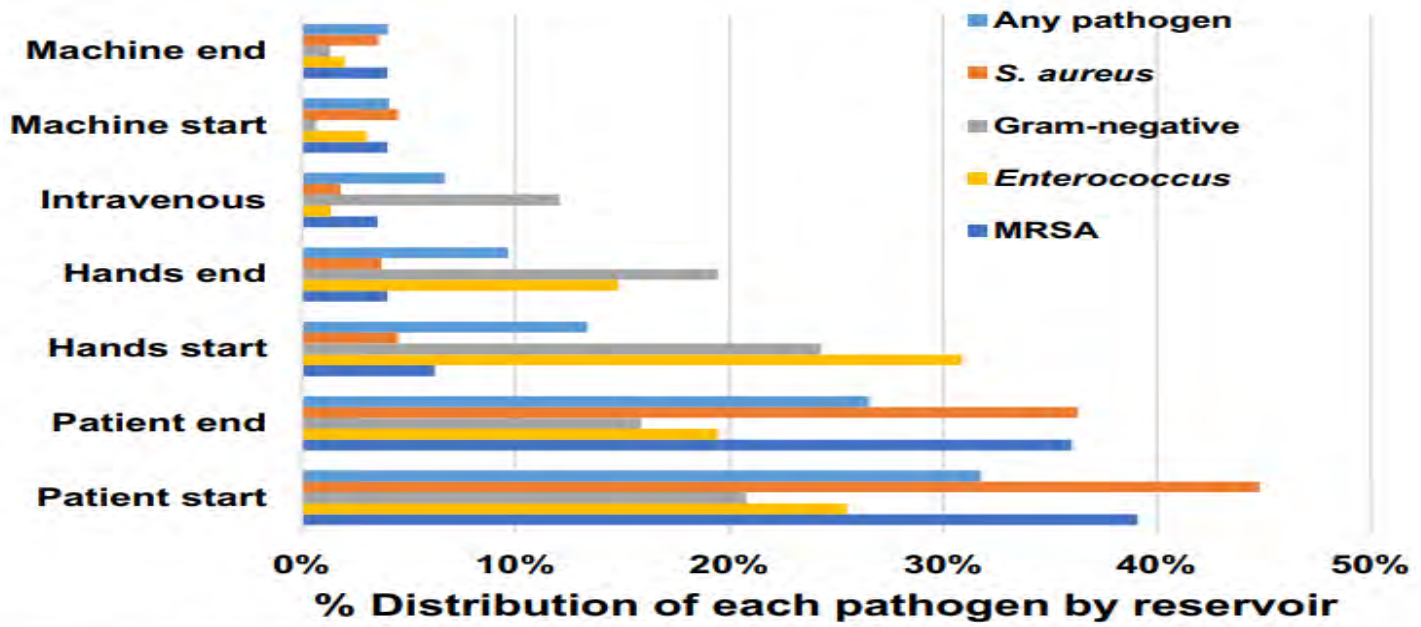


Figure Percentage distribution of each bacterial pathogen by reservoir. For "any pathogen," the total sample size was 7,601 isolates. The sum of the blue bars among the seven categories of reservoirs equals 100%. In other words, the percentages along the horizontal axis sum to 100% for each of the five classes. The categories of reservoirs are displayed in ascending frequency of percentage contribution to any pathogen (e.g., 4% contribution from anesthesia machine at end of case and increasing progressively to 32% at case start for patients). "*S. aureus*" refers to methicillin-sensitive *Staphylococcus aureus*. The total sample size was 1,424 isolates. Again, the sum of the orange bars among the seven categories of reservoirs equals 100%. The total sample sizes were 606 for gram-negatives, 298 for vancomycin-sensitive or vancomycin-resistant *Enterococcus*, and 225 for MRSA. The sample sizes of isolates are each slightly larger than the count of distinct samples from Table 1 because a few samples contain more than one class of pathogen. The hands at the start and at the end of each case includes two reservoirs, hands of the anesthesiologist, and hands of the anesthesia assistant (e.g., nurse anesthetist). The patient at the start and end each includes three reservoirs: nose, axilla, and groin.

MRSA = methicillin-resistant *Staphylococcus aureus*; *S. aureus* = *Staphylococcus aureus*

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CFU < 100 Threshold

CFU > 100

Table 2 Observed prevalence of return of ≥ 100 colony-forming units by reservoir and pathogen

Reservoir	Samples	Any pathogen	*S. aureus*	Gram-negative	*Enterococcus*	MRSA
Machine, start of case	1,083/2,599 (42%)	264/1,083 (24%)	50/1,083 (5%)	3/1,083 (0%)	9/1,083 (1%)	5/1,083 (0%)
Patient axilla, start of case	1,866/2,566 (73%)	544/1,866 (29%)	90/1,866 (5%)	26/1,866 (1%)	14/1,866 (1%)	14/1,866 (1%)
Patient nose, start of case	2,454/2,564 (96%)	1,028/2,454 (42%)	444/2,454 (18%)	50/2,454 (2%)	8/2,454 (0%)	55/2,454 (2%)
Machine, end of case	1,179/2,551 (46%)	257/1,179 (22%7)	40/1,179 (3%)	6/1,179 (1%)	6/1,179 (1%)	8/1,179 (1%)
Intravenous lumen, end of case	705/2,545 (28%)	339/705 (48%)	13/705 (2%)	43/705 (6%)	4/705 (1%)	5/705 (1%)
Patient groin, start of case	2,009/2,543 (79%)	807/2,009 (40%)	88/2,009 (4%)	50/2,009 (2%)	54/2,009 (3%)	17/2,009 (1%)
Patient axilla, end of case	1,779/2,512 (71%)	493/1,779 (28%)	76/1,779 (4%)	20/1,779 (1%)	17/1,779 (1%)	10/1,779 (1%)
Patient nose, end of case	2,324/2,503 (93%)	847/2,324 (36%)	345/2,324 (15%)	41/2,324 (2%)	15/2,324 (1%)	59/2,324 (3%)
Patient groin, end of case	1,738/2,489 (70%)	630/1,738 (36%)	80/1,738 (5%)	32/1,738 (2%)	25/1,738 (1%)	10/1,738 (1%)
Anesthesiologist hands, start of case	1,814/2,394 (76%)	581/1,814 (32%)	37/1,814 (2%)	75/1,814 (4%)	54/1,814 (3%)	10/1,814 (1%)
Anesthesiologist hands, end of case	1,396/2,028 (69%)	405/1,396 (29%)	29/1,396 (2%)	62/1,396 (4%)	28/1,396 (2%)	9/1,396 (1%)
Anesthesia provider, hands, start of case	1,450/1,714 (85%)	425/1,450 (29%)	25/1,450 (2%)	71/1,450 (5%)	38/1,450 (3%)	4/1,396 (0%)
Anesthesia provider, hands, end of case	1,308/1,597 (82%)	315/1,308 (24%)	22/1,308 (2%)	55/1,308 (4%)	16/1,308 (1%)	0/1,308 (0%)
Not anesthesia work area	453/1,178 (38%)	250/453 (55%)	7/453 (2%)	32/453 (7%)	8/453 (2%)	6/453 (1%)

Numbers are *n*/total *N* (%) samples. Table 1 provides the complete list of classes of pathogens. "*S. aureus*" refers to methicillin-sensitive *Staphylococcus aureus*. *Enterococcus* includes both vancomycin-sensitive and vancomycin-resistant *Enterococcus*. The columns match the categories in the Figure. The rows are listed in descending sequence of the counts of samples. The "not anesthesia work areas" included circulating nurse's computer mouse, circulating nurses' hands, attending surgeons' hands, instrument tray, and recovery room nurses' hands. For an example of interpretation, from the second to last row, the anesthesia providers' hands were contaminated (≥ 100 CFU) for 82% of the 1,308/1,597 end-of-case samples. Among the 1,308 samples with contamination, 24% (315) were contaminated with any pathogen and 2% (22) were contaminated with methicillin-sensitive *S. aureus*.

CFU = colony-forming units; MRSA = methicillin-resistant *Staphylococcus aureus*

CFU < 100

Threshold for detecting environmental pathogens

Table 3 Observed prevalence of pathogens when measured reservoirs return < 100 colony-forming units

Reservoir	Samples	Any pathogen	*S. aureus*	Gram-negative	*Enterococcus*	MRSA
Machine, start of case	1,516	47/1,516 (3%)	14/1,516 (1%)	1/1,516 (0%)	0/1,516 (0%)	4/1,516 (0%)
Patient axilla, start of case	700	17/700 (2%)	11/700 (2%)	0/700 (0%)	0/700 (0%)	0/700 (0%)
Patient nose, start of case	110	11/110 (10%)	3/110 (3%)	0/110 (0%)	0/110 (0%)	2/110 (2%)
Machine, end of case	1,372	49/1,372 (4%)	11/1,372 (1%)	2/1,372 (0%)	0/1,372 (0%)	1/1,372 (0%)
Intravenous lumen, end of case	1,840	170/1,840 (9%)	13/1,840 (1%)	30/1,840 (2%)	0/1,840 (0%)	3/1,840 (0%)
Patient groin, start of case	534	7/534 (1%)	2/534 (0%)	0/534 (0%)	0/534 (0%)	0/534 (0%)
Patient axilla, end of case	733	17/733 (2%)	6/733 (1%)	2/733 (0%)	0/733 (0%)	1/733 (0%)
Patient nose, end of case	179	11/179 (6%)	3/179 (2%)	0/179 (0%)	0/179 (0%)	0/179 (0%)
Patient groin, end of case	751	19/751 (3%)	7/751 (1%)	1/751 (0%)	1/751 (0%)	1/751 (0%)
Anesthesiologist hands, start of case	580	7/580 (1%)	2/580 (0%)	0/580 (0%)	0/580 (0%)	0/580 (0%)
Anesthesiologist hands, end of case	632	9/632 (1%)	2/632 (0%)	1/632 (0%)	0/632 (0%)	0/632 (0%)
Anesthesia provider, start of case	264	3/264 (1%)	0/264 (0%)	1/264 (0%)	0/264 (0%)	0/264 (0%)
Anesthesia provider, end of case	289	5/289 (2%)	0/289 (0%)	0/289 (0%)	0/289 (0%)	0/289 (0%)
Not anesthesia work area	725	44/725 (6%)	4/725 (1%)	2/725 (0%)	1/725 (0%)	1/725 (0%)

Numbers are *N* or *n*/total *N* (%) samples. Table 1 includes the complete list of classes of pathogens. "*S. aureus*" refers to methicillin-sensitive *Staphylococcus aureus*. *Enterococcus* includes both vancomycin-sensitive and vancomycin-resistant *Enterococcus*. The columns match the categories in the Figure. The rows are listed in the same sequence as for Table 2. See from the third column that for < 100 CFU there are three reservoirs with observed prevalence of any pathogen greater than 5%, those reservoirs being the patient nose at the start of the case, intravenous catheter at the end of the case, and patient nose at the end of the case. We repeated calculations for < 10 CFU. The corresponding any pathogen percentages then are 7% (6/92) for patient nose start of case, 5% (81/1649) for intravenous lumen end of case, and 5% (7/140) for patient nose end of case.

CFU = colony-forming units; MRSA = methicillin-resistant *Staphylococcus aureus*

Dexter F, Walker KM, Brindeiro CT, Loftus CP, Banguid CCL, Loftus RW. A threshold of 100 or more colony-forming units on the anesthesia machine predicts bacterial pathogen detection: a retrospective laboratory-based analysis. Can J Anaesth. 2024 Feb 27. English. doi: 10.1007/s12630-024-02707-3. Epub ahead of print. PMID: 38413516.

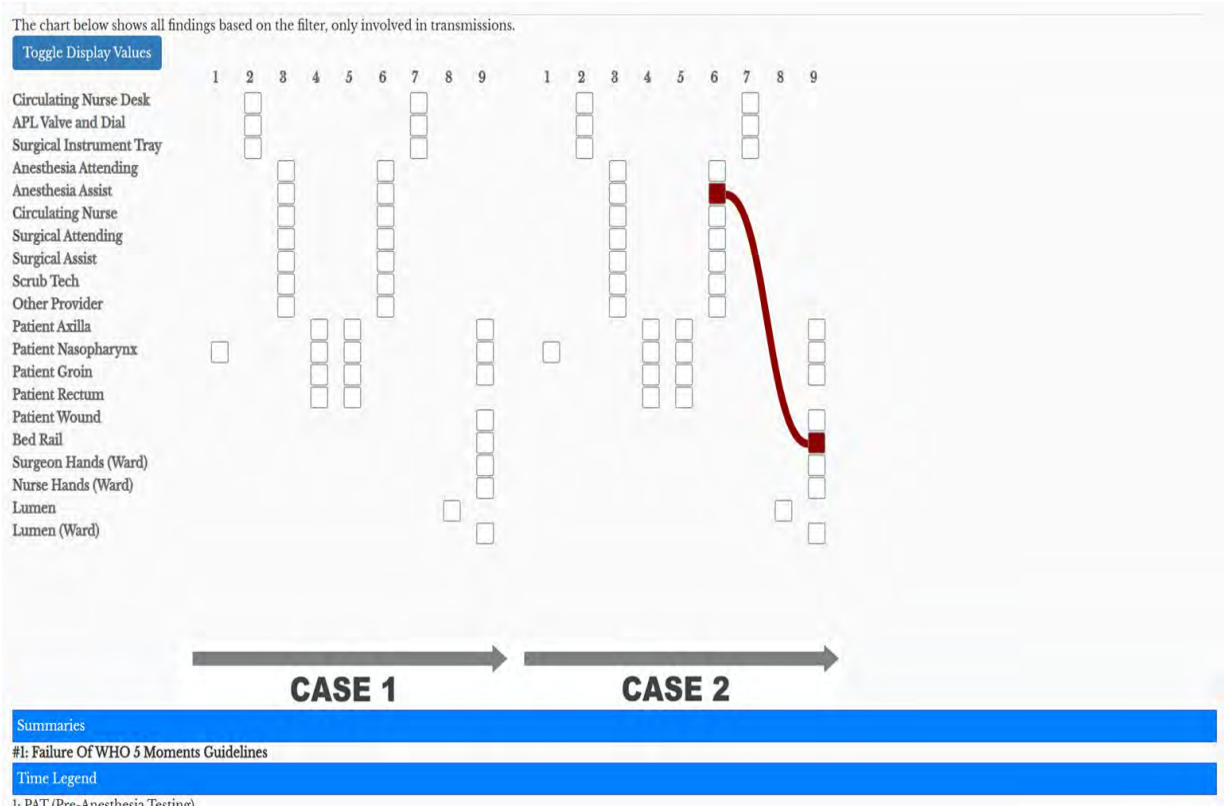
Dashboard Colony Forming Unit (CFU) 100: Maps to Preventive Measures

Drilling Down

Robinson ADM, Dexter F, Renkor V, Reddy S, Loftus RW. Operating room PathTrac analysis of current intraoperative Staphylococcus aureus transmission dynamics. Am J Infect Control. 2019 Oct;47(10):1240-1247. doi: 10.1016/j.ajic.2019.03.028. Epub 2019 Apr 27. PMID: 31036398.

Identify Pathogens Driving Failure

- Map transmission
- Address improvement targets



Robinson ADM, Dexter F, Renkor V, Reddy S, Loftus RW. Operating room PathTrac analysis of current intraoperative Staphylococcus aureus transmission dynamics. Am J Infect Control. 2019 Oct;47(10):1240-1247. doi: 10.1016/j.ajic.2019.03.028. Epub 2019 Apr 27. PMID: 31036398.

Implementation

Table 4
Implementation steps for surveillance of *S. aureus* transmission to monitor effectiveness and provide feedback on intraoperative infection control.

Step	Protocols
1	Identify for each hospital what populations would be evaluated Apply the principles in Table 5 and its legend to choose combinations of specialty and operating room
2	For each population selected from Step 1, sample from 25 successive pairs of cases For large initial incidences of transmission, 15 pairs of cases may be enough
3	For each population from Step 2 with incidences of transmission exceeding threshold by the binomial test, perform additional sampling while implementing enhanced infection control Sampling would be 75 additional pairs of cases, but for large initial incidences 43 additional pairs of cases may be enough
4	For each population from Step 3 with significant decline in transmission by Boschloo's exact test, monitor sustained performance by sampling from 1-2 (average 1.5) pairs of cases per workday Using Bernoulli Cumulative Sum control charts (CUSUM), expect to detect increase comparable to Table 1 within 3 months, while keeping the average number of observations to false signal at 15 months, as shown in the uploaded file at https://FDshort.com/SampleSize2SeqTests

Dexter F, Ledolter J, Wall RT, Datta S, Loftus RW. Sample sizes for surveillance of S. aureus transmission to monitor effectiveness and provide feedback on intraoperative infection control including for COVID-19. Perioper Care Oper Room Manag. 2020 Sep;20:100115. doi: 10.1016/j.pcorm.2020.100115. Epub 2020 May 21. PMID: 32501426; PMCID: PMC7240254.

Example Hospital

Journal of Clinical Anesthesia
Volume 77, May 2022, 110632

Original Contribution

Effectiveness and feasibility of an evidence-based intraoperative infection control program targeting improved basic measures: a post-implementation prospective case-cohort study ☆

Russell T. Wall MD [a], Subhradeep Datta [b], Franklin Dexter MD PhD FASA [c], Niloofar Ghyasi [b], Alysha D.M. Robinson [d], Deanna Persons [e], Kate A. Boling [f], Christopher A. McCloud [b], Emily K. Krisanda [b], Brandon M. Gordon [g], Matthew D. Koff MD [h], Mark P. Yeager MD [i], Jeremiah Brown PhD [j],

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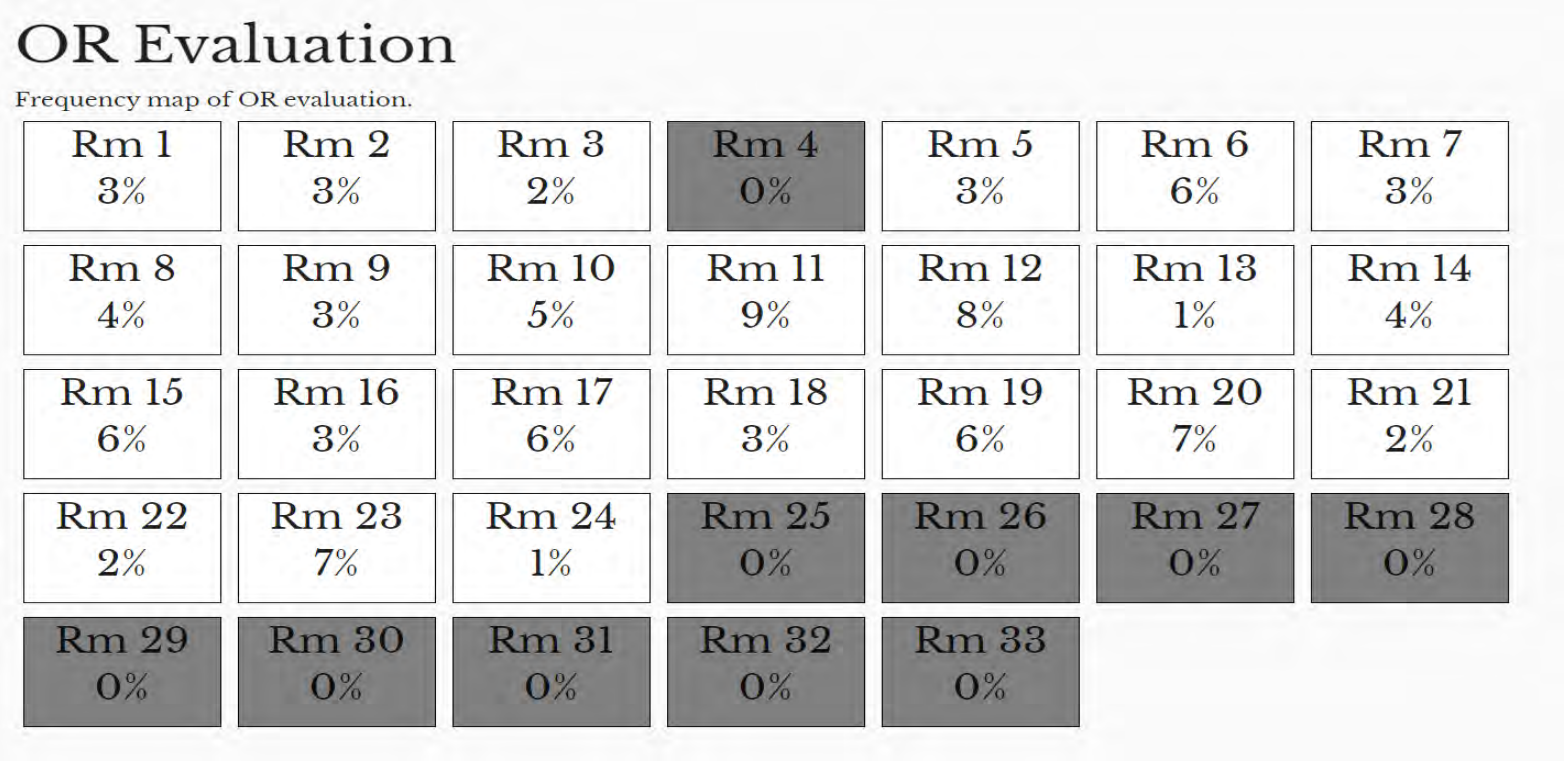

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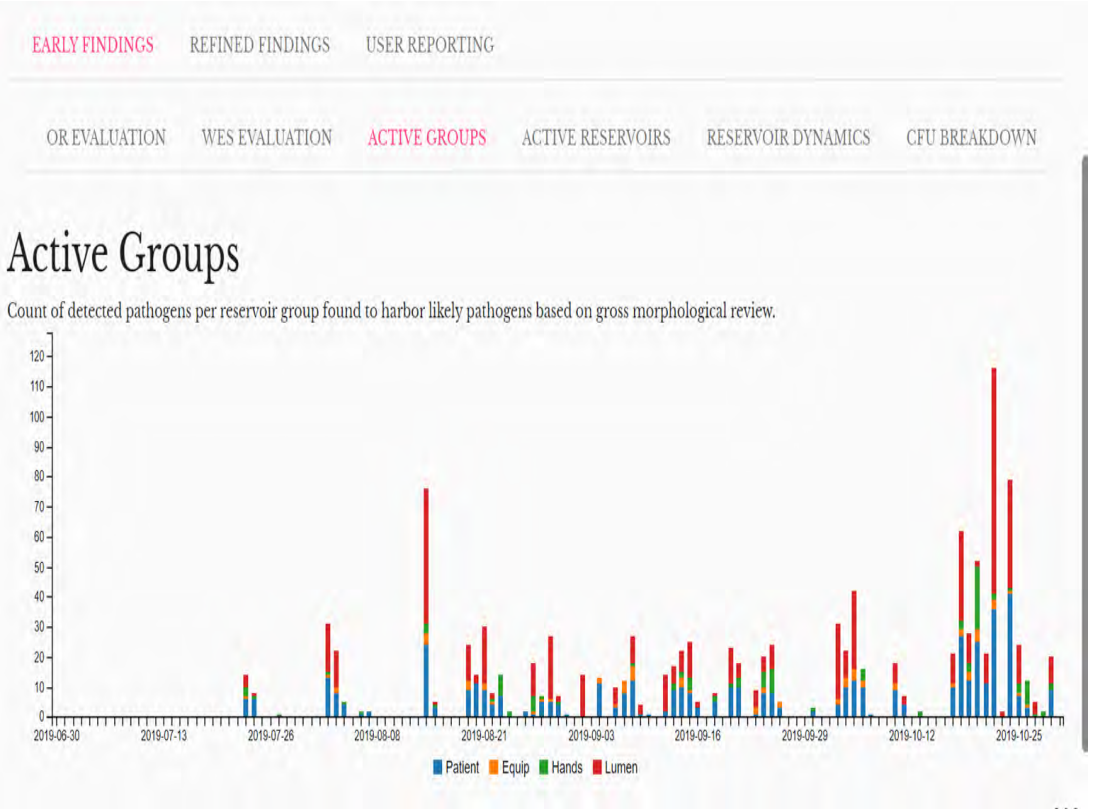

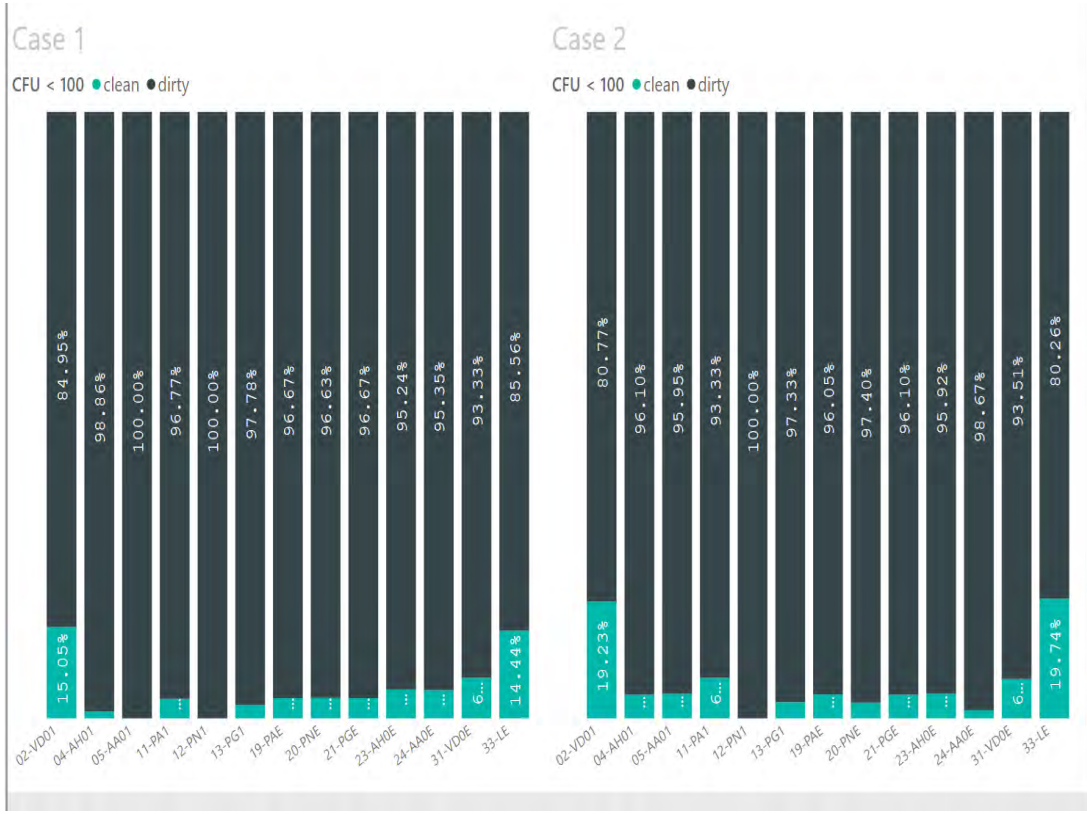

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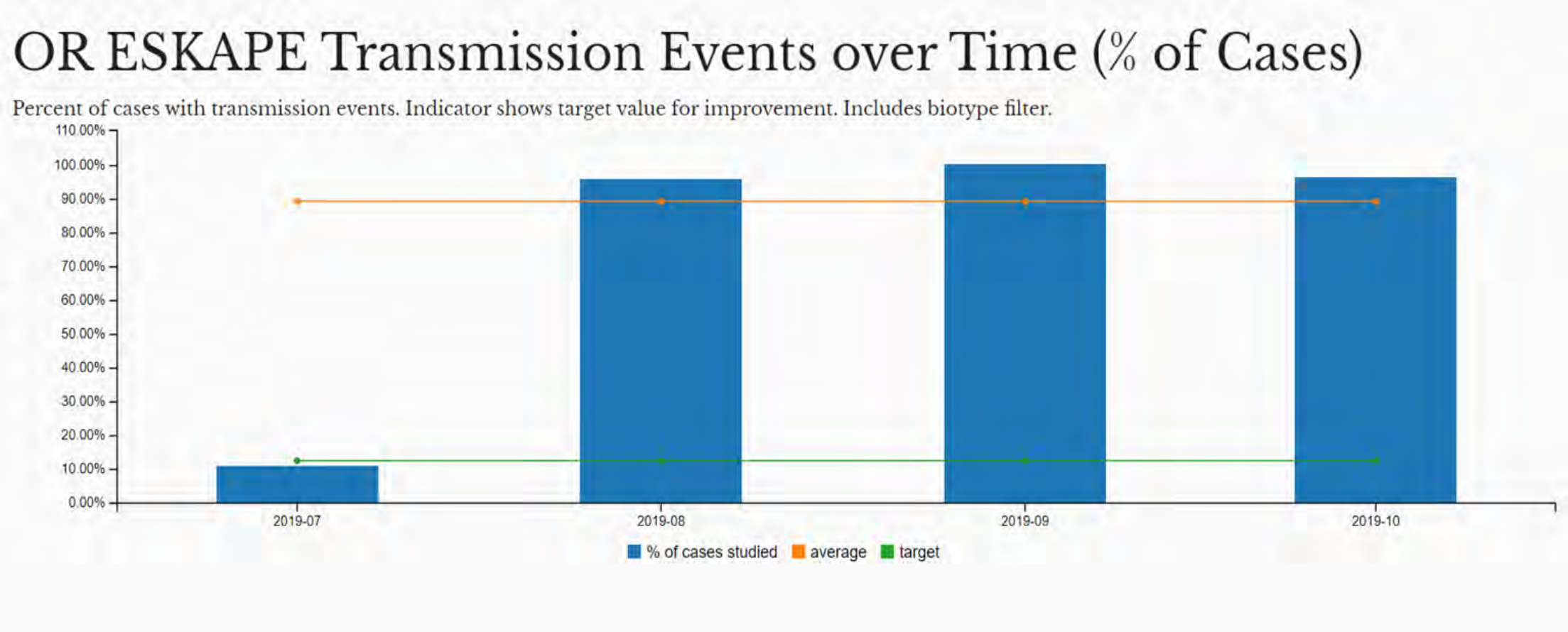

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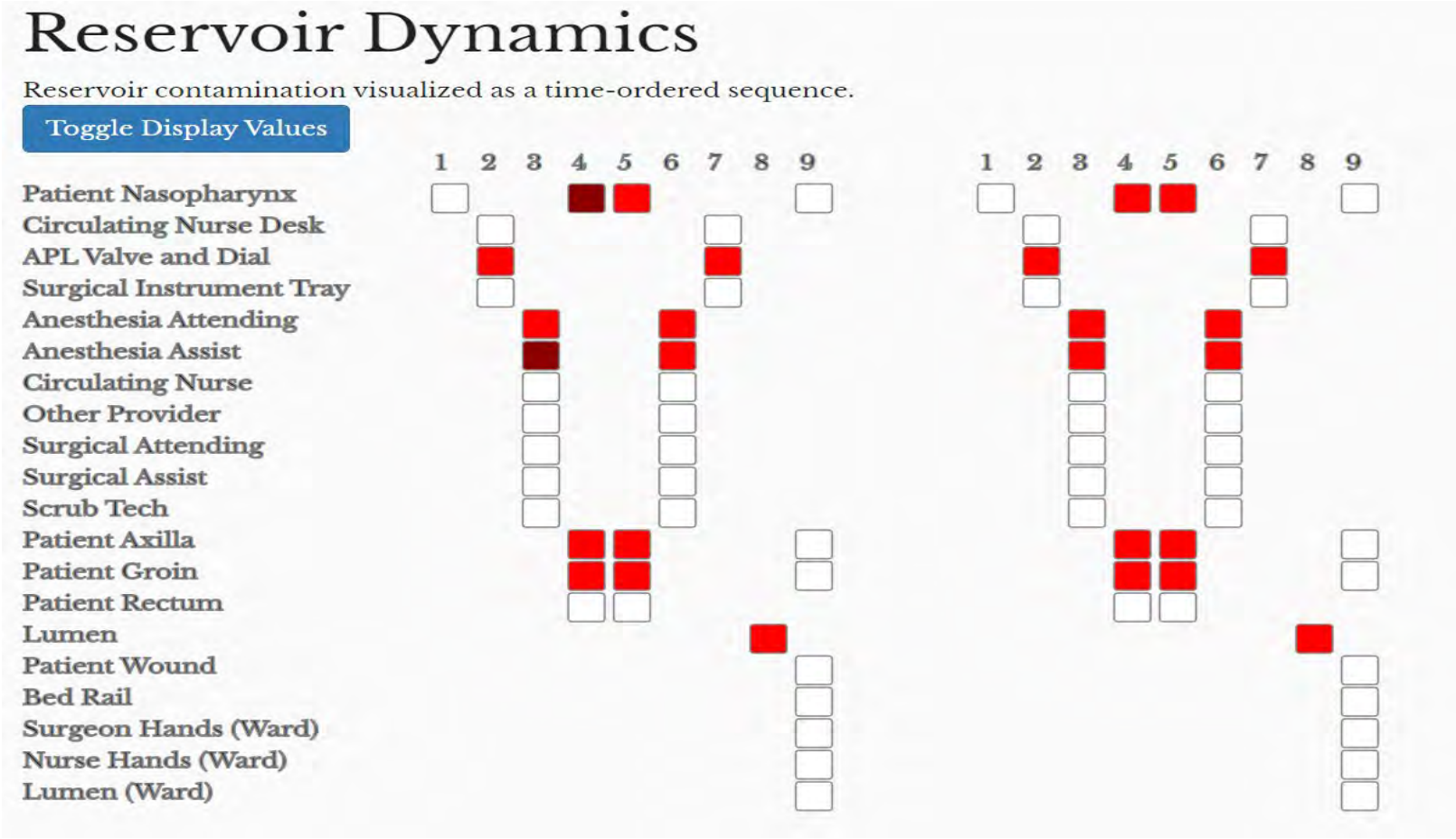
Optimization: Improvement Timing



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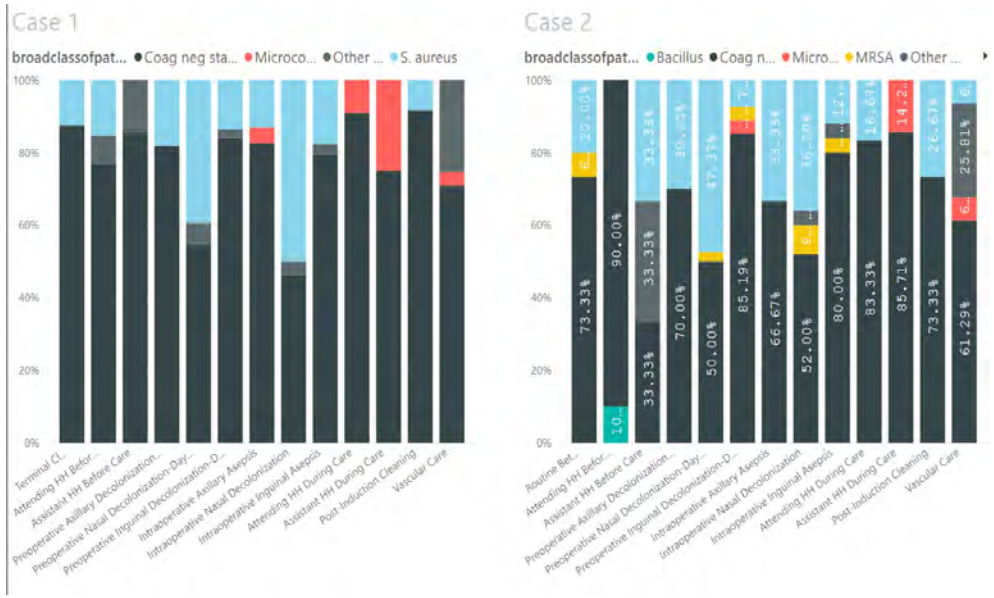
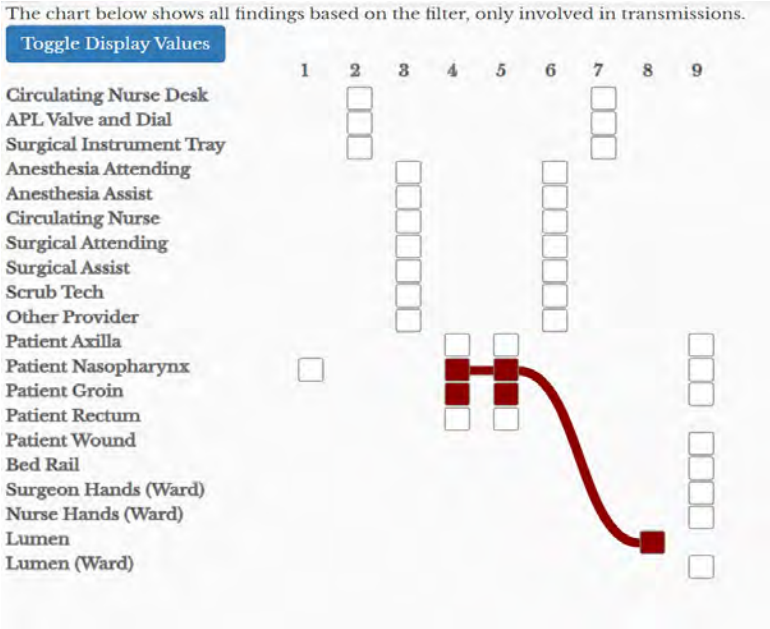
Drilling Down

Pathogens Driving Failure



Transmission Stories: Improvement Targets



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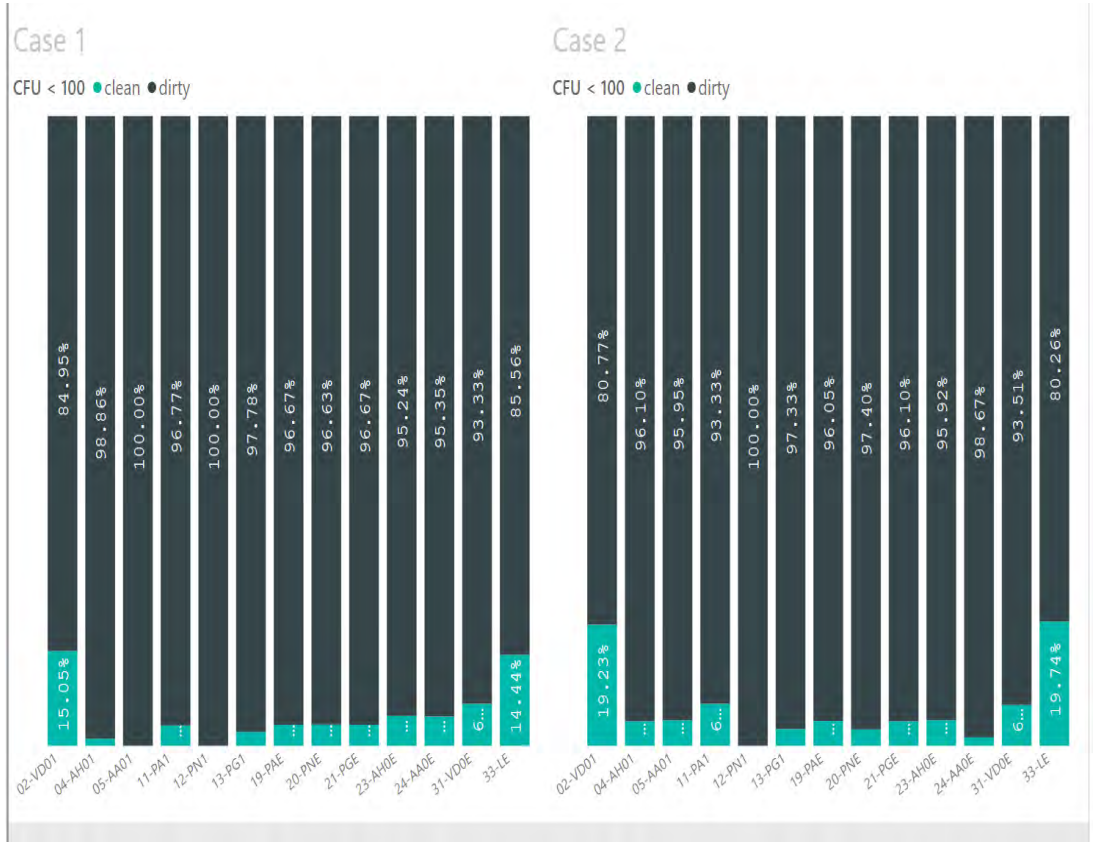

After

Optimization

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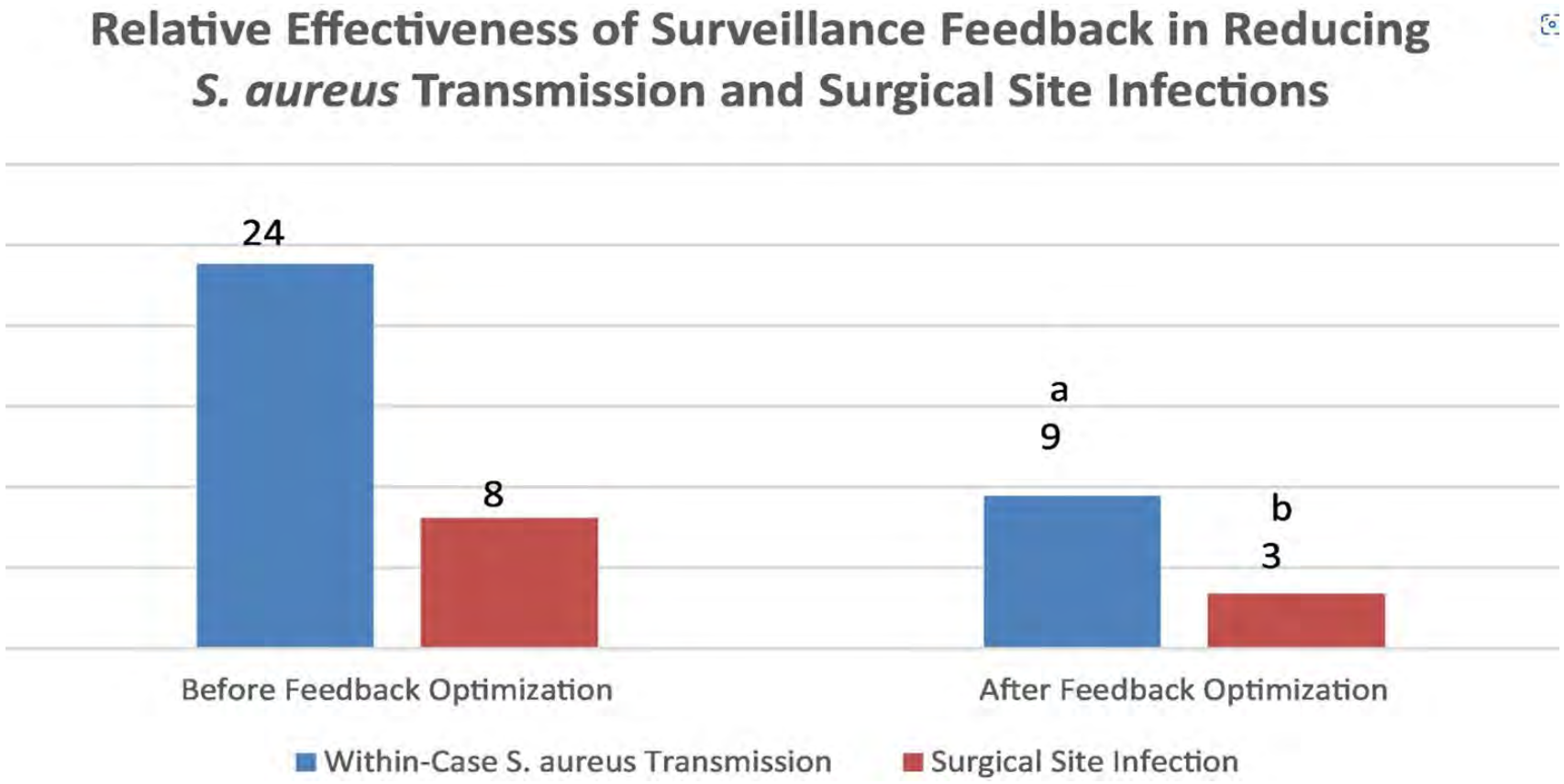
Effectiveness



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Questions?

Journal of Clinical Anesthesia 77 (2022) 110632

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Original Contribution

Effectiveness and feasibility of an evidence-based intraoperative infection control program targeting improved basic measures; a post-implementation prospective case-cohort study☆

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ABSTRACT

Study objective: A randomized controlled study demonstrated that an optimized intraoperative infection control program targeting basic preventive measures can reduce *Staphylococcus aureus* transmission and surgical site infections. In this study we address potential limitations of operating room heterogeneity of infections and compliance with behavioral interventions following adoption into clinical practice.
Design: A post-implementation prospective case-cohort study.
Setting: Twenty-three operating rooms at a large teaching hospital.
Patients: A total of 801 surgical patients [425 (53%) women; 350 (44%) ASA > 2, age 54.6 ± 15.9 years] were analyzed for the primary and 804 for the secondary outcomes.
Interventions: A multifaceted, evidence-based intraoperative infection control program involving hand hygiene, vascular care, and environmental cleaning improvements was implemented for 23 operating room environments. Bacterial transmission monitoring was used to provide monthly feedback for intervention optimization.
Measurements: S. aureus transmission (primary) and surgical site infection (secondary).
Materials and methods: The incidence of *S. aureus* transmission and surgical site infection before (3.5 months) and after (4.5 months) infection control optimization was assessed. Optimization was defined by a sustained reduction in anesthesia work area bacterial reservoir isolate counts. Poisson regression with robust error variances was used to estimate the incidence risk ratio (IRR) of intraoperative *S. aureus* transmission and surgical site infection for the independent variable of optimization.
Main results: Optimization was associated with decreased *S. aureus* transmission [24% before (85/357) to 9% after (42/444), IRR 0.39, 95% CI 0.28 to 0.56, $P < .001$] and surgical site infections [8% before (29/360) and 3% after (15/444) (IRR 0.42, 95% CI 0.23 to 0.77, $P = .005$; adjusted for American Society of Anesthesiologists' physical status, aIRR 0.45, 95% CI 0.25 to 0.82, $P = .009$].

☆ We followed the StaRI statement for reporting implementation studies.

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Conclusion: An optimized intraoperative infection control program targeting improvements in basic preventive measures is an effective and feasible approach for reducing *S. aureus* transmission and surgical site infection development.

1. Introduction

Perioperative *Staphylococcus aureus* transmission contributes to surgical site infections which affect 3–5% of surgical patients [1,2]. Surgical site infections are associated with increased patient morbidity and mortality [3–9]. *S. aureus* transmission has been detected in up to 39% of surgical cases, has been directly linked to 50% of *S. aureus* surgical site infections by genome analysis, and is associated with surgical site infection development [6–11].

Reducing perioperative *S. aureus* transmission is a proven surgical site infection prevention strategy. We previously reported the results of a randomized clinical trial that assessed the efficacy of this approach [11]. This involved hand hygiene, environmental cleaning, patient decolonization, and vascular care improvements optimized by surveillance feedback [11]. A subset of surgeons, patients, and operating rooms (ORs) were randomized to the approach (treatment) or to usual care (control). Substantial reductions in *S. aureus* transmission (44%) and surgical site infections (88%) were observed for the treatment group [11].

Despite proven efficacy, additional factors should be considered prior to widespread adoption of these previously tested interventions. Operating room environments vary by specialty, case duration, and urgency due to nonrandom provider and surgical case assignments [12]. This accounts for large heterogeneity of surgical site infections among operating room and specialty combinations [13]. In addition, behavioral interventions may have limited effectiveness due to poor provider compliance and/or lack of administrative support [14,15]. Given these potential limitations, the effectiveness and feasibility of the interventions should be assessed following implementation.

In response, we conducted a post-implementation, prospective case-cohort study involving 23 operating room environments at a large teaching hospital. We hypothesized that the prospective and dynamic implementation approach would combat potential barriers involving the fast-paced, high-task density, and heterogenous intraoperative arena and achieve reductions in *S. aureus* transmission and surgical site infections comparable to the randomized trial [11,16–18].

2. Materials and methods

This study was approved by the Georgetown-MedStar internal review board system (# 00000375) before first patient enrollment.

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2.1. Implementation overview

The following steps were conducted (see timeline Appendix A); 1) An evidence-based intraoperative infection control program incorporating anesthesia work area hand hygiene, vascular care, patient decolonization, and environmental cleaning interventions (details below) was implemented over 8 months (November 2018–June 2019) at a large teaching hospital with 23 operating rooms. Initial quality assessment included human factors analysis and DAZOÒ Fluorescent Marking Gel (Ecolab – St. Paul, MN) simulation designed to identify gaps and improvement targets [19]; 2) Anesthesia work area reservoir monitoring was implemented to further assess intervention compliance where isolation of >100 colony forming units per surface area sampled indicated noncompliance (July 2019-August 2019) [6,11]; 3) Feedback regarding reservoirs exceeding 100 CFU, the epidemiology of *S. aureus* transmission, and bacterial transmission dynamics was utilized to increase intervention compliance to achieve work area infection control optimization (September 11, 2019-February 27, 2020). Optimization was defined a priori by a sustained reduction in anesthesia work area reservoir pathogen isolation counts and was achieved by December 2019 and maintained through March 2020; 4) Anesthesia work area reservoir monitoring was re-initiated to assess sustainability following the acute COVID-19 period (July 2020-September 2020); and 5) The association of reduced *S. aureus* transmission and surgical site infections following implementation optimization (December 2019-March,2020) was assessed.

2.2. Study participants

Operating room environments with at least two adult patients scheduled sequentially for surgery requiring general and/or regional anesthesia and peripheral intravenous and/or central venous catheter placement (a case-pair) were considered eligible for enrollment. A case-pair observational unit was leveraged in order that bacterial transmission occurring within and between cases could be assessed. A randomized list of operating room case-pairs was generated each day via a random number generator, and the first case-pair on the list meeting inclusion criteria was selected for prospective observation of the primary and secondary endpoints.

2.3. Baseline implementation

The following interventions were applied for 23 operating rooms 8 months prior to study start [11,16–20]. A video emphasizing component compliance was created and shared with all stakeholders prior to implementation (VIDEO). Existing full-time equivalents were used for intervention implementation given adoption into routine practice. The cost of disposables is estimated at $14 per patient [13].

2.3.1. Hand hygiene

The intervention involved a bag of 70% isopropyl alcohol connected to a one-handed pump (Saxa Medical Solutions, Mentor, Ohio) located in the anesthesia workspace. Key implementation feature: provider proximity to combat the barrier of high task density by clamping to the intravenous (IV) pole. Anticipated potential barriers included competition for space on the IV pole, alcohol allergy, and skin irritation [11,16,19].

2.3.2. Organization of the anesthesia work area

The intervention involved a wire basket (https://www.wtfarley.com/Pole-Mounted-Accessory-Basket) lined with a plastic bag for disposal of used and contaminated equipment. The basket was located on the IV pole to separate clean and dirty environments. Key implementation feature: provider proximity to combat task density to effectively separate clean and dirty environments and ultimately reduce the magnitude of environmental contamination, a potent transmission vehicle [11 19, 20]. Anticipated potential barriers included competition for space on the IV pole.

2.3.3. Frequency and quality of environmental cleaning

The intervention involved anesthesia provider post-induction cleaning of the anesthesia workspace with surface disinfection wipes (Sani-Cloth with a quaternary ammonium compound and isopropyl alcohol, PDI Healthcare, Woodcliff Lake, NJ) located on the top of each anesthesia machine. Key implementation feature: use of disinfection wipes during the period of induction when peaks in environmental contamination are correlated with nadirs in hand hygiene compliance

[11,18,19]. Anticipated potential barriers included time constraint during the busy period of induction.

2.3.4. Patient decolonization

Chlorhexidine gluconate (2%) wipes were provided for patients undergoing hip and knee surgery. Key feature: to address a proven transmission vehicle [22]. Anticipated potential barrier: Suboptimal adherence to use of the wipes by patients and/or healthcare providers.

2.3.5. Intravascular catheter and syringe tip disinfection

The intervention involved a tray of disinfection caps containing 70% isopropyl alcohol (Saxa Medical, Mentor, Ohio, 44,060) attached to the intravenous pole. These devices disinfect in 10 s with two turns. Key implementation feature: provider proximity and disinfection of both injection ports and syringe tips [11,17,19]. Anticipated potential barriers included competition for space on the IV pole and time constraints.

2.4. Anesthesia work area reservoir monitoring to assess baseline intervention compliance

2.4.1. Reservoirs monitored

See Appendix A for the reservoir monitoring dashboard utilized. Bacterial surveillance was conducted by medical students, typically one to two each day, who each surveyed 1–2 case-pairs over approximately 20 min per pair [21].

2.4.1.1. Provider hands. Provider hands were sampled before and after patient care using a glove juice technique to assess hand hygiene where recovery of <100 colony forming units from measured samples indicated compliance [11,16,22,23].

2.4.1.2. Patient skin. Patient nasopharyngeal, axillary, and inguinal skin sites were sampled to assess preoperative patient decolonization where recovery of <100 colony forming units from measured samples indicated compliance [6–9,11,22,23].

2.4.1.3. Environmental. Proven representatives of the anesthesia environment, the adjustable pressure-limiting valve and agent dial, were sampled at baseline and at case end by swabbing the entire surface area [11,18,20,22,23]. These reservoirs were used to assess routine, terminal, and post-induction environmental cleaning by anesthesia and operating room personnel where recovery of <100 colony forming units from measured samples indicated compliance [11,22,23].

2.4.1.4. Peripheral intravenous tubing injection ports. A positive stopcock set at case end was defined as ≥1 colony forming unit per culture plate. This reservoir was used to assess syringe tip and intravascular catheter injection port cleaning where recovery of <100 colony forming units from measured samples indicated compliance [11,17,22,23].

2.4.2. Materials

Bacterial transport medium collection tubes were assembled into kits (OR PathTrac, RDB Bioinformatics, Omaha, NE) [6,7,11].

One collection tube and swab (ESwab, Copan Diagnostics Inc., Murrieta, CA) was used to sample each location by the same research assistant except for provider hands as previously described [6,7,11,22,23].

2.4.3. Microbial culture conditions

All blood agar plates were incubated at 35 °C for 48 h, and microorganisms were quantified according to colony forming units and identified according to standard laboratory methods as described below [22,23].

2.4.4. Bacterial identification

Bacterial isolates were presumptively identified by colony morphology, Gram stain, and simple rapid tests. Organism identification was based on modified conventional and chromogenic tests using pH changes, substrate utilization, and growth in the presence of antimicrobial agents after 16–44 h of incubation at 35 °C [22,23].

2.4.5. Reservoir contribution to intraoperative transmission events

A *S. aureus* transmission event was defined as a *S. aureus* isolate present at case end that was not present at case start or ≥ 2 epidemiologically related isolates obtained from two distinct reservoirs [11].

2.5. Feedback to optimize intervention compliance

Culture results obtained from the reservoir sampling above were entered into a software program (OR PathTrac) [6,7,11] which was used to analyze, display, and to report improvement targets to operating room management and infection control teams. Reports included the proportion of measured reservoirs with >100 CFU, the epidemiology of *S. aureus* transmission, and bacterial transmission dynamics including counts of pathogens by reservoir over time, reservoir contamination occurring before, during, or after surgery, operating room patient care arena exposure to *S. aureus*, and typical bacterial transmission pathways stratified by bacterial class and strain characteristics (See Appendix B for an example of a monthly feedback report). Counts of reservoir pathogens over time provided an overall assessment of compliance and effectiveness with intraoperative infection control practices (Fig. 1.) [6,7,11]. The cost of surveillance feedback, including culturing disposables, software, and consultation, was $32,000/125 case-pairs, approximately half of the cost calculated to provide a favorable return-on-investment [13].

Initial surveillance results and recommended improvement targets were communicated via a summary report to the institution on September 11, 2019, and October 12, 2019 (Appendix B, example report). Additional feedback was provided to anesthesiology resident physicians on October 30, 2019, to anesthesia faculty on October 31, 2019, and at seven anesthesia faculty meetings occurring on the last Thursday of every month. These meetings were attended by attending physicians, certified registered nurse anesthetists, and certified anesthesiologist assistants with 86% recorded attendance. Institutional and departmental responses to feedback are organized by date in appendix C.

2.6. Implementation schematic

The interventions utilized along with implementation barriers and solutions are summarized in Fig. 2.

2.7. Assessment of intervention sustainability following the acute COVID-19 period (July–September 2020)

An additional 196 case-pairs were randomly selected for observation following resolution of the acute COVID-19 period, a potential contextual change, and to assess intervention effectiveness during the summer months.

2.8. Assessment of primary and secondary outcomes

2.8.1. Primary

The primary outcome was within-case *S. aureus transmission* defined as a *S. aureus* isolate present at case end that was not present at case start or ≥ 2 epidemiologically related isolates obtained from two distinct reservoirs [11].

2.8.2. Secondary

The secondary outcome was surgical site infection within 90 days of

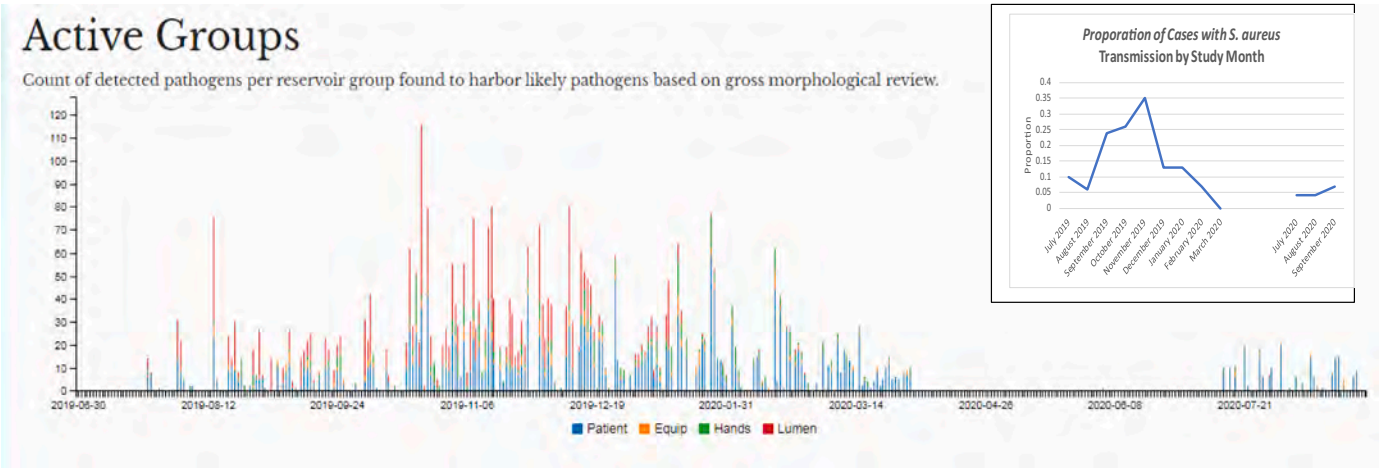

Fig. 1. The Count of Pathogens by Reservoir Group and *Staphylococcus aureus* Transmission (Upper Right Panel) by Study Month. There was an evident reduction in count of pathogen by reservoir group beginning December 2019. There was a concordant reduction in *S. aureus* transmission within cases during the same period. Thus, December 2019 through March 2020 was considered the optimized period. The largely unaffected reservoir, patient nares, was not addressed (Appendix A). The effect of the intervention was sustained for 6 months following the acute COVID-19 period (July–September 2020).

surgery. Research assistants blinded to the treatment group prospectively screened all patient medical records for evidence of elevated white blood cell count, fever, antimicrobial administration order, office note documentation of infection, and culture acquisition [6]. Infections were defined by National Healthcare Safety Network definitions [24,25].

2.8.3. Process measures

Compliance with the evidence-based interventions before and after optimization was assessed according to; 1) Counts of reservoir pathogens over time (Fig. 1.) and 2) the proportion of relevant reservoirs (e.g., anesthesia attending hand reservoir before and after care to assess anesthesia attending hand hygiene compliance before and after care) exceeding the 100 CFU threshold [11,22,23].

2.8.4. Accounting for contextual changes and seasonal variation

We assessed intervention sustainability following the acute COVID-19 period and during the summer months (July,12,020-September 30, 2020).

2.9. Patient demographics and procedural information

Information pertaining to age, sex, American Society of Anesthesiologists physical status classification (ASA PS), Study on the Efficacy of Nosocomial Infection Control (SENIC) score (an index predicting the probability of postoperative infection development for a given patient from 0 to 4 where a higher number indicates increased risk) [26], summer (July, August, and September) [27], and case order [22] was compiled for analysis.

2.10. Sample size

A pilot study was conducted at the University of Iowa (September 2018) in which *S. aureus* transmission [11] was detected in 11 of 30 cases in the usual care group and 3 of 34 cases in the optimized, multifaceted approach group. With 500 cases in each of two groups and using a 2-tailed Fisher's exact test, 500 patients in each of the 2 periods (with and without surveillance feedback) would provide 99% power at $\alpha = 0.05$ to detect a difference in the incidence of *S. aureus* transmission. Assuming a reduction in surgical site infections from a baseline hospital rate of 7.2% [21] to 3.2% and using a 2-tailed Fisher's exact test, 500 cases in each of the two groups would provide 80% power at $\alpha = 0.05$ to detect a difference in the incidence of surgical site infections. The latter was the basis for a planned sample size of 1000 patients. Due to the COVID-19 interruption, 804 patients were enrolled from July 2019 to March 2020 and the remaining following resumption of the acute COVID-19 period from July–September 2020.

2.11. Statistical analysis

S. aureus transmission was measured by research personnel who were not aware of patient grouping assignments. Infections were tracked by the Georgetown research group blinded to grouping assignments via de-identified kit numbers.

Simple descriptive statistics were used to summarize patient and procedural demographic characteristics. To assess for selection bias, Fisher's exact test was used to compare ASA PS and sex. The Wilcoxon-Mann-Whitney test was used to compare age for patients who consented to participate to those who declined.

We used Poisson regression with robust error variances to estimate the incidence risk ratio (IRR) of *S. aureus* transmission for the independent variable of optimization. The Fisher's exact test was used to examine the association between sex, ASA PS, Study on the Efficacy of Nosocomial Infection Control (SENIC), procedure, and case, [7,22] and the Wilcoxon-Mann-Whitney test for age, with the outcome of transmission, for each cohort. Because there were increasing rates of transmission before initiation of *S. aureus* surveillance, we repeated the Poisson regression analysis adjusting for the weeks from the start of the study and from the start of the surveillance intervention, both starts being entered as integer 1. A second sensitivity analysis excluded second cases and demographic units involving incomplete pairs (first case only).

Poisson regression was used to estimate the IRR of surgical site infection for the independent variable of optimization. Fisher's exact and Wilcoxon-Mann-Whitney tests were used to examine the potential association of each of the covariates as described above for each cohort with SSI. We repeated the Poisson regression analysis adjusting for ASA PS, the covariate associated with both the dependent and independent variables.

Poisson regression was used to analyze the association of optimization with the proportion of measured reservoirs (anesthesia attending and assistant hands), patient skin sites (nasopharynx, axilla, and groin), and environmental sites (anesthetic agent dial and adjustable pressure-limiting valve of the anesthesia machine) that exceeded the colony forming unit $\geq$100 threshold [22,23]. Poisson regression was used to evaluate the association of reservoir contamination exceeding the colony forming unit threshold for provider hand, patient skin sites, and

FIGURE 2: Implementation and Optimization Overview for Basic Intraoperative Infection Control Measures

(caption on next page)

Fig. 2. Overall implementation schematic.
A: An initial survey assessed baseline knowledge on principles of perioperative infection control. A nationally recognized authority delivered grand grounds covering the importance and methods for controlling intraoperative bacterial transmission to prevent surgical site infections. The Division of Factors Engineering analyzed anesthesia provider workflow and identified areas for improvement. A simulation exercise was designed to demonstrate contamination during the conduction of anesthesia. The providers were surveyed again following these efforts.
B: Chlorhexidine wipes were initially used for patients undergoing total knee and hip surgery. The anesthesia workspace was cleaned before the first case of the day, after induction of each anesthetic, and at the end of each case.
C: Communication to Providers – Email 1 (10/26/2019): stressed aseptic IV medication administration using alcohol-based caps for IV ports and syringes as well as appropriate hand hygiene methods and frequency; Email 2 (2/3/2020): reminded providers to use new wall mounted alcohol dispensers. Infection control checklist (posted on all OR anesthesia machines 12/20/2019) served as permanent reminder of infection control guidelines in OR (supplementary material). *Aseptic medication administration* – alcohol dispensers were operational inside and outside all ORs starting 2/3/2020. *Patient decolonization* – expanded patient decolonization started 12/23/2019. *Environmental cleaning* – UV-C (Surfacide Helios, Waukesha WI) treatments were added. *B.* Plastic keyboard covers (started on 8/1/2019) were also wiped clean before the first case of the day, after intubation, and in between cases during turnover.
D: *Vascular care* –Changes included rearranging device locations, such as use of a kidney basin for prepared medications in capped syringes, mounting the alcohol dispenser to the anesthesia machine for easier accessibility, and repositioning the tray containing alcohol-based syringe, IV injection port disinfection caps, and 45 mL hand hygiene dispensers to the anesthesia machine for easier access.

environmental sites with contamination of intravenous tubing stopcock sets exceeding 100 colony forming units [22,23].

Missing data for the primary and secondary outcomes were less than 10%. No patients were lost to follow-up. Calculations were performed using Stata version 16.1 (StataCorp, College Station, TX). All *P* values and confidence intervals were 2-sided. $P < .05$ indicated statistical significance.

3. Results

3.1. Patient characteristics

3.1.1. Recruitment

A total of 804 patients were enrolled with 801 analyzed for the primary and 804 for the secondary outcome (Fig. 3.) from July 15, 2019, until 90 days from the last patient enrollment on March 20, 2020. There were no differences in ASA PS, age, and sex between enrolled patients and those patients who declined enrollment (all $P > .21$, data not shown).

3.1.2. Baseline data

Baseline patient and procedural demographics stratified by optimization are shown in Table 1.

3.2. Outcomes and estimation

Sex, ASA PS, SENIC, procedure, case, and age were not associated with *S. aureus* transmission ($P \leq .10$). Only ASA PS, procedure, and sex were associated with surgical site infection. Optimization was associated with reduced *S. aureus* within-case transmission, 24% without (85/357) and 9% with (42/444) (IRR 0.40, 95% CI 0.28 to 0.56, $P < .001$) (Fig. 4.). Each week without optimization was associated with increased risk of transmission of 1.09 per week (95% CI 1.06 to 1.13, $P < .001$). With optimization, the change in slope was associated with a reduced

Fig. 3. Patient enrollment schematic.
A total of 1000 cases were enrolled, 804 prior to and 196 after the COVID-19 interruption. A total of 801 cases prior to the acute COVID-19 period were included in the primary (missing data = 3 cases) and 804 in the secondary analyses while 196 patients were enrolled after the COVID-19 period to assess sustainability and season.

Table 1
Baseline patient and procedural characteristics.

	Before Optimization ($N = 360$)	After Optimization ($N = 444$)	P-Value[a]
Covariate			
Age, mean (SD), y	54 (17)	55 (15)	0.93
Female N (%)	191 (53)	236 (53)	1
ASA PS N (%)			0.08
1	31 (9)	26 (6)	
2	174 (48)	222 (50)	
3	141 (39)	188 (42)	
4	14 (4)	7 (2)	
SENIC >2 N (%)[b]	16 (4)	14 (3)	0.36
Procedure N (%)			0.62
General abdominal	51 (14)	79 (18)	
Involving joint or spine	130 (36)	155 (35)	
Oncologic gynecological	22 (6)	28 (6)	
Plastic	29 (8)	33 (7)	
Cardiac, vascular, generalized extremity[b]	18 (5)	14 (3)	
Other[c]	110 (31)	135 (30)	
Case 2 Present (complete pair) N (%)	162 (45)	211 (48)	0.52

Abbreviations: ASA PS, American Society of Anesthesiologists Physical Status; SENIC, Study on Efficacy of Nosocomial Infection Control.

[a] All Fisher's exact test except Wilcoxon-Mann-Whitney test for age.

[b] Endarterectomy, stab phlebectomy, arteriovenous fistula, below knee amputation, stump revision, decortication, thoracotomy, mediastinal mass, and generalized upper and/or lower extremity procedures.

[c] Neurosurgery, urology, otolaryngology, or miscellaneous (spinal cord stimulator insertion/removal, spinal cord stimulator generator change, baclofen pump, nerve decompression/excision, nerve transposition/transfer, neurolysis, exploration brachial plexus, ablation extremity radiofrequency, Le Fort 1 fracture repair, lymph node excision, hemorrhoidectomy, sphincterotomy, anal fistulotomy, excision anal lesion, excision pilonidal cyst, flexible sigmoidoscopy/rectal exam, debridement tendon, bone marrow harvest, loop excision, and excision suture granuloma), or other procedures.

[b] Study on the Efficacy of Nosocomial Infection control (SENIC) score (an index predicting the probability of postoperative infection development for a given patient by general abdominal surgery, duration >2 h, dirty or infected site, and > 2 comorbidities (0–4).[15,23]

risk of transmission of 0.81 events per week (95% CI 0.76 to 0.87, $P < .001$), and there was a step decline in the risk of transmission 0.492 (95% CI 0.292 to 0.828, $P = .008$). The sensitivity analysis excluding second cases and demographic units involving incomplete pairs resulted in a similar IRR (data not shown).

A total of 44 surgical site infections were identified [95% (42/44) surgical site and 5% (2/44) soft tissue, with both soft tissue infections in the optimized cohort]. Optimization was associated with a reduced risk of infection, 8% without (29/360) vs. 3% with (15/444) (IRR 0.42, 95% CI 0.23 to 0.77, $P = .005$; adjusted for ASA PS, aIRR 0.45, 95% CI 0.25 to 0.82, $P = .009$) (Fig. 4.). There were several causative organisms of infection. By species, the incidence of *S. aureus* culture isolation was 3.1% (11/360) without and 0.9% (4/444) with optimization, risk ratio 3.39 without, 95% CI 1.09 to 10.56, Fisher's $P = .03$). *S. aureus* was implicated as a potential cause of infection in 34.1% (15/44) of infections. There were no confirmed cases of *S. aureus* bacteremia.

3.3. Process measures

3.3.1. Counts of pathogens per measured reservoir group

A persistent decline in reservoir pathogen counts and *S. aureus* transmission was observed following feedback optimization from December 2019–March 2020 given (Fig. 1.).

3.3.2. Proportion of measured reservoirs exceeding 100 CFU before and after feedback

The period of optimization was associated with a significant reduction in in the proportion of measured reservoirs exceeding the100 CFU threshold associated with increased risk of transmission and infection [16,22,23] for; 1) injection ports, representing improved vascular care, including syringe tips, 2) provider hands (attending and assistant), representing improved hand hygiene, 3) anesthesia machine adjustable pressure-limiting valve and anesthetic agent dial, representing improved environmental cleaning, and 4) patient axilla and groin, representing improved patient skin decolonization. There was no effect on contamination of the patients' nasopharynx.

Contamination of valve/dial of the anesthesia machine, provider hands (assistant hands), and patient skin sites (axilla) exceeding 100 colony forming units were associated with intravenous stopcock contamination of >100 colony forming units (Table 2).

3.4. Contextual changes during the study period and seasonal variation

The incidence of within-case *S. aureus* transmission (5%, 10/196, Fig. 1.) and SSIs (2%, 4/196) remained low following resolution of the acute COVID-19 period and during the summer months (July 2020–September 2020).

4. Discussion

We previously demonstrated the efficacy of a multifaceted infection control program leveraging basic preventive measures optimized by surveillance feedback in reducing *S. aureus* transmission and surgical site infections [11], building on two prior randomized studies at Dartmouth [16,17]. In this study we demonstrate effectiveness and

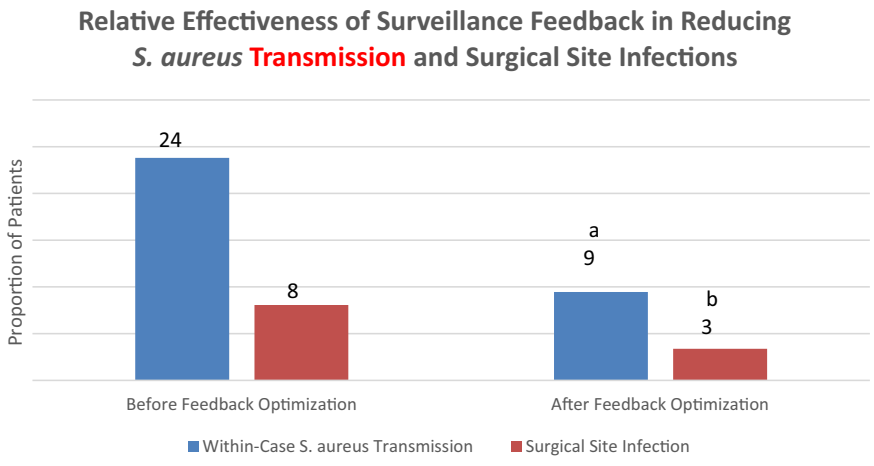

Fig. 4. Within-case *Staphylococcus aureus* transmission and surgical site infection during the optimized period.
*Optimization was associated with a reduction in the incidence of *S. aureus* within-case transmission, from 24% without (85/357) to 9% with (42/444) (incident rate ratio [IRR] 0.40, 95% CI 0.28 to 0.56, $P < .001$). # Optimization was associated with a reduced risk of surgical site infection (8% before [29/360] and 3% after [15/444] (IRR 0.42, 95% CI 0.23 to 0.77, $P = .005$; adjusted for American Society of Anesthesiologists' physical status, aIRR 0.45, 95% CI 0.25 to 0.82, $P = .009$).

Table 2
Programmatic Fidelity (Impact) Across Measured Reservoirs by Incidence of Magnitude of Contamination Exceeding 100 Colony Forming Units, and the Association of Reservoir Contamination Exceeding 100 Colony Forming Units with High-Risk Stopcock Contamination [23,24].

Reservoir Risk of Exceeding 100 Colony Forming Units After vs. Before Feedback	IRR	95% CI	*P* value
Anesthesia workspace reservoirs			
Stopcock	0.27	0.21–0.36	<0.001
Anesthesia assist	0.74	0.69–0.80	<0.001
Anesthesia attending	0.78	0.73–0.84	<0.001
Valve/dial	0.62	0.52–0.73	<0.001
Non anesthesia Reservoirs			
Patient axilla	0.78	0.72–0.84	<0.001
Patient groin	0.87	0.82–0.92	<0.001
Patient nasopharynx	0.97	0.93–1.00	0.09

Stopcock CFU > 100	IRR	95% CI	*P* Value
Valve and dial Colony Forming Units >100	1.38	1.09–1.73	0.006
Patient axilla Colony Forming Units >100	1.79	1.23–2.61	0.002
Anesthesia assistant Colony Forming Units >100	1.95	1.34–2.85	0.001
Anesthesia attending Colony Forming Units >100	1.45	0.99–2.11	0.051
Patient nasopharynx Colony Forming Units >100	1.32	0.69–2.49	0.400
Patient groin Colony Forming Units >100	1.06	0.70–1.62	0.769

Analyses (top table) has each row as dependent variable and period (after vs. before optimization) as independent variable; there were 7 Poisson regressions, one per row. Analysis (bottom table) has Stopcock Colony Forming Unit >100 as dependent variable and each row as independent variable; there was 1 Poisson regression including 6 independent variables. Abbreviations: IRR, incidence risk ratio; CI, confidence interval.

feasibility of adoption of this previously tested approach into practice.

One randomized study demonstrated efficacy of improved hand hygiene in reducing high-risk bacterial transmission events, environmental contamination, and 30-day healthcare-associated infections, including surgical site infections [16]. Another randomized study demonstrated efficacy of improved vascular care in reducing intravascular contamination and 30-day healthcare-associated infections, including surgical site infections [17]. A more recent randomized study [11] included the evidence-based hand hygiene and vascular care improvement strategies [16,17] along with improved environmental organization and cleaning [18,20], patient decolonization [28], and surveillance feedback optimization [6,7,11]. All trials involved a surgical/operating room subset and controlled conditions [11,16,17,28]. Thus, an important limitation of these randomized trials was that they could not account for operating room variation by specialty, case duration, and urgency resulting in very large heterogeneity of infections among operating room and specialty combinations due to surgical/operating room subsets, or potential provider or institutional noncompliance with the behavioral measures given controlled conditions of the trials.

The current study involved adoption of the previously tested interventions into anesthesia practice for 23 OR environments at a large medical center. Regardless of operating room variation by specialty, duration, and urgency [12], associated heterogeneity of surgical site infections [13], and use of behavioral interventions [14,15], a reduction in *S. aureus* transmission and surgical site infections comparable to that of the randomized trial [11] was observed. These findings remained significant despite adjustment for potentially confounding variables (e.g., risk of infection development, season).

These results were expected for two reasons. First, the bacterial inoculum contributes to the pathophysiology of surgical site infection development [29,30]. This can occur directly or indirectly through aerosolization and settling or intravascular injection and contamination of the wound hematoma. In turn, a reduction in the perioperative inoculum results in a reduced surgical site infection rate [11]. Therefore, provider and institutional compliance with basic infection control measures such as hand hygiene, vascular care, patient decolonization, and environmental cleaning are of paramount importance because they address the bacterial inoculum [31,32]. We show that a significant reduction in the proportion of reservoirs exceeding 100 CFU mapped to improved compliance with hand hygiene, vascular care, environmental cleaning, and patient skin decolonization during the optimized period. Second, we utilized a strategy that employed interventions with implementation features designed to account for the high task-density intraoperative arena [11]. While we encountered expected and unexpected implementation barriers, none were insurmountable. The greatest barrier was management of the available space on the IV pole which was easily addressed by simply relocating the vascular care intervention to the anesthesia cart (storage of disinfection caps) and anesthesia machine (location of the kidney basin for storage of capped syringes). Ongoing feedback and encouragement along with top-down support was necessary to combat time-constraint.

Importantly, the implementation approach utilized is associated with a favorable return on investment and low consumption of human resources [13,21,33], and it is in alignment with Society for Healthcare Epidemiology of America (SHEA) expert guidance recommending a multifaceted approach with monitoring for data transparency to facilitate proactive improvements [34]. For those just getting started with perioperative infection control, a more focused approach potentially associated with lesser consumption of human resources could include proactive attenuation and monitoring of targets associated with intravascular injection; anesthesia assistant hands, patient axillary skin sites, and the environment, results that are consistent with prior reports [22,23].

We showed 6 months of sustainability following resolution of the acute COVID-19 period, the only contextual change temporally associated with the study period that could have impacted study results. This period included summer months which provided an opportunity to assess the potential impact of seasonal variation [27]; none was apparent. There were no complaints of patient or provider harm (e.g., provider or patient skin irritation) that were reported during the study period.

4.1. Limitations

While an observational study design can be affected by confounding variables, a randomized study would not have added to the current body of literature. We addressed this potential limitation by; 1) use of extensive microbiological investigation where a reduction in isolation and transmission of causative organisms of infection correlated with improved process measures, and in turn, a reduction in infections, 2) randomizing observational unit (case-pair) selection to balance known and unknown covariates, 3) utilizing a time-series analysis to generate a level of evidence approximating that of a randomized trial and to account for seasonal variation [27], and 4) by adjusting for covariates known to predict transmission and infection such as severity of illness [6–11,22,23]. Remaining intrinsic bias is unlikely to have explained the results which have been repeatedly shown in randomized trials [11,16,17]. A potential contextual change included the acute COVID-19 period, but this occurred after data collection. Low rates of transmission and infection were maintained for 6 months following resolution of the acute COVID-19 period, including the summer months. Other pathogens besides *S. aureus* can cause SSIs. There was in fact a reduction in the overall bacterial inoculum. The reduction in *S. aureus* transmission was used as a marker for overall behavioral compliance with interventions [33] (i.e., isopropyl alcohol) with broad-spectrum activity against a variety of pathogens. For example, gram-negative pathogens can cause healthcare-associated infections, but they too would have been addressed by the interventions employed [35]. We chose to measure *S. aureus* because *S. aureus* transmission, using the evidence-based method employed [11,33], is associated with surgical site infections at the patient level [11], and systematic attenuation of *S. aureus*

transmission, a marker of improved compliance with behavioral interventions, reduces surgical site infections [11].

In conclusion, these study results demonstrate that an evidence-based, optimized intraoperative infection control program targeting improvements in basic preventive measures is an effective and feasible approach for reducing *S. aureus* transmission and surgical site infection development.

Author contributions

Russell T. Wall and Subhradeep Datta helped to design and conduct the study, including data collection with manuscript preparation, and reviewed and approved the final version of the submitted manuscript, Franklin Dexter and Jeremiah Brown helped to analyze the data, prepare the manuscript, and reviewed and approved the final version of the manuscript, Niloofar Ghyasi, Kate Boling, Emily Krisanda, and Christopher McCloud helped to conduct the study, including data collection, to prepare the manuscript, and reviewed and approved the final version of the manuscript, Alysha Robinson and Deanna Persons helped to conduct microbiological analysis, to prepare the manuscript, and reviewed and approved the final version of the manuscript, Brandon Gordon managed the information technology aspects of the project, contributed edits to the manuscript, and reviewed and approved the final version of the manuscript, Matthew Koff, Mark Yeager, and Cynthia Wong helped to prepare the manuscript and reviewed and approved the final version of the manuscript. Randy Loftus guided the microbiological sample collection, managed the microbiological analysis, managed microbiological data collection, worked with Gordon on the informatics, drafted the original version of the manuscript, contributed to ongoing manuscript edits, and reviewed and approved the final version of the manuscript.

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Submission declaration

This work has not been previously published and is not currently submitted elsewhere.

Disclosures

Randy W. Loftus reported research funding from Sage Medical Inc., BBraun, Draeger, and Kenall, has one or more patents pending, and is a partner of RDB Bioinformatics, LLC, and1055 N 115th St #301, Omaha, NE 68154, a company that owns OR PathTrac, and has spoken at educational meetings sponsored by Kenall (AORN) and BBraun (APIC). Brandon Gordon is a partner of RDB Bioinformatics, LLC, a company that owns OR PathTrac and has one or more patents pending. Matthew D. Koff is a minor shareholder in RDB Bioinformatics, LLC, a company that owns OR PathTrac. All other authors report no conflicts of interest.

Declaration of Competing Interest

Randy W. Loftus reported research funding from Sage Medical Inc., BBraun, Draeger, and Kenall, has one or more patents pending, and is a partner of RDB Bioinformatics, LLC, and 1055 N 115th St #301, Omaha, NE 68154, a company that owns OR PathTrac, and has spoken at educational meetings sponsored by Kenall (AORN) and BBraun (APIC). Brandon Gordon is a partner of RDB Bioinformatics, LLC, a company that owns OR PathTrac and has one or more patents pending. Matthew D. Koff is a minor shareholder in RDB Bioinformatics, LLC, a company that owns OR PathTrac. All other authors report no conflicts of interest.

Acknowledgements

None.

Appendix A. Appendix A: Study timeline and reservoir contamination process measure

A.1. Study timeline

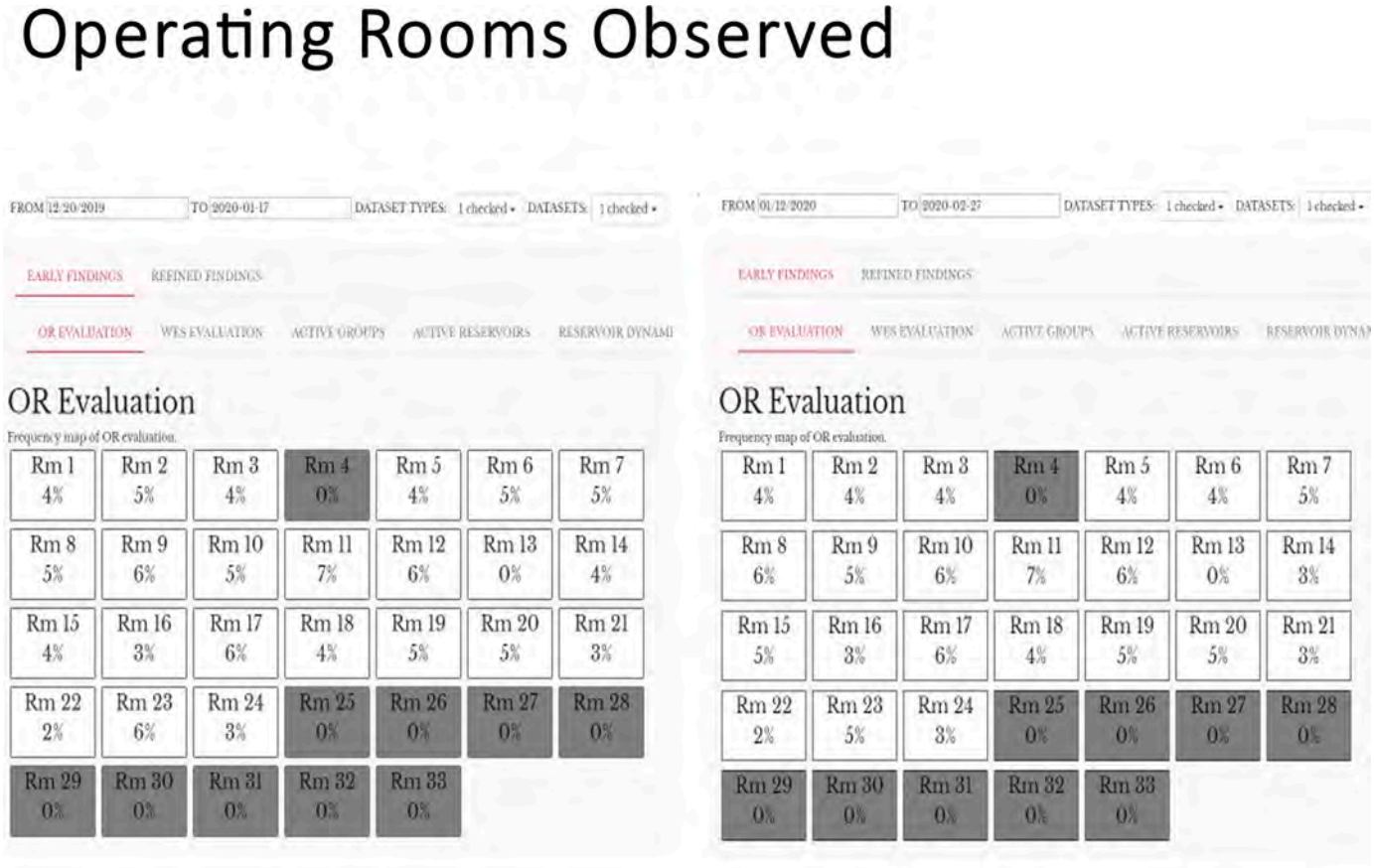
Study Timeline	Nov -18	Jun-19	Jul-19	Aug -19	Sept -19	Dec -19	Feb -20	Mar -20	Acute Covid Period	Jul-20	Sept -20
Baseline Implementation											
Initial Compliance Assessment											
Surveillance Feedback											
Optimization achieved											
Acute Covid Period											
Post-Covid Assessment											

A.2. Reservoir contamination process measure

Reservoirs with >100 colony forming units (CFU) increase the probability of high-risk transmission events, to stopcock sets, which is in turn repeatedly associated with increased mortality and directly linked to infection (whole cell genome analysis) [7,22,23]. Fifty percent of *S. aureus surgical site infections* (SSIs) can be traced back to transmission/reservoir contamination occurring while the patient was in the operating room [7]. Black, > 100 CFU, indicates room for improvement. **Left**: Case 1. **Right**: Case 2, a case-pair. **Case 1 Reservoirs**: VDO1= anesthesia machine adjustable pressure-limiting valve and agent dial at the start of the day, mapping to terminal environmental cleaning. AA01= the anesthesia assistant hands at baseline, prior to patient care. AHO1= the anesthesia attending hands at baseline, prior to patient care, mapping to hand hygiene before care. PA1= the patient axilla after induction and stabilization, PG1= the patient groin after induction and stabilization, PN1= the patient anterior nares after induction and stabilization, mapping to patient decolonization preoperatively. PAE, PGE, and PNE are those same patient skin sites at the end of surgery, mapping to maintenance of skin asepsis during surgery. Acquisition of *S. aureus* during care is associated with increased risk invasive infections post-discharge [36], so this is a very important measure. AAOE, AHOE are those same provider hands at the end of surgery, mapping to hand hygiene during care. VDOE= the same environmental sites of the anesthesia machine at the end of surgery, mapping to maintenance of a clean workspace achieved in part by post induction wiping and environmental organization (11, 17, 18, 20), and LE= the primary injection port used during the procedure, mapping to vascular care. **Case 2 reservoirs**: VD01= the same sites on the anesthesia machine sampled after routine cleaning, mapping to routine between case cleaning. The other sites mirror those of case 2 and serve to monitor for transmission occurring between cases occurring sequentially in the same operating room environment (case-pair).

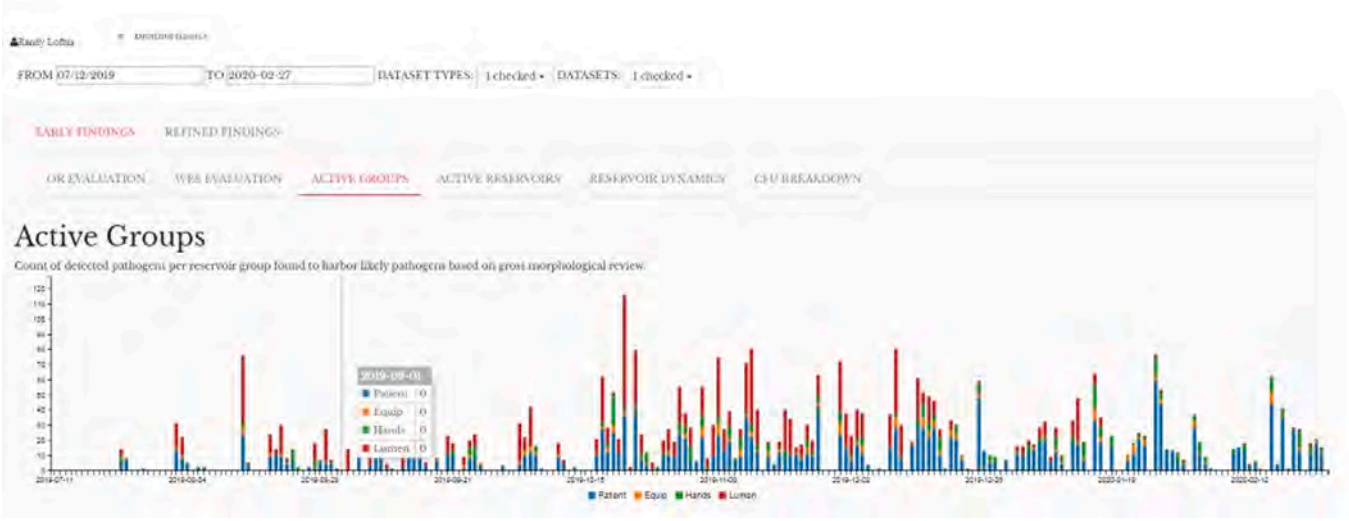
Appendix B. Appendix B: Feedback reports

B.1. Evaluating operating room environments observed



B.2. Evaluating intervention performance by counts of reservoir pathogens over time

Overall Magnitude of Contamination Trend: Count of Reservoir Pathogens



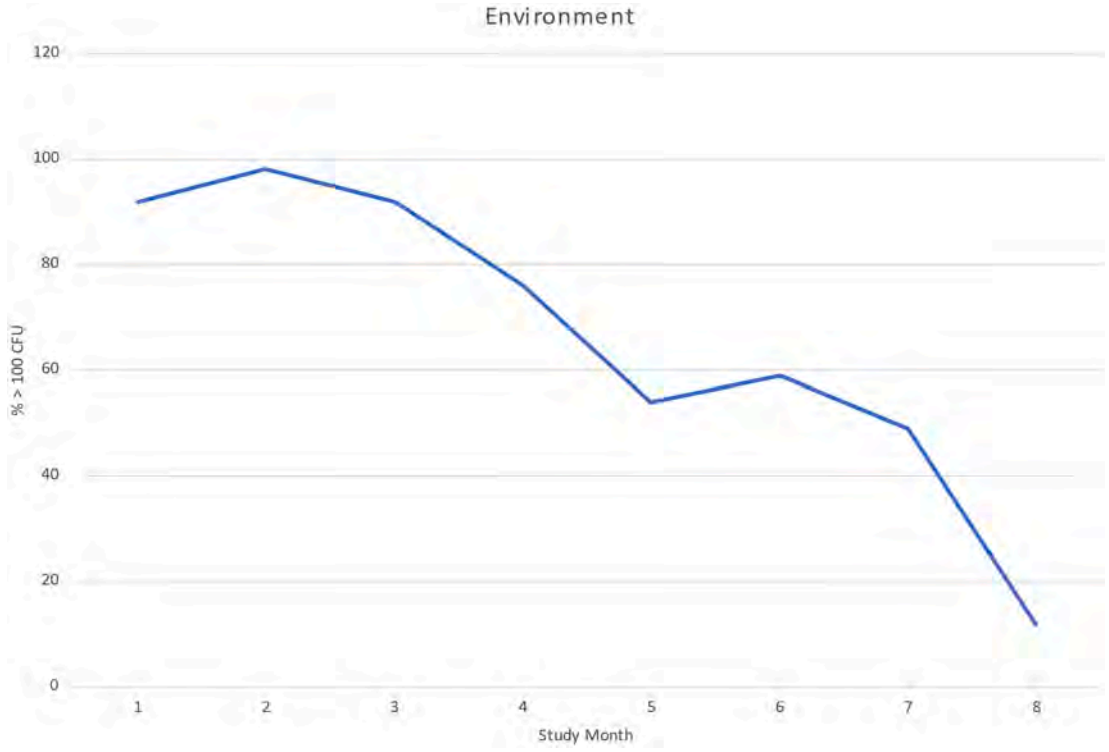
B.3. Evaluating intervention performance by proportion of measured reservoirs exceeding the critical 100 colony forming unit (CFU) threshold [11,22,23]

Overall Bundle Effect by Time: Percent >100 CFU per Surface Area Sampled (Dirty)

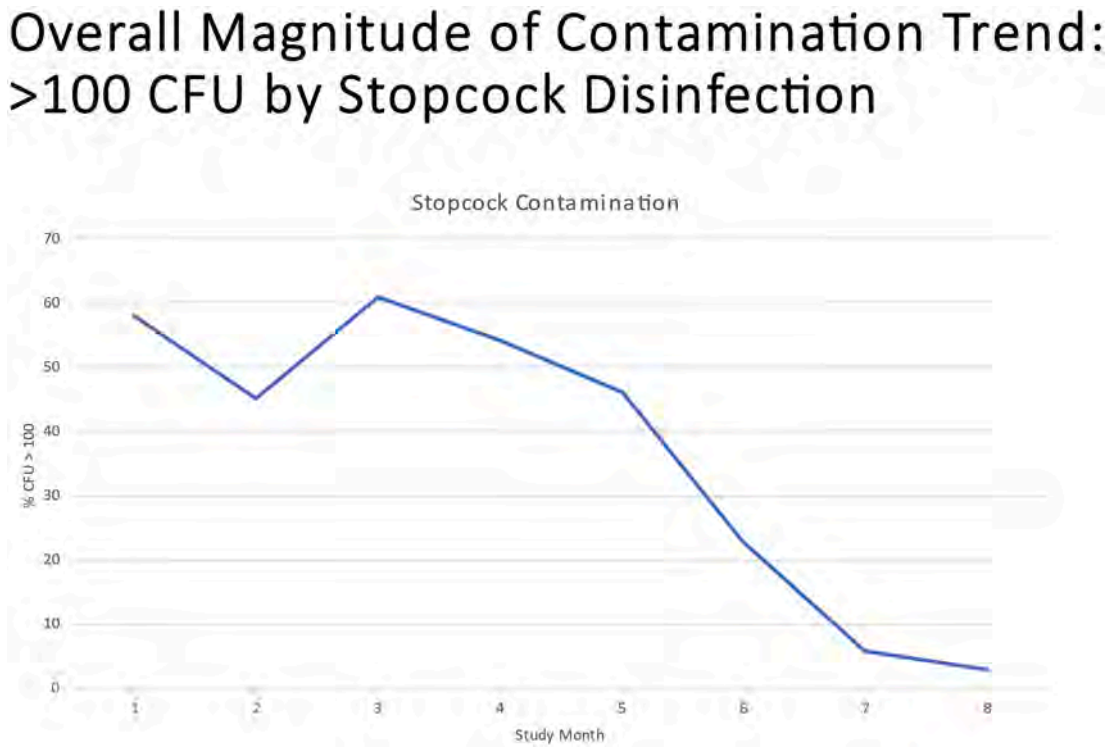
Study Month

Reservoir	1	2	3	4	5	6	7	8
Assistant (percent)	92	98	100	97	94	91	90	37
Attending (percent)	100	100	97	99	94	91	91	40
Stopcock (percent)	58	45	61	54	46	23	6	3
Axilla (percent)	96	97	95	100	93	96	82	34
Groin (percent)	96	98	100	100	95	100	89	43
Nasopharynx (percent)	96	100	100	100	99	100	97	48
Environment (percent)	92	98	92	76	54	59	49	12

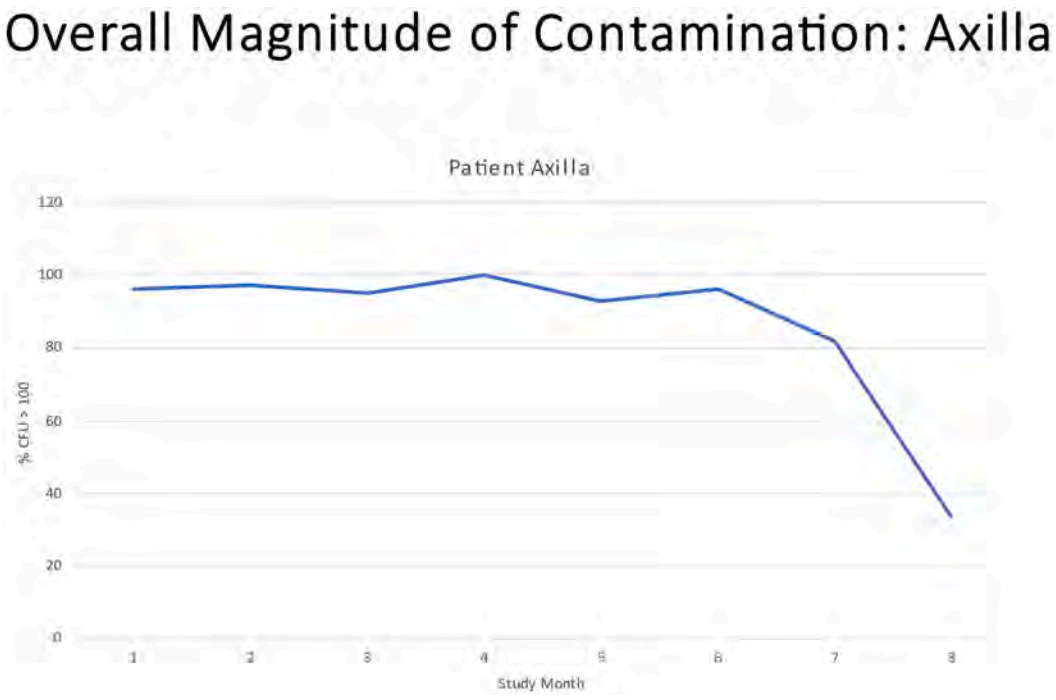
B.4. Monitoring of environmental contamination as an indicator of compliance with terminal, routine, and post-induction cleaning



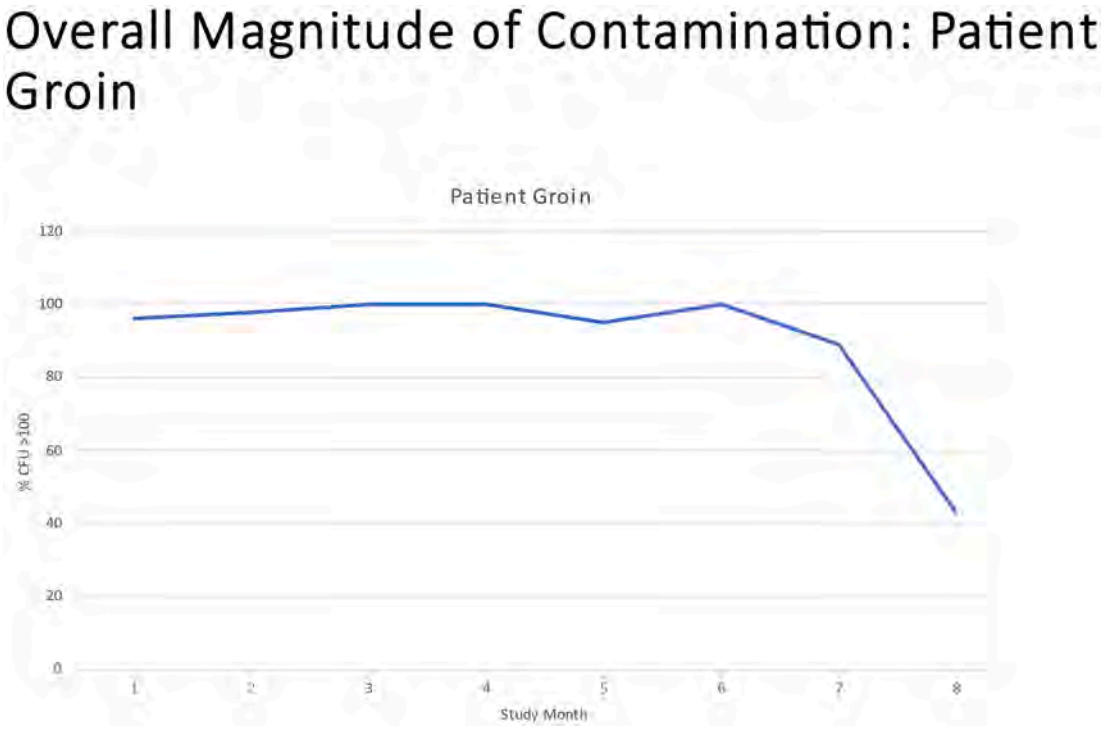
B.5. Monitoring of injection port contamination as an indicator of syringe tip and injection port disinfection



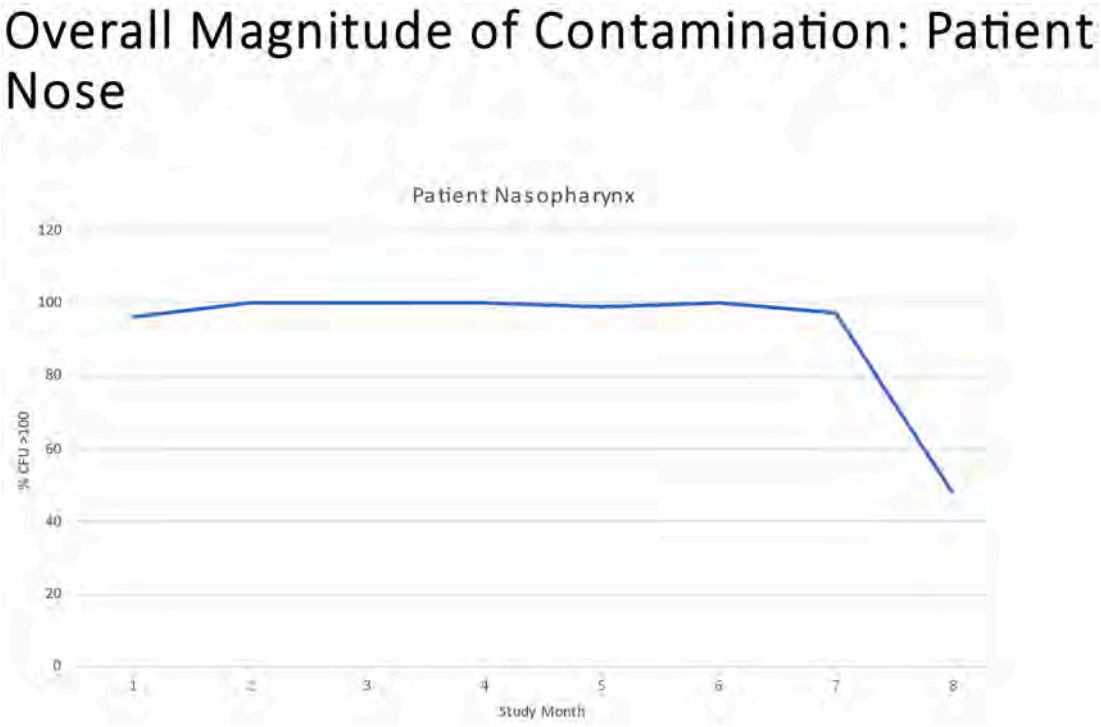
B.6. Monitoring axillary contamination as an indicator of skin decolonization compliance



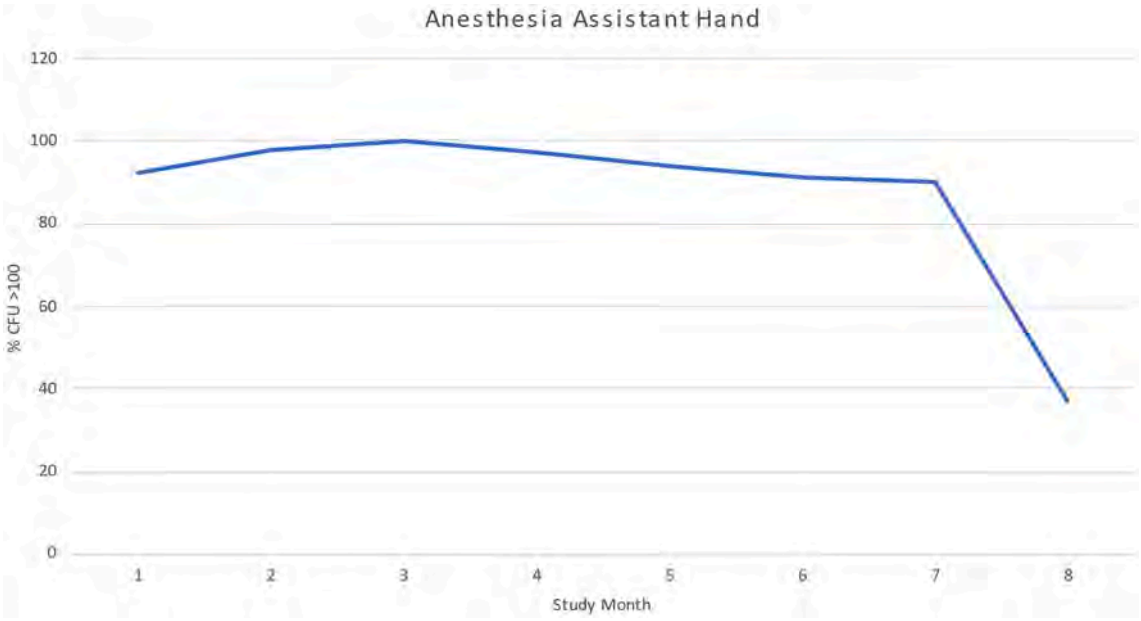
B.7. Monitoring patient groin contamination as an indicator for skin decolonization compliance



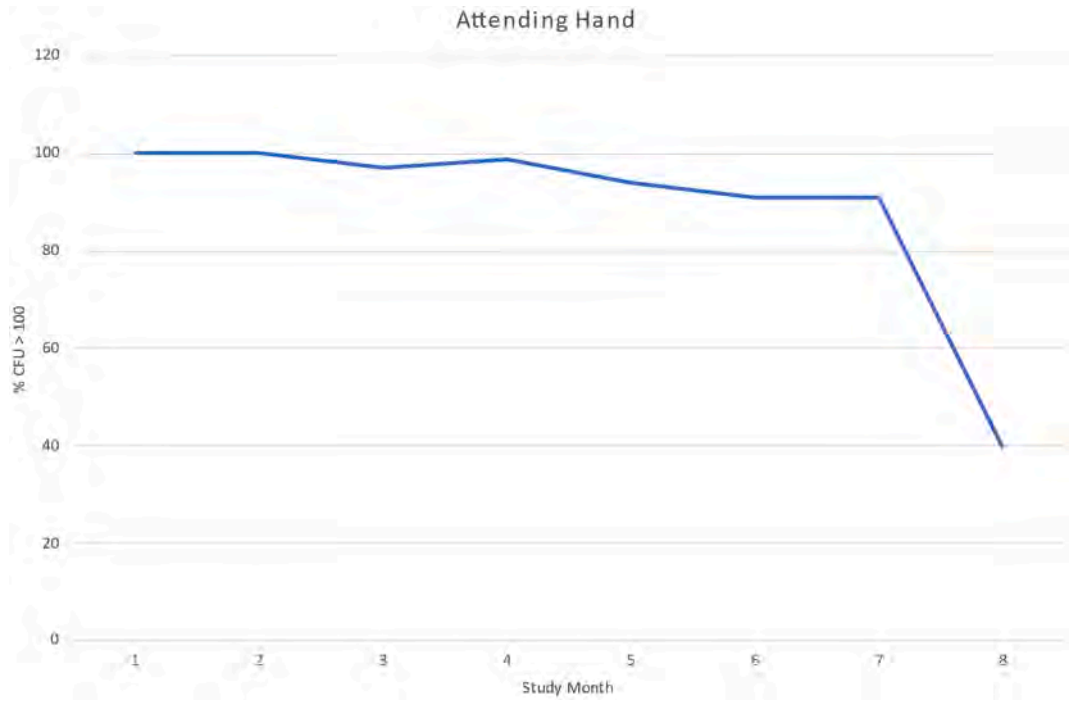
B.8. Monitoring patient nares contamination as an indicator of nasal decolonization compliance



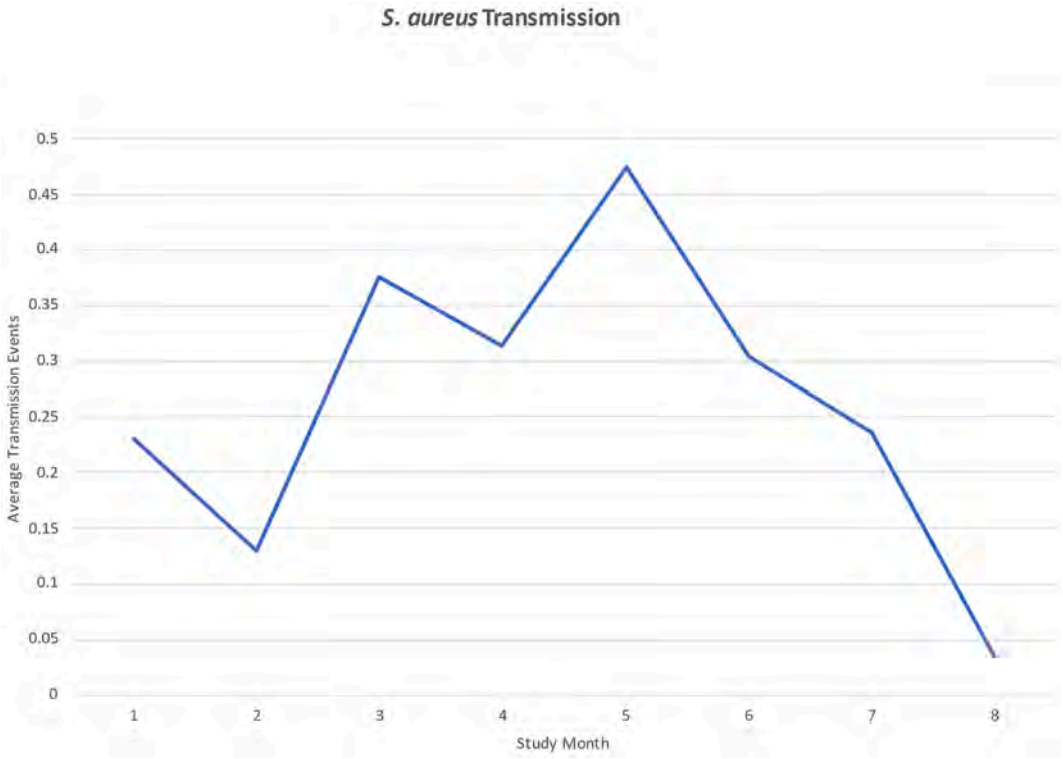
B.9. Monitoring contamination of assistant anesthesia hand contamination as an indicator for hand hygiene compliance



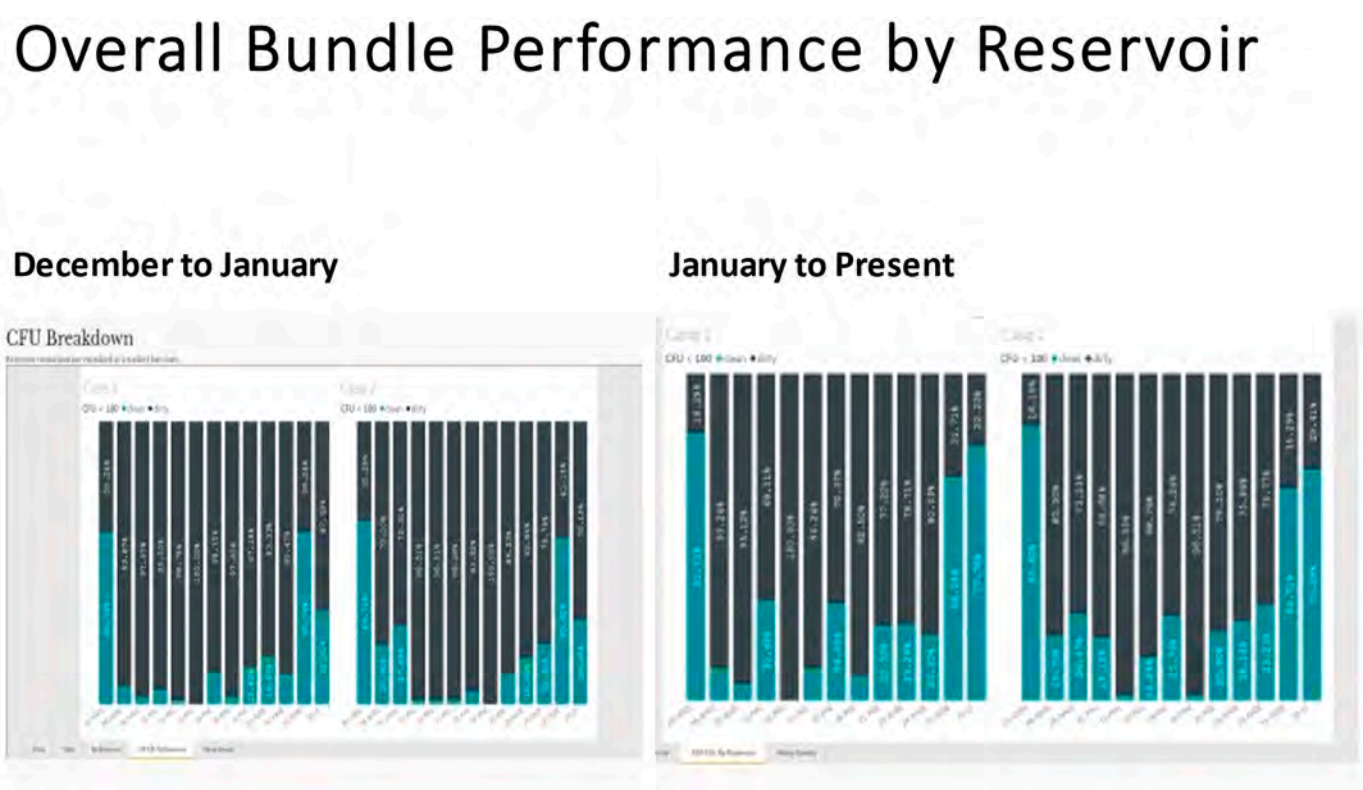
B.10. Monitoring attending anesthesia hand contamination as indicator of hand hygiene compliance



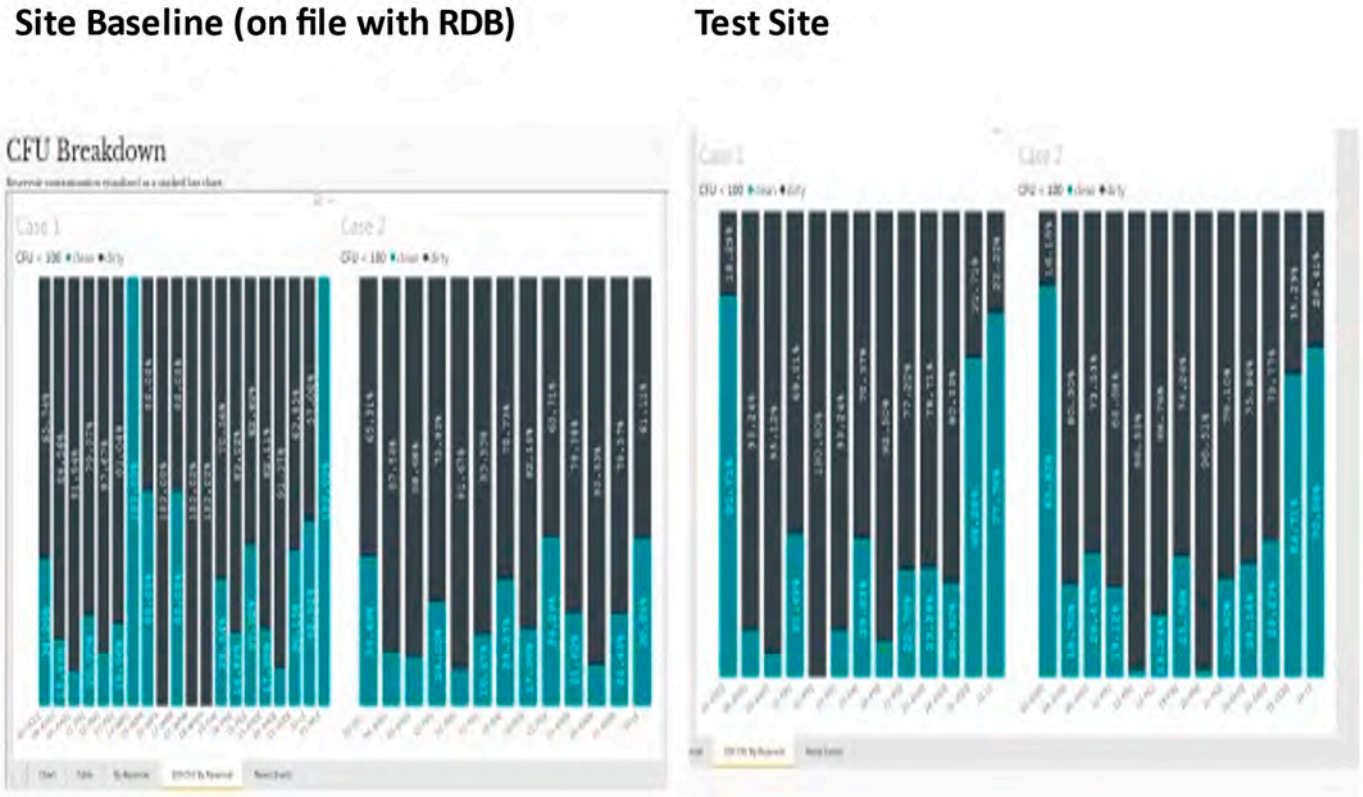
B.11. Monitoring S. aureus transmission, a marker of behavioral compliance [11,33]



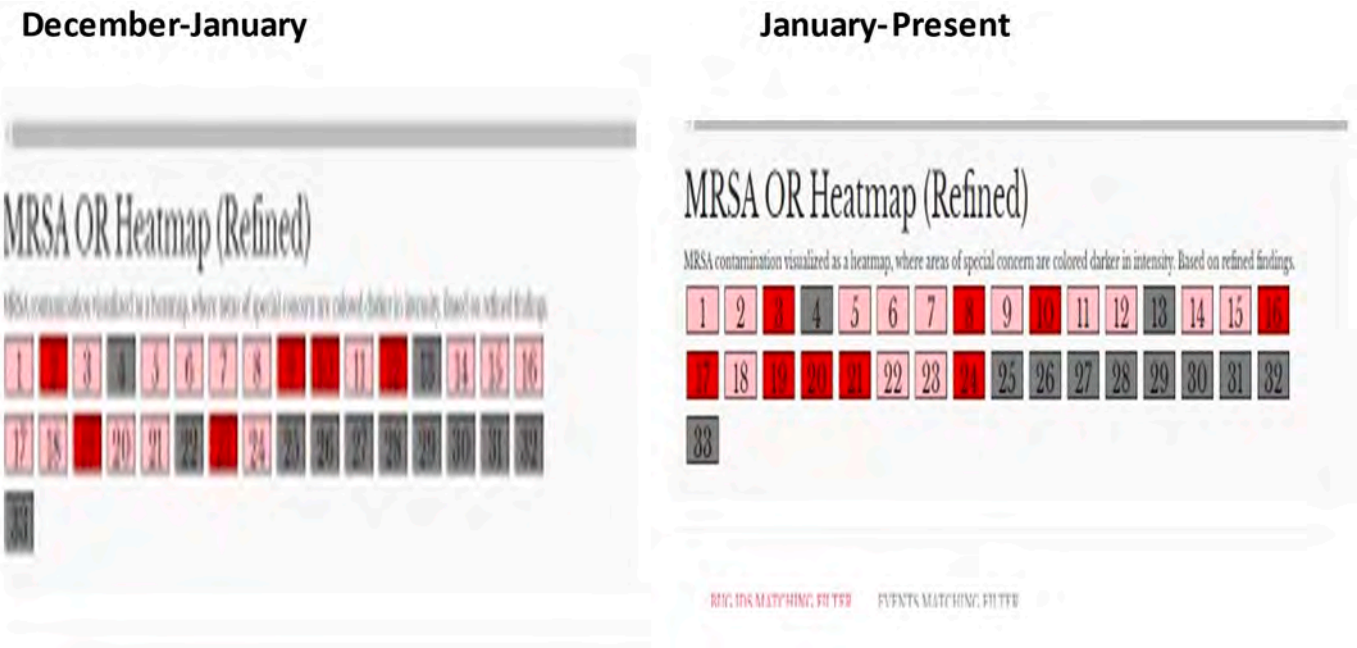
B.12. Evaluating intervention performance over time by mapping reservoir contamination >100 CFU



B.13. Comparing intervention performance to prior success [11]. Looking for improvement, not perfection



B.14. Targeted environmental cleaning-ultraviolet irradiation



B.15. Summary

- Improvement in patient decolonization is visualized.
- Bundle overall is effective and approaching optimization
  - OR targets are dynamic, high-risk areas can be strategically targeted routinely via software use, please target high-risk MRSA OR's
  - Patient nasal decolonization should begin
- Consider perioperative extension of effective bundle.

Appendix C. Appendix C: Response to feedback

C.1. Provider hand reservoir

4.1.1. Feedback

- September 11, 2019-nearly 100% of measured provider hands yielded >100 colony forming units.
- October 12, 2019-provider hand hygiene at baseline needed further improvement, especially anesthesia assistants at the start of case 2 given significant contribution to *S. aureus* transmission events.
- November 20, 2019-significant lapse in bundle compliance, with provider hand hygiene, especially attending physicians, a significant contributor.
- December 20, 2019- hand hygiene improved but far from target.
- January 17, 2020-continued improvement with downward trend visualized indicating reduced hand contamination.
- February 27, 2020-tremendous improvement seen.

Acute COVID-19 interruption, sampling resumed July 1, 2020 for assessment of sustainability.

C.1.1. Response to feedback

- November 20, 2019: Hand hygiene alcohol-based dispensers were relocated to the automatic drug dispensing machine in the anesthesia workspace of each operating room beginning.
- January 27, 2020: Alcohol-based hand sanitizer solution dispensers were placed at the entrance and exit of ORs 1–12, 21, 23 and 24, and the department was emailed to encourage device utilization.
- February 3, 2020: The importance of hand sanitizing was communicated to the entire anesthesia department via email.
- March 2020: A three-minute preoperative surgical scrub on the morning of surgery by attending anesthesia providers was initiated.

C.2. Patient axillary, nasal, and inguinal skin reservoir

C.2.1. Feedback

- September 11, 2019: Nearly 100% of measured patient skin surfaces yielded >100 CFU. Patient reservoir a significant contributor to reservoir of origin for *S. aureus* transmission.
- October 12, 2019: Patient reservoir continues to be problematic (66–100% > 100 CFU). Driving high rates of contamination and linked to intravascular device contamination.
- November 20, 2019: Patient decolonization is a significant issue. Based on transmission maps, particularly concerning for methicillin-resistant *S. aureus* (MRSA), and high rates of axillary and inguinal contamination at case start and case end, would start with chlorhexidine, once in place for 3 months, reassess the patient reservoir(s) and impact on transmission. This will address contributions from axilla and inguinal sites. This will not address the significant contribution of the nares (this is what is linked to transmission). Recommend povidone iodine (once on A.M. of surgery and again after induction and patient stabilization) to address this issue.
- ■
- December 20, 2019: Patient decolonization is again highlighted, a big player in *S. aureus* transmission stories.
- ■
- January 17, 2020: Improvement in patient decolonization axillary/groin is already visualized, continue, need to address nasopharynx.
- February 27, 2020: Improvement in patient decolonization axillary/groin is visualized, need to address nasopharynx.

Acute COVID-19 interruption, sampling resumed 7/1/2020.

C.2.2. Response to feedback

- December 23, 2019: Surgical clinics assessed, and decolonization protocol compliance encouraged. All patients received 2% chlorhexidine gluconate wipes (Sage Medical, Cary, Illinois 60,013) on the morning of surgery.

C.3. Environmental reservoir

C.3.1. Feedback

- September 11, 2019: Terminal environmental cleaning identified in failure mode analysis. Operating rooms with a high rate of *S. aureus* and MRSA identified and communicated.
- October 12, 2019: Terminal environmental cleaning identified in failure mode analysis. Operating rooms with a high rate of *S. aureus* and MRSA identified and communicated.
- November 20, 2019: Some improvement is seen. Still need to improve environmental cleaning-time UV-C light targeting of affected environment as close to prior to patient care as possible (settling overnight). Recommend improved frequency and quality of cleaning. New OR improvement targets have been identified.
- December 20, 2019: Environmental improvement is apparent.
- January 17, 2020: Cleaning of the anesthesia environment (machine) was flat the first three months but has dramatically improved since September and his holding. High-risk operating rooms identified, including those overlapping with *S. aureus* and MRSA exposure.
- February 27, 2020: Tremendous improvement seen, less than 20% of sampled sites >100 CFU as compared to 80% at baseline.

Acute COVID-19 interruption, sampling resumed 7/1/2020.

C.3.2. Response to feedback

C.3.2.1. Targeted UV-C light therapy (Helios, Surfacide, Waukesha, WI 53188).

- UV-C therapy was directed to operating room environments exposed to *S. aureus* transmission within the prior 2 weeks as detected by surveillance.

C.4. Intravascular device injection port reservoir

C.4.1. Feedback

- September 11, 2019: Intravascular injection port (lumen) the most consistently contaminated with 100% > 100 CFU. Improve syringe tip and injection port decontamination.
- October 12, 2019: Intravascular devices still with a very high magnitude of contamination, 60% > 100 CFU.
- November 20, 2019: Sustained lapse in overall compliance is contributing to a high rate of stopcock contamination.
- December 20, 2019: Stopcock disinfection is better but far from target.
- January 17, 2020: Significant improvement. Risk factors for stopcock contamination include inpatient surgery, ≥ 2 comorbidities, and contaminated environments.
- February 27, 2020 "Tremendous improvement in overall stopcock contamination." Acute COVID-19 interruption, sampling resumed 7/1/2020.

C.4.2. Response to feedback

- October 26, 2019-Entire anesthesia department emailed and encouraged to use the green disinfection caps provided and to improve hand hygiene compliance.
- November 11, 2019: The vascular care and hand hygiene station were moved to the pyxis for better access.
- December 20, 2019: The infection control checklist was placed on the pyxis for improved access.

C.5. Feedback pertaining to each reservoir monitored following the acute COVID-19 period (7/1/2020–9/16/2020)

C.5.1. Provider hand reservoir

- Change in interventions: personalized body worn alcohol dispensers for all providers 7/1/2020.
- August 6, 2020- Overall stable, slight uptick in hand contamination.

C.5.2. Patient axillary, nasal, and inguinal skin reservoir

- Change in interventions: None.
- August 6, 2020-Axillary and groin improvement need to address nasopharynx.

C.5.3. Environmental reservoir

- Change in interventions: Shortage in surface disinfection wipes due to COVID-19.
- August 6, 2020: Increase in sites >100 CFU from <20% to 60%, high-risk rooms identified, routine and terminal cleaning failures flagged.

C.5.4. Intravascular device reservoir

- Change in interventions: None.

Appendix D. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclinane.2021.110632.

References

[1] Magill SS, Hellinger W, Cohen J, Kay R, Bailey C, Boland B, et al. Prevalence of healthcare-associated infections in acute care hospitals in Jacksonville, Florida. Infect Control Hosp Epidemiol 2012;33:283–91.
[2] Boucher HW, Talbot GH, Bradley JS, Edwards JE, Gilbert D, Rice LB, et al. Bad bugs, no drugs: no ESKAPE! An update from the Infectious Diseases Society of America. Clin Infect Dis 2009;48:1–12.
[3] Vogel TR, Dombrovskiy VY, Lowry SF. Impact of infectious complications after elective surgery on hospital re-admission and late deaths in the U.S. Medicare population. Surg Infect 2012;13. 307–1.
[4] Awad SS. Adherence to surgical care improvement project measures and postoperative surgical site infections. Surg Infect 2012;13:234–7.
[5] Centers for Disease Control and Prevention. Updated guidelines for evaluating public health surveillance systems: recommendations from the guidelines working group. MMWR 2001;50:1–35.
[6] Loftus RW, Dexter F, Robinson ADM. High-risk Staphylococcus aureus transmission in the operating room: a call for widespread improvements in perioperative hand hygiene and patient decolonization practices. Am J Infect Control 2018;46:1134–41.
[7] Robinson ADM, Dexter F, Renkor V, Reddy S, Loftus RW. Operating room PathTrac analysis of current intraoperative Staphylococcus aureus transmission dynamics. Am J Infect Control 2019;47:1240–7.
[8] Loftus RW, Dexter F, Robinson ADM. Methicillin-resistant Staphylococcus aureus has greater risk of transmission in the operating room than methicillin-sensitive S aureus. Am J Infect Control 2018;46:520–5.
[9] Loftus RW, Dexter F, Robinson ADM, Horswill AR. Desiccation tolerance is associated with Staphylococcus aureus hyper transmissibility, resistance, and infection development in the operating room. J Hosp Infect 2018;100:299–308.
[10] Loftus RS, Koff MD, Patel HM, Brown JR, Patel HM, Jensen JT, et al. The epidemiology of Staphylococcus aureus transmission in the anesthesia work area. Anesth Analg 2015;120:807–18.
[11] Loftus RW, Dexter F, Goodheart MJ, McDonald M, Keech J, Noiseux N, et al. The effect of improving basic preventive measures in the perioperative arena on *Staphylococcus aureus* transmission and surgical site infections: a randomized clinical trial. JAMA Netw Open 2020;3:e201934.
[12] Dexter F, Ledolter J, Epstein RH, Loftus RW. Importance of operating room case scheduling on analyses of observed reductions in surgical site infections from the purchase and installation of capital equipment in operating rooms. Am J Infect Control 2020;2020(48):566–72.
[13] Dexter F, Epstein RH, Loftus RW. Quantifying and interpreting inequality of surgical site infections among operating rooms. Can J Anesth 2021;68:812–24.
[14] Rupp ME, Fitzgerald T, Puumala S, Anderson JR, Craig R, Iwen PC, et al. Prospective, controlled, cross-over trial of alcohol-based hand gel in critical care units. Infect Control Hosp Epidemiol 2008;29:8–15.
[15] Konvalinka A, Errett L, Fong IW. Impact of treating Staphylococcus aureus nasal carriers on wound infections in cardiac surgery. J Hosp Infect 2006;64:162–8.

[16] Koff MD, Loftus RW, Burchman CC, Schwartzman JD, Read ME, Henry ES, et al. Reduction in intraoperative bacterial contamination of peripheral intravenous tubing through the use of a novel device. Anesthesiology. 2009;110:978–85.
[17] Loftus RW, Brindeiro BS, Kispert DP, Patel HM, Koff MD, Jensen JT, et al. Reduction in intraoperative bacterial contamination of peripheral intravenous tubing through the use of a passive catheter care system. Anesth Analg 2012;115:1315–23.
[18] Rowlands J, Yeager MP, Beach M, Patel HM, Huysman BC, Loftus RW. Video observation to map hand contact and bacterial transmission in operating rooms. Am J Infect Control 2014;42:698–701.
[19] Kuvadia M, Wall R, Pehjar A, Nishida K, Darling N. Designing a program for infection prevention in the anesthesia work environment. Anesthesia Experts 2020. September 10th, 2020 by Dr. Clemens, http://anesthesiaexperts.com/uncategorized/designing-program-infection-prevention-anesthesia-work-environment/ (Last accessed Monday, November 9th, 2020).
[20] Clark C, Taenzer A, Charette K, Whitty M. Decreasing contamination of the anesthesia environment. Am J Infect Control 2014;42:1223–5.
[21] Datta S, Dexter F, Ledolter J, Wall RT, Loftus RW. Sample times for surveillance of S. aureus transmission to monitor effectiveness and provide feedback on intraoperative infection control. Perioper Care Oper Room Manag 2020;21:100137.
[22] Loftus RW, Brown JR, Koff MD, Reddy S, Heard SO, Patel HM, et al. Multiple reservoirs contribute to intraoperative bacterial transmission. Anesth Analg 2012;114:1236–48.
[23] Loftus RW, Koff MD, Burchman CC, Schwartzman JD, Thorum V, Read ME. Transmission of pathogenic bacterial organisms in the anesthesia work area. Anesthesiology. 2008;109:399–407.
[24] 2020 NHSN Surgical Site Infection (SSI) Checklist. https://www.cdc.gov/nhsn/pdfs/checklists/2020/ssi-checklist-508.pdf; 2020. Last accessed Tuesday, October 20th, 2021.
[25] 2021 NHSN Skin and Soft Tissue (SST) Infection Checklist. https://www.cdc.gov/nhsn/pdfs/checklists/sst-checklist-508.pdf; 2021 (Last accessed October 20th, 2021. Last accessed Tuesday, October 20th, 2021).
[26] Haley RW, Quade D, Freeman HE, Bennett JV. The SENIC project. Study on the efficacy of nosocomial infection control (SENIC project). Summary of study design. Am J Epidemiol 1980;111:472–85.
[27] Durkin MJ, Dicks KV, Baker AW, Lewis SS, Moehring RW, Chen LF, et al. Seasonal variation of common surgical site infections: does season matter? Infect Control Hosp Epidemiol 2015;36:1011–6.
[28] Phillips M, Rosenberg A, Shopsin B, Germaine C, Skeete F, Foti A, et al. Preventing surgical site infections: a randomized, open-label trial of nasal mupirocin ointment and nasal povidone iodine solution. Infect Control Hosp Epidemiol 2014;35:826–32.
[29] Giacometti A, Cirioni O, Schimizzi AM, Del Prete MS, Barchiesi F, D'Errico MM, et al. Epidemiology and microbiology of surgical wound infections. J Clin Microbiol 2000;38:918–22.
[30] Rubin RH. Surgical wound infection: epidemiology, pathogenesis, diagnosis and management. BMC Infect Dis 2006;6:171.
[31] Kwanten LE. Anaesthetists and syringe hygiene: getting to the pointy end-a summary and recommendations. Br J Anaesth 2019;123:e475–9.
[32] Loftus RW. The anaesthetist's role in perioperative infection control: what is the action plan? Br J Anaesth 2019;123:531–4.
[33] Dexter F, Ledolter J, Wall RT, Datta S, Loftus RW. Sample sizes for surveillance of S. aureus transmission to monitor effectiveness and provide feedback on intraoperative infection control including for COVID-19. Perioperat Care Oper Room Manag 2020;20:100115. https://doi.org/10.1016/j.pcorm.2020.100115.
[34] Munoz-Price LS, Bowdle A, Johnston BL, Bearman G, Camins BC, Dellinger EP, et al. Infection prevention in the operating room anesthesia work area. Infect Control Hosp Epidemiol 2018;1-17. https://doi.org/10.1017/ice.2018.303.
[35] Hadder B, Patel HM, Loftus RW. Dynamics of intraoperative Klebsiella, Acinetobacter, Pseudomonas, and Enterobacter transmission. Am J Infect Control 2018;46(5):526–32 [PMID: 29395508].