ORIGINAL ARTICLE

Pseudomonas infection reduction in the ICU: a successful multidisciplinary quality improvement project

Running title: Pseudomonas infection reduction in the ICU

Anwar **Khedr**[1], Bijoy M. **Mathew**[2], Hisham **Mushtaq**[1], Courtney A. **Nelson**[3], Jessica L. **Poehler**[3], Abbas B. **Jama**[1], Jeanine M. **Borge**[4], Jennifer L. **von Lehe**[3], Eric O. **Gomez Urena**[5], Syed Anjum **Khan**[6]

[1]Research Trainee in Critical Care, Mayo Clinic Health System – Southwest Minnesota region, Mankato, MN, USA;

[2]Strategy Department, Mayo Clinic Health System – Southwest Minnesota region, Mankato, MN, USA;

[3]Department of Nursing, Mayo Clinic Health System – Southwest Minnesota region, Mankato, MN, USA;

[4]Respiratory Therapy, Mayo Clinic Health System – Southwest Minnesota region, Mankato, MN, USA;

[5]Internal Medicine/Infectious Disease, Mayo Clinic Health System – Southwest Minnesota region, Mankato, MN, USA;

[6]Critical Care, Mayo Clinic Health System – Southwest Minnesota region, Mankato, MN, USA

Corresponding author

Syed Anjum Khan

E-mail: khan.syed@mayo.edu

SUMMARY

Pseudomonas aeruginosa infection causes high morbidity and mortality, especially in immunocompromised patients. Pseudomonas can develop multidrug resistance. As a result, it can cause serious outbreaks in hospital and intensive care unit (ICU) settings, increasing both length of stay and costs. In the second quarter of 2020, in a community hospital's 15-bed ICU, the *P. aeruginosa*-positive sputum culture rate was unacceptably high, with a trend of increasing prevalence over the previous 3 quarters. We performed a multidisciplinary quality improvement (QI) initiative to decrease the *P. aeruginosa*-positive rate in our ICU. We used the Define, Measure, Analyze, Improve, and Control model of Lean Six Sigma for our QI initiative to decrease the *P. aeruginosa*-positive sputum culture rate by 50% over the following year without affecting the baseline environmental services cleaning time. A Plan-Do-Study-Act approach was used for key interventions, which included use of sterile water for nasogastric and orogastric tubes, adherence to procedure for inline tubing and canister exchanges, replacement of faucet aerators, addition of hopper covers, and periodic water testing. We analyzed and compared positive sputum culture rates quarterly from pre-intervention to post-intervention. The initial *P. aeruginosa*-positive culture rate of 10.98 infections per 1,000 patient-days in a baseline sample of 820 patients decreased to 3.44 and 2.72 per 1,000 patient-days in the following 2 post-intervention measurements. Environmental services cleaning time remained stable at 34 minutes. Multiple steps involving all stakeholders were implemented to maintain this progress. A combination of multidisciplinary efforts and QI methods was able to prevent a possible ICU *P. aeruginosa* outbreak.

Keywords: health care-associated infections, intensive care unit, *Pseudomonas aeruginosa*, quality improvement, water systems

INTRODUCTION

Of the many types of Pseudomonas bacteria, the most detrimental to humans is *Pseudomonas aeruginosa*, which can cause infections in the blood, lungs, or other parts of the body. *P. aeruginosa* is one of the most common Gram-negative bacteria causing nosocomial and health care-associated infections in hospitalized patients. *P. aeruginosa* infections usually occur in patients who are immunocompromised, and they are particularly dangerous for patients with chronic lung diseases requiring mechanical ventilation. *P. aeruginosa* was the fourth most frequently reported pathogen in adult health care–associated infections in a recent study [1]. It is the most serious and the second most common cause of ventilator-associated pneumonia. Poor outcomes, including increased cost, morbidity, mortality, and prolonged hospital stays, are often associated with *P. aeruginosa* infection [2].

According to the Centers for Disease Control and Prevention, multidrug-resistant *P. aeruginosa* led to approximately 32,600 infections in hospitalized patients and 2,700 deaths in 2017, contributing to an estimated $767 million in health care costs. These rates caused *P. aeruginosa* to be placed on the Centers for Disease Control and Prevention's list of Antibiotic Resistance Threats in the United States [3]. In addition, Pseudomonas outbreaks have been reported in many intensive care units (ICUs) [4-9].

The *P. aeruginosa*-positive culture rates increased in our ICU beginning in mid-2019 and led to an unacceptably high rate of 10.98 positive sputum cultures per 1,000 patient-days in a baseline sample of 820 patients. Thus, we aimed to investigate the cause of this increase and explore tactics to mitigate it. We performed a multidisciplinary quality improvement (QI) project to decrease the *P aeruginosa*–positive sputum culture rate in our ICU.

METHODS

Context and intervention

This QI project occurred in a 15-bed, adult medical/surgical ICU in a 157-bed rural community hospital in the Midwest. The Define, Measure, Analyze, Improve, and Control model of Lean Six Sigma was used to guide this project. This study was performed in adherence with the SQUIRE (Standards for Quality Improvement Reporting Excellence) guidelines [10].

Beginning in mid-2019, the ICU saw an upsurge in the *P. aeruginosa*-positive sputum culture rate of 10.98 infections per 1,000 patient-days as of quarter 2 of 2020 (Figure 1). The project began in quarter 3 of 2020 (September 3, 2020), and the goal was to decrease this positivity rate by half to 5.5 infections per 1,000 patient-days over the following 9 months (October 1, 2020 - June 30, 2021) without adversely affecting environmental services (EVS) cleaning time. A multidisciplinary team was formed, including stakeholders from facilities management, respiratory therapy, infection prevention and control, and EVS, along with critical care providers, infectious disease specialists, nursing management and staff, and patients. A stakeholder analysis was conducted (Table 1), and a fishbone diagram was completed to define and sort potential quality gaps and possible causes of the increase in *P. aeruginosa* infections (Figure 2).

For rooms in which patients tested positive, visual room mapping was performed to explore potential patterns and to determine targeted areas in the ICU to perform microbiology testing (Figure 3). Cases with positive cultures at admission were excluded. The microbiology results indicated that *Pseudomonas* did not exist in the hospital's main water supply; however, it was identified in 1 of 3 ICU patient room faucets tested (measured in colony-forming units/mL). The fishbone diagram and microbiology results were examined by the team to narrow down the list of causes and determine points for intervention. The faucet in ICU room 3407 grew Pseudomonas, which was the only faucet tested with an aerator still in place. Potential areas of water source contamination and transmission were narrowed down to hoppers, sinks, countertops, hands, inline and oral suction, and water supply. These causes were then scored on an impact effort matrix to determine next steps (Figure 4). The causes that had the highest impact-to-effort ratio were chosen for implementation.

Multiple high-impact, low-effort interventions were implemented. Nursing staff changed the practice from using tap water to using sterile water for nasogastric and orogastric tube feedings. Nursing leadership reinforced the importance of changing suction tubing and canisters every 24 hours. Respiratory therapy resumed the facility procedure of changing inline suction catheters every 72 hours for patients supported on mechanical ventilation despite their medical complexities or COVID-19 status. Facilities management replaced all aerators/faucets in the ICU rooms and associated clinical areas with non-aerating faucets. In addition, they defined an ongoing maintenance plan to clean faucets in high-risk areas. Although it was determined to be a high-effort measure, the team elected to design and install hopper covers to prevent splashes and bacteria aerosolization. Even though surveillance cultures were conducted annually before the intervention, post-intervention surveillance cultures were sampled on a quarterly basis to validate the interventions. Sixteen people were mainly involved in the execution of this project. Funds spent were approximately $12,000 for hopper toppers, $9,214 for faucets and aerators, and $8,987 for microbiologic water testing.

Study of the intervention and measures

The chosen improvement measure was *P. aeruginosa*-positive sputum rate per 1,000 patient-days in all ICU patients. The balancing measure was chosen as the mean (SD) EVS discharge room cleaning time in the ICU because cleaning practices can affect infection rates (Table 2).

Statistical analysis

An independent-samples *t* test was conducted to compare the ICU *P aeruginosa*–positive sputum rate per 1,000 patient-days for the 5 months before (April through August 2020) and the 5 months after (October 2020 through February 2021) implementing countermeasures. We compared the mean of each 5-month period as a whole. $P<.05$ was considered statistically significant. BlueSky Statistics software was used for analysis.

Ethical considerations

Institutional review board approval was not required. There were no conflicts of interest among the stakeholders. The project was funded internally without any commercial funding.

RESULTS

Before the inception of the QI project, the *P. aeruginosa*-positive sputum rate in the ICU was 10.98 infections per 1,000 patient-days. This represents the sum of 9 positive cultures in 820 patients screened for quarter 2 of 2020 (100% of ICU patients during this time frame). Over the prior 3 calendar quarters, the positivity rate showed an increasing trend (Figure 1). We assessed the timeline of quality gaps and interventions that occurred during this project, as shown in Table 3.

At the first post-intervention measurement (quarter 4 of 2020), the rate had decreased to 3.44 positive cultures per 1,000 patient-days (3 positive cultures in 872 patients). A second post-intervention measurement collected in quarter 1 of 2021 noted a further decrease to 2.72 positive cultures per 1,000 patient-days (2 positive cultures in 736 patients) (Figure 1). Analysis of the ICU *P. aeruginosa*-positive sputum rate showed a significantly higher rate for the 5 months before implementing countermeasures than for the 5 months after (mean [SD]: 8.97 [2.93] vs 3.49 [1.95] per 1,000 patient-days; t(df)=8; P=.01 independent samples t test). The post-intervention balancing measure of post-discharge cleaning time remained stable at 34 minutes in quarter 4 of 2020 (Figure 5).

DISCUSSION

This multidisciplinary QI study shows how QI frameworks may be used in a wide range of medical and surgical settings to address patient safety concerns regarding increased rates of hospital-acquired infections. After implementation of our interventions, the positive Pseudomonas sputum culture rates decreased significantly in our ICU without affecting our balancing measure of discharge room cleaning time. Changes to cleaning processes, such as frequency, cleaning agents, and ownership between departments, can influence infection rates, which may affect patient outcomes [11].

To ensure ongoing sustainment of improvement efforts, the following interventions were implemented:

1. Water microbiology testing will be repeated biannually.
2. Decisions regarding ongoing use of sterile water for tube feedings will be based on the results of microbiology testing.
3. The laboratory will notify Infection Prevention and Control of any positive Pseudomonas sputum cultures identified in the ICU.
4. Data will be reviewed monthly at ICU division meetings attended by multidisciplinary project team members.
5. Faucets in high-risk areas will be cleaned annually.

Because *P. aeruginosa* causes a wide range of infections, such as hospital-acquired bloodstream infections, pneumonia, catheter-associated urinary tract infections, skin and soft-tissue infections, and intra-abdominal infections, decreasing the rate of these infections would improve outcomes such as hospital and ICU length of stay, progression to mechanical ventilation, duration of mechanical ventilation, and death [12]. It would also decrease the incidence of antimicrobial resistance [13]. One cross-sectional study showed that 7.1% of health care-associated infections are caused by *P. aeruginosa* [14]. In addition, a retrospective cohort study in Thailand showed that 22% of extensively drug-resistant and 12.5% of multidrug-resistant infections occurred in adults with hospital-acquired *P. aeruginosa* infection [15]. In the US, the rates of multidrug-resistant *P. aeruginosa* infections were 21.7% for central line-associated bloodstream infections, 5.3% for surgical site infections, and 18.6% for catheter-associated urinary tract infections [16]. Furthermore, *P. aeruginosa* pneumonia is linked to high in-hospital mortality rates and lengthy hospital stays [17]. In a 13-year prospective cohort study, bloodstream infection due to *P. aeruginosa* was shown to have higher mortality rates than those due to other bacteria [18]. In an ICU setting, *P. aeruginosa* was reported to cause a prolonged outbreak with the involvement of a multidrug-resistant strain and was associated with significantly increased mortality rates [5,6].

Health care-associated *P. aeruginosa* infections can be prevented by implementing measures for direct patient care and environmental measures, such as daily room cleaning [3]. The most crucial measure for direct patient care is hand hygiene. This includes hand washing using soap and water or alcohol hand gel before and after caring for patients and touching medical devices. In a study from Switzerland, an outbreak of *P. aeruginosa* occurred in a surgical ICU as a result of transmission via the hands of one nurse [9]. Because hand hygiene measures were already in place at our institution, our focus was shifted to environmental sources, including water, hoppers, sinks, aerator faucets, and suction tubes and catheters [19].

Particular attention must be paid to water in the hospital setting. Moist environments have been shown to increase the risk of bacterial overgrowth, drug-resistant pathogens, and health care-associated infections. Even though tap water meets strict safety criteria in the US, it is not sterile. Microbial growth can be facilitated by certain circumstances in hospital plumbing systems. This may result in dangerously high quantities of pathogens [19]. Tap water previously had been linked to nosocomial infections when used for enteral feedings [4, 20]. Additionally, tap water had been reported to cause an outbreak of multidrug-resistant *P. aeruginosa* in a neurosurgical ICU [4]. Even though the use of sterile water for enteral feeding is debated, we opted to use sterile water for orogastric and nasogastric tube feedings, especially because of the critical conditions of our ICU patients and because the safety of the tap water could not be presumed [21, 22]. It is recommended that water management programs be installed in health care institutions to safeguard vulnerable patient groups, employees, and visitors. This includes ensuring that water entering a health care facility meets applicable quality standards, that hospital hot- and cold-water piping systems are designed and maintained to reduce the growth and spread of waterborne pathogens on both the supply and waste sides, and that infectious risks from water sources are minimized [19].

Faucet aerators were replaced in all of the ICU rooms, and a maintenance plan was adopted for routine cleaning and replacement. Faucet aerators were previously shown to be a persistent source of multidrug-resistant *P. aeruginosa*, and their replacement led to a decrease in the incidence of infections [5]. In one case series, 4 cases of severe wound infections due to *P. aeruginosa* after cardiac catheterization were traced to contamination of faucet aerators [23]. Faucet aerators were also identified as one of the sources of a *P. aeruginosa* outbreak in a pediatric hospital in Canada, and organisms were still detectable several years after the resolution of the outbreak [24]. For these reasons, routine cleaning and disinfecting of surfaces near water drains, including faucet aerators, faucet handles, sink basins, and countertops, are recommended [20].

Because sinks and other drains such as toilets and hoppers can become colonized with multidrug-resistant organisms such as *P. aeruginosa*, the team decided to install hopper covers to prevent splashes and bacterial droplet aerosolization [20]. This contamination occurs when pathogens stick to pipes and form biofilms, which are difficult to remove and persist for prolonged periods. This then allows the transfer of antibiotic-resistant genes between bacterial species because different types of bacteria may contaminate the same drain. Splashes from water striking drain covers and flushing toilets or hoppers can spread droplets and contaminate the immediate environment as well as the skin of health care workers and patients [20]. In one study, an imperfect room design and the formation of biofilms in the sink led to the propagation of a multidrug-resistant *P. aeruginosa* outbreak for more than a year [8].

Another important potential source of *P. aeruginosa* infection/colonization is suction tubing and catheters [25-27]. The frequency of changing suction tubing and catheters was already a specified procedure in our institution. This frequency increased high-risk exposure to staff during the COVID-19 pandemic. Hence, the frequency decreased as an infection-control measure. After the rate of positive *P. aeruginosa* sputum cultures increased, we reinstated this procedure (increasing the frequency of changing) as a key intervention in our project.

Limitations

Our study has some important limitations. Our interventions may be difficult to replicate in other institutions because of lack of personnel, financial resources, and involvement of key stakeholders. Also, our study was performed in a mid-size community hospital that is a part of a large academic enterprise, which limits its generalizability to other institutions with different infrastructure and size. We did not adjust the final analysis for possible confounders or modifiers of effect factors such as patient comorbid conditions, immunosuppression, or disease severity at admission. Because all the interventions were implemented almost simultaneously, it is difficult to determine which specific intervention had the greatest impact on decreasing the *P. aeruginosa*–positive culture rate.

Conclusions

This study demonstrates a reduction in *P. aeruginosa*-positive sputum culture rate as a result of structured multidisciplinary interventions using the Define, Measure, Analyze, Improve, and Control framework approach. Use of a multidisciplinary team also helped increase staff awareness of the various perspectives of different departments, such as the complexity of water source infrastructure and the potential for contamination. Our collaborative ICU QI project met all deliverables toward the original goals of the effort. The positive effects on patient safety have been monitored and sustained for the past 3 quarters.

Acknowledgments

The Scientific Publications staff at Mayo Clinic provided editorial consultation, proofreading, and administrative and clerical support.

Conflict of interest

None.

Funding declaration

The project was funded internally without any commercial funding.

Data Availability Statement

All relevant data supporting the findings of this study are reported within the article.

REFERENCES

1. Weiner-Lastinger LM, Abner S, Edwards JR, et al. Antimicrobial-resistant pathogens associated with adult healthcare-associated infections: Summary of data reported to the National Healthcare Safety Network, 2015-2017. *Infect Control Hosp Epidemiol*. 2020; 41 (1), 1-18.
2. Nathwani D, Raman G, Sulham K, Gavaghan M, Menon V. Clinical and economic consequences of hospital-acquired resistant and multidrug-resistant *Pseudomonas aeruginosa* infections: a systematic review and meta-analysis. *Antimicrob Resist Infect Control*. 2014; 3 (1), 32.
3. Centers for Disease Control and Prevention. Pseudomonas aeruginosa in Healthcare Settings. 2019. Available from: https://www.cdc.gov/hai/organisms/pseudomonas.html. [accessed 13 Nov 2019].
4. Bert F, Maubec E, Bruneau B, Berry P, Lambert-Zechovsky N. Multi-resistant *Pseudomonas aeruginosa* outbreak associated with contaminated tap water in a neurosurgery intensive care unit. *J Hosp Infect*. 1998; 39 (1), 53-62.
5. Knoester M, de Boer MG, Maarleveld JJ, et al. An integrated approach to control a prolonged outbreak of multidrug-resistant *Pseudomonas aeruginosa* in an intensive care unit. *Clin Microbiol Infect*. 2014; 20 (4), O207-15.
6. Bukholm G, Tannaes T, Kjelsberg AB, Smith-Erichsen N. An outbreak of multidrug-resistant *Pseudomonas aeruginosa* associated with increased risk of patient death in an intensive care unit. *Infect Control Hosp Epidemiol*. 2002; 23 (8), 441-446.
7. Eckmanns T, Oppert M, Martin M, et al. An outbreak of hospital-acquired *Pseudomonas aeruginosa* infection caused by contaminated bottled water in intensive care units. *Clin Microbiol Infect*. 2008; 14 (5), 454-458.

8. Hota S, Hirji Z, Stockton K, et al. Outbreak of multidrug-resistant *Pseudomonas aeruginosa* colonization and infection secondary to imperfect intensive care unit room design. *Infect Control Hosp Epidemiol*. 2009; 30 (1), 25-33.

9. Widmer AF, Wenzel RP, Trilla A, Bale MJ, Jones RN, Doebbeling BN. Outbreak of *Pseudomonas aeruginosa* infections in a surgical intensive care unit: probable transmission via hands of a health care worker. *Clin Infect Dis*. 1993; 16 (3), 372-376.

10. Ogrinc G, Davies L, Goodman D, Batalden P, Davidoff F, Stevens D. SQUIRE 2.0 (Standards for QUality Improvement Reporting Excellence): revised publication guidelines from a detailed consensus process. *BMJ Qual Saf*. 2016; 25 (12), 986-992.

11. Everett BR, Sitton JT, Wilson M. Efficacy and Cost-Benefit Analysis of a Global Environmental Cleaning Algorithm on Hospital-Acquired Infection Rates. *J Patient Saf*. 2017; 13 (4), 207-210.

12. Alhussain FA, Yenugadhati N, Al Eidan FA, Al Johani S, Badri M. Risk factors, antimicrobial susceptibility pattern and patient outcomes of *Pseudomonas aeruginosa* infection: A matched case-control study. *J Infect Public Health*. 2021; 14 (1), 152-157.

13. Pachori P, Gothalwal R, Gandhi P. Emergence of antibiotic resistance *Pseudomonas aeruginosa* in intensive care unit; a critical review. *Genes Dis*. 2019; 6 (2), 109-119.

14. Magill SS, Edwards JR, Bamberg W, et al. Multistate point-prevalence survey of health care-associated infections. *N Engl J Med*. 2014; 370 (13), 1198-1208.

15. Palavutitotai N, Jitmuang A, Tongsai S, Kiratisin P, Angkasekwinai N. Epidemiology and risk factors of extensively drug-resistant *Pseudomonas aeruginosa* infections. *PLoS One*. 2018; 13 (2), e0193431.

16. Weiner LM, Webb AK, Limbago B, et al. Antimicrobial-Resistant Pathogens Associated With Healthcare-Associated Infections: Summary of Data Reported to the National Healthcare Safety Network at the Centers for Disease Control and Prevention, 2011-2014. *Infect Control Hosp Epidemiol*. 2016; 37 (11), 1288-1301.

17. Crabtree TD, Gleason TG, Pruett TL, Sawyer RG. Trends in nosocomial pneumonia in surgical patients as we approach the 21st century: a prospective analysis. *Am Surg*. 1999; 65 (8), 706-709.

18. Thaden JT, Park LP, Maskarinec SA, Ruffin F, Fowler VG, Jr., van Duin D. Results from a 13-Year Prospective Cohort Study Show Increased Mortality Associated with Bloodstream Infections Caused by Pseudomonas aeruginosa Compared to Other Bacteria. *Antimicrob Agents Chemother*. 2017; 61 (6).

19. Centers for Disease Control and Prevention. Reduce Risk from Water. 2019. Available from: https://www.cdc.gov/hai/prevent/environment/water.html. [accessed 11 Sep 2019].

20. Venezia RA, Agresta MD, Hanley EM, Urquhart K, Schoonmaker D. Nosocomial legionellosis associated with aspiration of nasogastric feedings diluted in tap water. *Infect Control Hosp Epidemiol*. 1994; 15 (8), 529-533.

21. Rice TW. Sterile water and enteral feeding: Fear over logic. Practical Gastroenterology, 34-40 pp, 2016. Retrieved from: https://www.practicalgastro-digital.com/practicalgastro/october_2016?article_id=1122761&lm=1497627404000&pg=NaN#pgNaN. Last accessed June 24, 2022.

22. Padula CA, Kenny A, Planchon C, Lamoureux C. Enteral feedings: what the evidence says. *Am J Nurs*. 2004; 104 (7), 62-69.

23. Cross DF, Benchimol A, Dimond EG. The faucet aerator - a source of pseudomonas infection. *N Engl J Med*. 1966; 274 (25), 1430-1421.

24. Bedard E, Laferriere C, Charron D, et al. Post-Outbreak Investigation of Pseudomonas aeruginosa Faucet Contamination by Quantitative Polymerase Chain Reaction and Environmental Factors Affecting Positivity. *Infect Control Hosp Epidemiol*. 2015; 36 (11), 1337-1343.

25. Lowbury EJ, Thom BT, Lilly HA, Babb JR, Whittall K. Sources of infection with Pseudomonas aeruginosa in patients with tracheostomy. *J Med Microbiol*. 1970; 3 (1), 39-56.

26. Orrett FA. Fatal multi-resistant Pseudomonas aeruginosa septicemia outbreak in a neonatal intensive care unit in Trinidad. *Ethiop Med J*. 2000; 38 (2), 85-91.

27. Brown DG, Baublis J. Reservoirs of pseudomonas in an intensive care unit for newborn infants: mechanisms of control. *J Pediatr*. 1977; 90 (3), 453-457.

Table 1 - Stakeholders' Analysis of Potential Quality Gaps

Stakeholders	**Method to gather input**	**Key input received regarding potential quality gaps**	**Key interests**	**Assessment of impact**	**Strategies for obtaining support and reducing obstacles**
Facilities management	Meetings	ICU remodel Water treatment & testing Faucets/aerators	Design of infrastructure Need for further capital outlay	H	Informational meetings
Critical care providers	Meetings	ICU remodel Room trends with infection	Patient outcomes Rate of Pseudomonas infections	H	Informational meetings
Nursing leadership	Meetings	Reviewed EVS & Nursing environmental cleaning practices Transmission sources: hoppers, sinks, countertops, hands, inline & oral suction Policies/procedures: nails, inline canister & suction changing	Patient outcomes Rate of Pseudomonas infections	H	Informational meetings

		Ventilator management Administering medications ICU remodel			
Nursing staff	Meetings	Potential areas using water source: oral care, tube feeding, handwashing, bathing, ice machines, water pitchers Transmission sources: hoppers, sinks, countertops, hands, inline & oral suction Policies/procedures: nails, inline canister & suction changing Mechanical care Administering medications ICU remodel	Patient outcomes Workload	H	Education

Respiratory therapy	Meetings	Policies/procedures: inline suction changing Mechanical care Administering medications COVID-19 process changes Medical gas, oxygen Vent tubing	Patient outcomes Workload	H	Education
IPAC	Meetings	Reviewed EVS & Nursing environmental cleaning practices Transmission sources: hoppers, sinks, countertops, hands, inline & oral suction ICU remodel Water treatment & testing Faucets/aerators	Patient outcomes Rate of Pseudomonas infections	M	Informational meetings Metrics
EVS	Meetings	Reviewed EVS & Nursing environmental cleaning practices	Workload Efficiency of workflow process	L	Informational meetings

Patients	EHR	Patient outcomes	Safety	L	Education

Abbreviations: EHR, electronic health record; EVS, environmental services; H, high; ICU, intensive care unit; IPAC, Infection Prevention and Control; L, low; M, medium.

Table 2 - Data Collection Plan for Improvement and Balancing Measures

Measure type	**Improvement**	**Balancing**
Measure name	ICU Pseudomonas-positive sputum rate per 1,000 patient-days	EVS cleaning time
Measure description	Number of sputum cultures collected in ICU patients that are positive for *Pseudomonas aeruginosa* divided by the total number of ICU patient days, multiplied by 1,000	Total number of minutes for EVS to perform room cleanings for ICU patient discharges divided by the total number of ICU rooms cleaned
Measure unit	Incidence rate per 1,000 patient-days	Minutes
Data source	EHR	EHR
Sampling	100% of patient population	100% of patient population
Collection personnel	Microbiology and IPAC	EVS housekeeping
Collection method	Weekly laboratory report and monthly patient-days report from EHR	EVS housekeeping attendant log time at point of service
Data recording	Data will be shared monthly with the project team and ICU division and analyzed and reviewed quarterly	Via iPad logged in to EHR

Abbreviations: EHR, electronic health record; EVS, environmental services; ICU, intensive care unit; IPAC, Infection Prevention and Control.

Table 3 - Timeline of Potential Gaps in Quality and Key Interventions

Start date	**End date**	**Quarter**	**Event**
1/15/18	2/15/18	Q1/2018	Water shutdowns: OR project
8/6/18	4/1/19	Q3/2018	ICU remodel
4/1/19	Cont	Q2/2019	ICU reopened for patients
9/3/20	6/30/21	Q3/2020	Sterile water for NG/OG
9/3/20	Cont	Q3/2020	Change suction canisters/tubing every 24 h
9/3/20	Cont	Q3/2020	Change inline suction every 72 h
9/23/20	9/23/20	Q3/2020	Remove aerators on faucets
10/10/20	10/10/20	Q4/2020	Hopper topper installation completed in ICU
3/19/21	3/19/21	Q1/2021	Changed out faucets

Abbreviations: Cont, continuing; ICU, intensive care unit; NG/OG; enteral feeding tubes; OR, operating room.

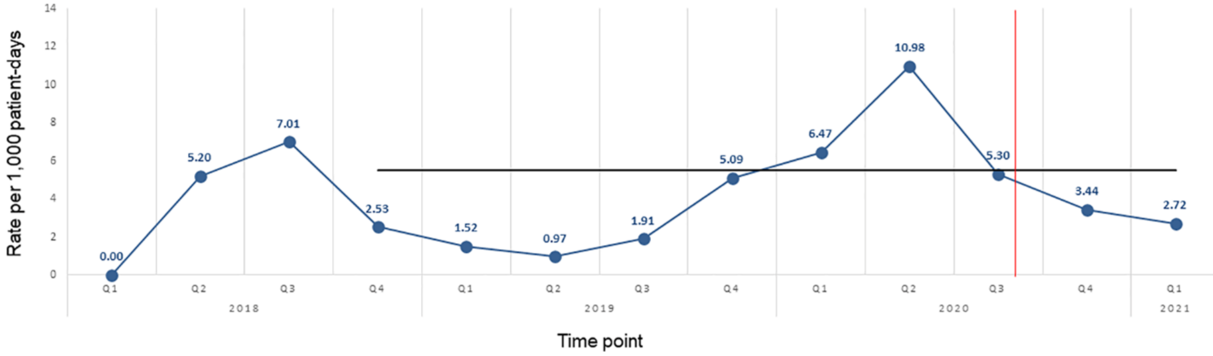


Figure 1. *Pseudomonas aeruginosa*-Positive Sputum Culture Rate. Graph shows the rate of *P aeruginosa*–positive cultures per 1,000 patient-days over time. The mean positivity rate per quarter (Q) is shown. Red vertical line indicates the start date for mitigation strategies (September 2020).

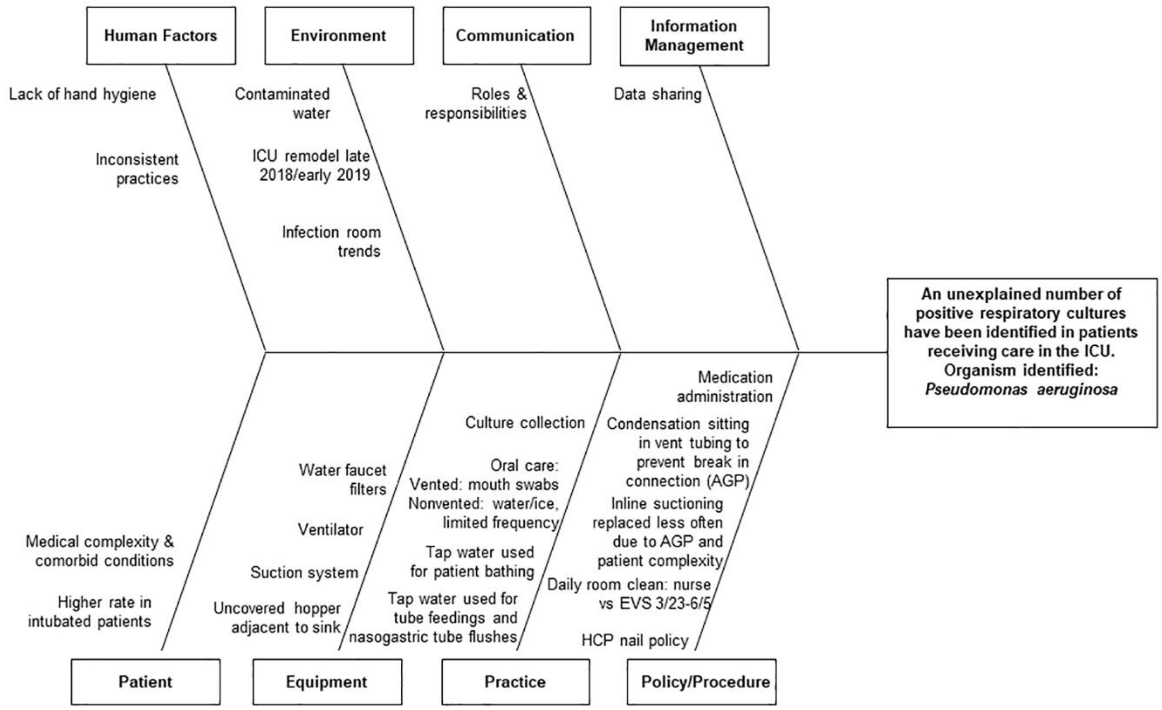


Figure 2 - Fishbone Diagram. Diagram showing potential causes of increased rate of Pseudomonas-positive sputum cultures. AGP indicates aerosol-generating procedure; HCP, health care professionals; ICU, intensive care unit.

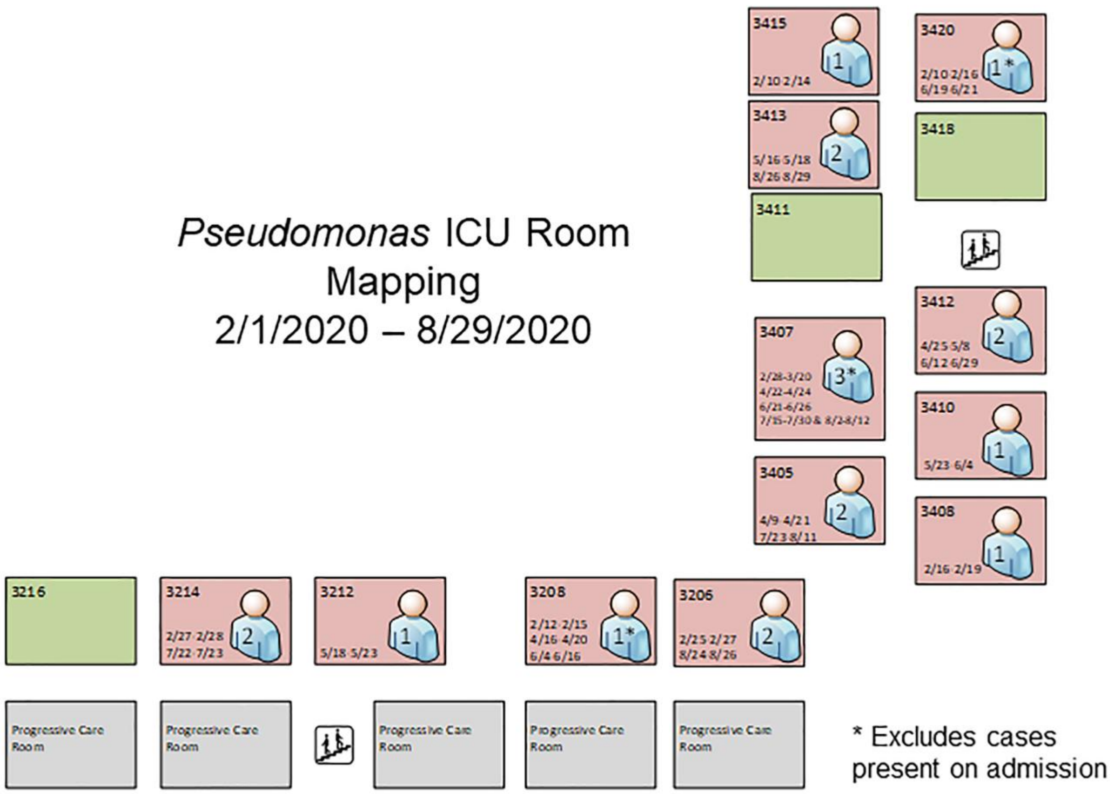
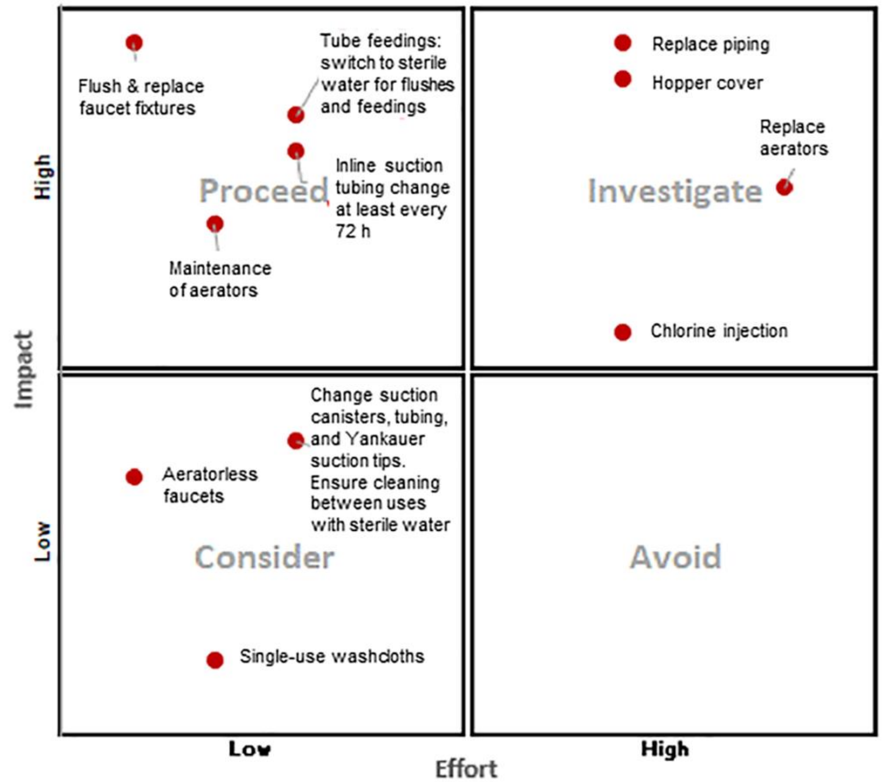


Figure 3 - Intensive Care Unit (ICU) Room Mapping. Colored squares show ICU room numbers (green indicates no positive Pseudomonas sputum cultures; red, positive Pseudomonas sputum cultures), with dates of positive samples shown. The patient icons demonstrate the number of patients with a positive culture that was not present on admission.



Impact	Effort	Countermeasure
9.5	7	Replace piping
9	7	Hopper cover
5.5	7	Chlorine injection
7.5	9	Replace aerators
4	3	Change suction canisters, tubing, and Yankauer suction tips. Ensure cleaning between uses with sterile water.
3.5	1	Aeratorless faucets
1	2	Single-use washcloths
9.5	1	Flush & replace faucet fixtures
8.5	3	Tube feedings: switch to sterile water for flushes and feedings

Figure 4 - Impact Effort Matrix. Grid matrix for assessing key interventions toward *Pseudomonas aeruginosa*-positive culture rate reduction in the intensive care unit.

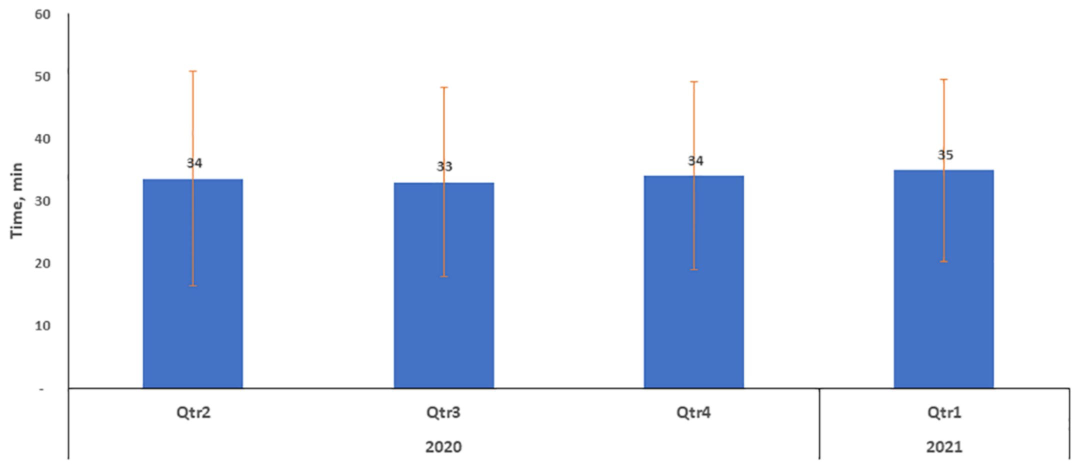


Figure 5 - Cleaning Time Per Quarter. Graph shows mean (SD) environmental services cleaning time for quarters (Qtr) 2-4 of 2020 and Qtr 1 of 2021.