American Journal of Infection Control 000 (2020) 1−6

Contents lists available at ScienceDirect

American Journal of Infection Control

journal homepage: www.ajicjournal.org

Major Article

Evaluating the effect of automated hand hygiene technology on compliance and *C. difficile* rates in a long-term acute care hospital

Maureen Banks DNP, RN, MBA, FACHE [a,*], Andrew B. Phillips PhD, RN [b]

[a] *Spaulding Rehabilitation Network, Chief Operating Officer and Chief Nursing Officer, Charlestown, MA*
[b] *MGH Institute of Health Professions, Spaulding Rehabilitation Network, Charlestown, MA*

Key Words:
Healthcare acquired infection
Employee compliance
Tracking technology
Infection control

Background: Compliance with hand hygiene (HH) standards is a critical component to reducing the prevalence of Health Care Acquired Infections (HAIs). The use of HH technologies is increasing and studies examining the success of these technologies on HH compliance and HAIs are important to inform standards of care. COVID-19 has emphasized compliance HH standards.

Methods: This study evaluated HH compliance and *Clostridium difficile (C difficile)* rates following implementation of an HH technology at a long-term acute care hospital. The HH technology required nursing and other staff with direct patient contact to wear a "badge" that measured alcohol concentration on a health care worker's hands or time washing hands at designated sinks upon exit/entry of patient rooms. No changes were made to environmental cleaning or antibiotic stewardship standards. Compliance and infection rates were compared 12 months pre−post implementation during 2017-2019.

Results: There was an increase in HH compliance (89.82%-97.10%, $P < .001$)) and a reduction in the incidence of *C. difficile* (9.541-3.720, $P = .0032$).

Conclusion: The HH technology significantly and quickly increased HH compliance and reduced rates of *C difficile*. The technology provided ancillary benefits, including data tracing of all patient and staff contacts and cross-contamination events.

Health care acquired infections (HAIs) remain a major problem despite ongoing global efforts. Data provided by the Centers for Disease Control (CDC) estimate that 1 in 31 hospitalized patients acquire an HAI annually.[1] This represents over $30 billion in economic costs and approximately 99,000 preventable deaths per year in the US.[2] Adoption and adherence to hand hygiene (HH) standards by health care workers (HCW) remains a critical challenge to reducing the prevalence of HAIs.[3,4]

Federal activities plus advancements in technologies are further raising the importance of the measurement and improvement in HH compliance. A planning document released in 2013 by Health and Human Services: *The National Action Plan to Prevent Health Care-Associated Infections: Road Map to Elimination*[2] emphasizes the continued need to improve HH compliance by HCWs. Long-term care settings were described as particularly vulnerable to HAIs due to longer lengths of stay, older populations, and diagnoses. The Center for Medicare and Medicaid Services has made HAI a priority with a portion of hospital and rehabilitation setting reimbursements now linked to the organization's HAI rates under the Hospital-Acquired Condition Reduction Program.[5] This has made efforts to reduce HAIs including HH compliance a greater priority.

In 2009, the World Health Organization (WHO) published *Guidelines on Hand Hygiene in Health Care* which included the "my 5 moments for HH" and strategies to improve adherence to HH.[3] The WHO 5 "moments" standard for HH include before touching a patient, before clean/aseptic procedures, after body fluid exposure/risk, after touching a patient, and after touching patient surroundings. Adherence to compliance at these 5 moments of HH by HCW remains an ongoing challenge. The WHO and others have suggested multimodal strategies to implementation and achieve adherence to HH best practices.[3,6,7] The recommended strategies include system change, including availability of alcohol-based hand rub at the point of patient care, access to a safe, continuous water supply and soap and towels at the point of care, training and education, reminders and feedback, institutional climate, monitoring, and involvement of patients in HH compliance. In response to the COVID-19 pandemic,

* Address correspondence to Maureen Banks, DNP, RN, MBA, FACHE, Spaulding Rehabilitation Network, Chief Operating Officer and Chief Nursing Officer, Charlestown, MA.
E-mail address: mbanks2@partners.org (M. Banks).
Funding: The authors received no specific funding for this work.
Conflicts of interest: None to report.

https://doi.org/10.1016/j.ajic.2020.10.018
0196-6553/

the WHO and CDC have issued additional guidance emphasizing the need for HH for greater public awareness beyond HCWs.[8,9] The WHO guidelines and the accompanying implementation strategies remain the gold standard for effective HH compliance and implementation.

The most recent of 3 Cochrane reviews in 2017 concluded that while the adoption of some or all of the WHO's strategies did improve HH compliance and in some cases reduced HAIs, the certainty (per GRADE[10] criteria) of this evidence was low.[4,11] The authors reported that significant limitations continue to exist in studies using a direct observation method for determining HH compliance rates; the current standard. Additional limitations identified by the authors include insufficient data points around HH opportunities and the limited duration of most pre−post studies. Longer term studies with increased data points were noted to be needed to effectively demonstrate links between HH compliance and HAIs.

Technology innovation has the potential to address some of the limitations identified in the literature and to reinforce the recommendations outlined by the WHO. These new innovations are providing opportunities to measure all 5 moments of HH and increase the number of data points available for research.[4] New technologies have also shown an ability to provide visual and other cues that incorporate patient involvement in HH compliance, furthering any multimodal approach to HH activities.[12-16] The additional capability to measure the adequacy of HH by HCW provides a further opportunity to improve HH compliance and reduce HAI rates. This newly available data on HH adequacy can also inform future research. An ongoing evaluation of methods, including new technologies, to improve HH compliance are needed to reduce the prevalence and spread of hospital-acquired infections and other infections.

The purpose of this study was to evaluate the effectiveness of an HH technology on HH compliance for 2 of the 5 moments of HH − before patient contact and after patient contact within a long-term acute care hospital setting. The study also evaluated the effect of HH technology use on rates of *Clostridium difficile* (*C. difficile*). CAUTI and CLABSI infection rates were not included in this study as these rates are influenced more by antiseptic policies than HH compliance related factors. Such factors include avoidance of catheter days, method of insertion, site preparation and management, use of antiseptic solutions, dressing type, regular replacement of central lines, and strict adherence to protocols.[17-19]

METHODS

Setting

The setting for this study was a 180 bed, long-term acute care hospital (LTACH). An LTACH exists for the care of those who are chronically critically ill. Major diagnostic groups in an LTACH include chronic and actively weaning ventilator dependent patients, pre- and post-transplant patients encompassing heart, lung and liver transplants, oncology patients actively receiving treatment such as IV chemotherapy and proton beam radiation. This specific LTACH setting also includes a large hemodialysis unit, providing over 40 dialysis treatments per week. Central lines are utilized for 40% of this hospital's population.

Technology selection

Four companies providing HH compliance technologies were evaluated. The chosen technology, BioVigil, was selected as it was able to capture both HH compliance opportunities and HH adequacy. The technology involves a wearable "badge" that provides audible and visual reminders emitted from the badge if HH compliance has not been registered within a specific timeframe of entering or exiting a patient room. Similar reminders are provided upon exit of *C. difficile*-designated rooms requiring hand washing with soap and water. HH adequacy is measured by the concentration of alcohol-based sanitizer on the HCWs' hands as they enter and exit patient rooms. HH adequacy with soap and water in *C. difficile*-designated rooms is measured through time spent actively washing hands at designated sinks. This information is captured in real-time, and can be programmed to reflect specific job classifications, for example, food service worker versus respiratory therapist. Testing and validation of the technology's functionality is performed on an ongoing basis. Functionality tests include badge activation upon room entry and exit, reminder parameters matching those set in the system, and appropriate alcohol concentrations triggering reminders as expected. The system also monitors badge performance during charging periods. BioVigil is responsible for all badge maintenance, including changing out of badges due to wear, integrated battery degradation, or other issues. Figure 1 illustrates the basic mechanics of the technology's process flow.[20] All communication between badges upon room entry and exit and time spent in front of sinks is via infrared technology.

Study design

This was a nonrandomized pre−post intervention study at a single LTACH. HH compliance and *C. difficile* rate data were collected over a 2-year period from June 2017 to July 2019 reflecting 12 months both pre- and postintervention of the HH technology. Preintervention data were collected retrospectively for the 52-week period prior to implementation from existing direct observation data and infectious disease reporting (June 2017-May 2018). Postintervention data were collected for the 52-week period beginning in July 2018. The month of June 2018 was excluded to reflect training, implementation, and transition activities during this period.

Study participants included all staff within the hospital who routinely enter patient rooms including: nurses, physicians, therapists, housekeeping and food service staff, lab, radiology, and respiratory therapists. Occasional staff such as consulting physicians and family members, were excluded from data collection, but were still subject to HH policies. No changes were made to environmental cleaning protocols or compliance monitoring, nor in antibiotic stewardship practices during the study period to best isolate the impact of the HH technology. Table 1 summarizes the testing and antimicrobial stewardship practices maintained during the study period. The days of antibiotic therapy were similar pre and post-intervention (39,913 antibiotic days preintervention compared to 39,729 days postintervention).

Training

All staff completed orientation to the system, beginning with an understanding of the technology and the data collected. An overview of the transmission of information linked to employee identification number and to direct managers was explained. The mechanics of the charging stations, cleaning of badges and the sensing function of the badge was detailed. All staff demonstrated competency with the new technology. In addition to the technology orientation, current infection control policies were re-reviewed with all employees. Signage highlighting the project was displayed throughout the hospital and patients were given information cards explaining the initiative.

Data elements

HH compliance and adequacy

A count of the total number of exit/entrance moments by individual HCW and a measure of the compliance and adequacy of HH at each of these moments was gathered using the badge technology.

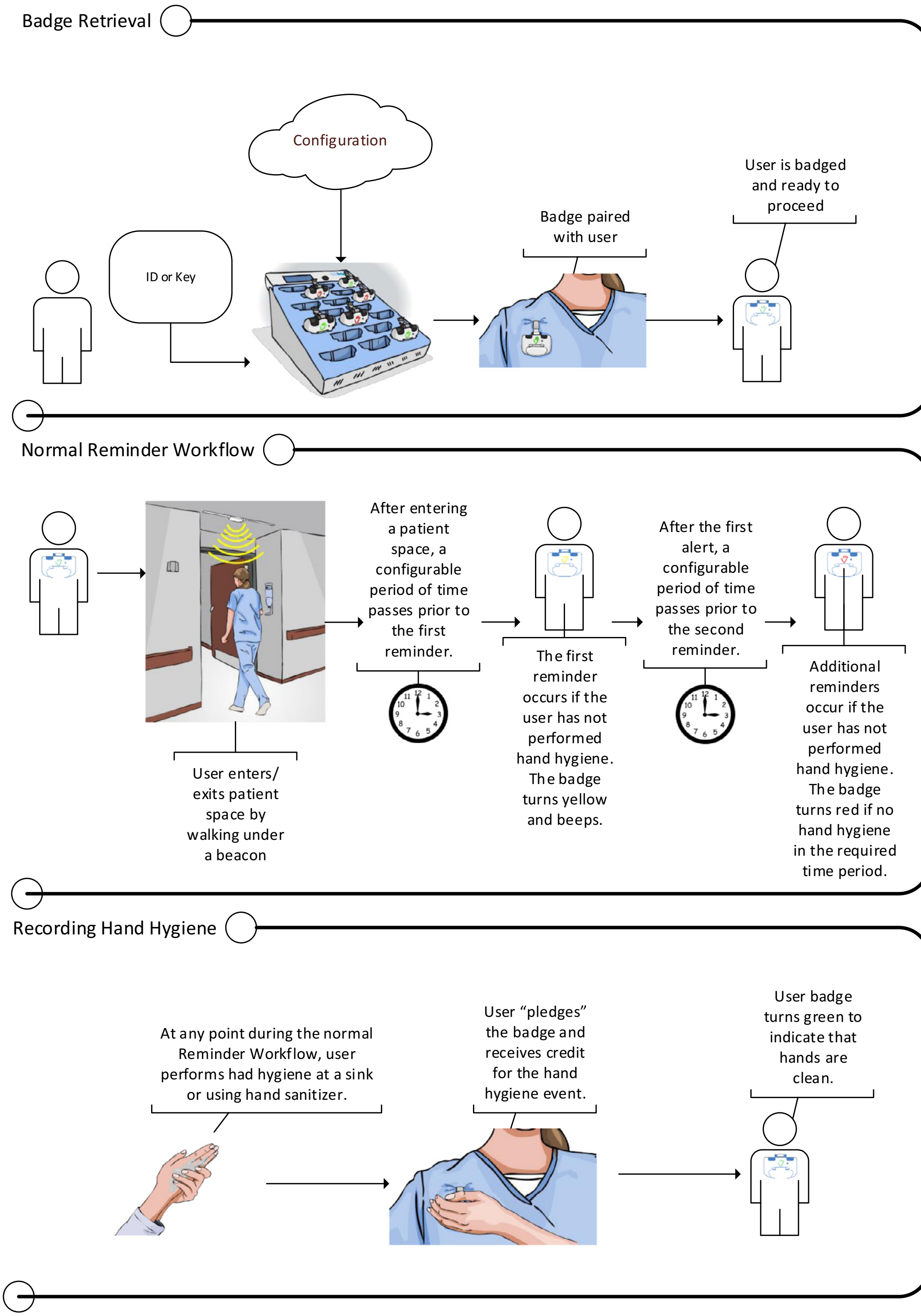

Fig. 1. Schematic of BioVigil process flow for room entry, exit and re-entry.

Staff were considered compliant with entry or exiting requirements if they performed HH within 60 seconds immediately before and after crossing the threshold of room entry or exit. At 15 seconds after crossing the threshold if the HCW did not complete HH, the badge provided an audio-visual reminder, with additional audio-visual reminders at 30 seconds and 45 seconds. If the HCW had still not performed HH at 60 seconds after crossing the threshold, they were considered noncompliant. These time periods varied slightly based on job classification. HH adequacy equaled a sufficient concentration of alcohol-based sanitizer on the HCW’s hands. The HH technology

Table 1
C. difficile testing protocols and antimicrobial stewardship practices maintained during the study period

C. difficile testing protocols
- At least 3 diarrheal stools within a 24-h period were required
- Stools that conformed to the container for testing were rejected
- Tests submitted within a 7-d period of the most recent test were rejected
- Testing for cure was prohibited

Antimicrobial stewardship practices
- The Clinical Pharmacist and Infectious Diseases Physician leading stewardship activities did not change pre- and postintervention
- Antibiotics from the formulary that are associated with inciting *C. difficile*, such as fluoroquinolones remained restricted
- Antibiotics were discontinued promptly if cultures returned negative
- Empiric broad-spectrum antibiotics were streamlined to narrow therapy whenever culture data allowed

could also measure HH compliance based on time actively washing hands in front of select sinks for designated patient rooms before or after exiting the room. A minimum of 15 seconds in front of selected sinks was considered compliant based on the facility's hand washing policy. Compliance rates reflected mean rates during the pre- and poststudy periods (HH compliance/HH Opportunities).

C. difficile *Rates*

Incidence rates of *C. difficile* were provided by infectious disease staff. A GDH-positive and Toxin-positive (GDH+/Toxin+) *C. difficile* test result was considered positive. Nonpositive results were defined as a GDH positive but toxin-negative (GDH+/Toxin-) or GDH-negative but toxin-positive (GDH−/Toxin+) test result. A polymerase chain reaction assay could be ordered in instances where either the GDH or Toxin results were negative, but was not required per the facilities infectious disease policy. Polymerase chain reaction results were therefore not considered in calculating *C. difficile* incidence rates.

Analysis

A two-tailed Welch's *t* test was conducted to examine whether the mean difference pre−post implementation and HH compliance was significantly different from zero. To determine the impact of intervention on the trajectory of percent compliance, a secondary time series analysis was performed. To assure sufficient data points for the calculation, preintervention data included weekly compliance rates from direct observations preintervention (June 2016-May 2018) and HH technology data postintervention (July 2018-July 2020). Data included in Appendix A. We used an autoregressive integrated moving average model with exogenous input (ie, and ARIMAX model) to model weekly compliance with a dummy variable indicating the stage (pre- vs postintervention). The model order (ie, size or autoregressive, integration, and moving average components) were determined to minimize Akaike and Bayesian Information Criteria via model selection based on the stepwise algorithm outlined in Hyndman and Khandakar, 2008[21] and Wang et al.[22] model residuals were inspected to assess comformity to model assumptions via Ljung-Box test statistic.

ARIMA models use maximum likelihood for estimation, and therefore, the coefficients are asymptotically normal. Given this, we calculated the statistical significance of the exogenous variable (ie, the impact of intervention on compliance trajectory) based on the z-statistics calculated by dividing corresponding coefficient by their standard errors.

An independent samples *t* test was performed to assess significance between *C. difficile* incidence rates. A Mann-Whitney two-sample rank-sum test was also conducted. The two-tailed Mann-Whitney two-sample rank-sum test is an alternative to the independent samples *t* test, but does not share the same distribution assumptions.

Human subjects

This study was determined to be quality improvement based on criteria established by the Institutional Review Board and was therefore exempt from IRB review.

RESULTS

Hand hygiene compliance and adequacy

The badge technology captured a total number of 3,778,830 HH moments during the 52 week postimplementation period. One thousand six hundred and twenty-four moments were captured via the direct observation method during the 52 weeks prior to implemenation (Appendix A). The result of the Welch's *t* test was significant based on an alfa (α) value of 0.05, t(11.13) = 4.86, $P < .001$. The results are presented in Table 2. The time series analysis model estimated, a 5.7% + 2.0% (standard error) increase in compliance (Fig 2), and this increase was statistically significant (z = 2.90,P = .004).

C. difficile *infection rates*

C. difficile incidence rates pre−post technology implementation are detailed in Appendix B. There were 12 observations preintervention and 12 observations postintervention of the HH technology. Results showed a significant reduction in the incidence of *C. difficile* ($P < .01$) as measured by GDH+/Toxin+ test results pre- and postimplementation (Table 2). The incidence rate was measured on a continuous scale. The result of the two-tailed Mann-Whitney *U* test was significant based on an α value of 0.05, U = 117, z = −2.61, P = .009. The mean rank preintervention was 16.25 compared to the mean rank postimplmentation of 8.75.

DISCUSSION

The technology captured a significantly greater number of HH moments than the direct observation method; 30-40 moments per week observed prior to implementation and 60-70,000 per week observed after implementation. The data also indicated a statistically significant increase in overall compliance with HH (Table 2 and Fig 2). This observed increase in HH compliance was most likely greater than that observed during the study period due to the small sample size prior to implementation and the known overstatement of compliance through direct observation from the Hawthorn effect.[23,24] The 65.4% HH compliance rate prior to any reminder from the HH technology is most likely a reflection of this effect and

Table 2
Hand hygiene mean compliance rates pre- and postimplementation of technology

Variable	Pre		Post				
	M	SD	M	SD	*t*	*P*	*D*
Mean HH compliance	0.8982	0.052	0.9710	0.004	4.862	<.001	1.985
C-difficile incidence rate[b]	9.541[c]	4.506	3.720[d]	4.113	3.305	.0032	1.349

[a]n = 24, df = 11.133. Confidence interval based on α = 0.05: lower limit = 0.040, mean difference = 0.0728, upper limit = 0.106.
[b]n = 24, df = 22.000. Confidence interval based on α = 0.05: lower limit = 2.168, mean difference = 5.820, upper limit = 9.473.
[c]Testing rate prehand hygiene technology: 439/42726 = 10.27 tests per 10,000 patient days.
[d]Testing rate posthand hygiene technology: 351/40936 = 8.57 tests per 10,000 patient days.

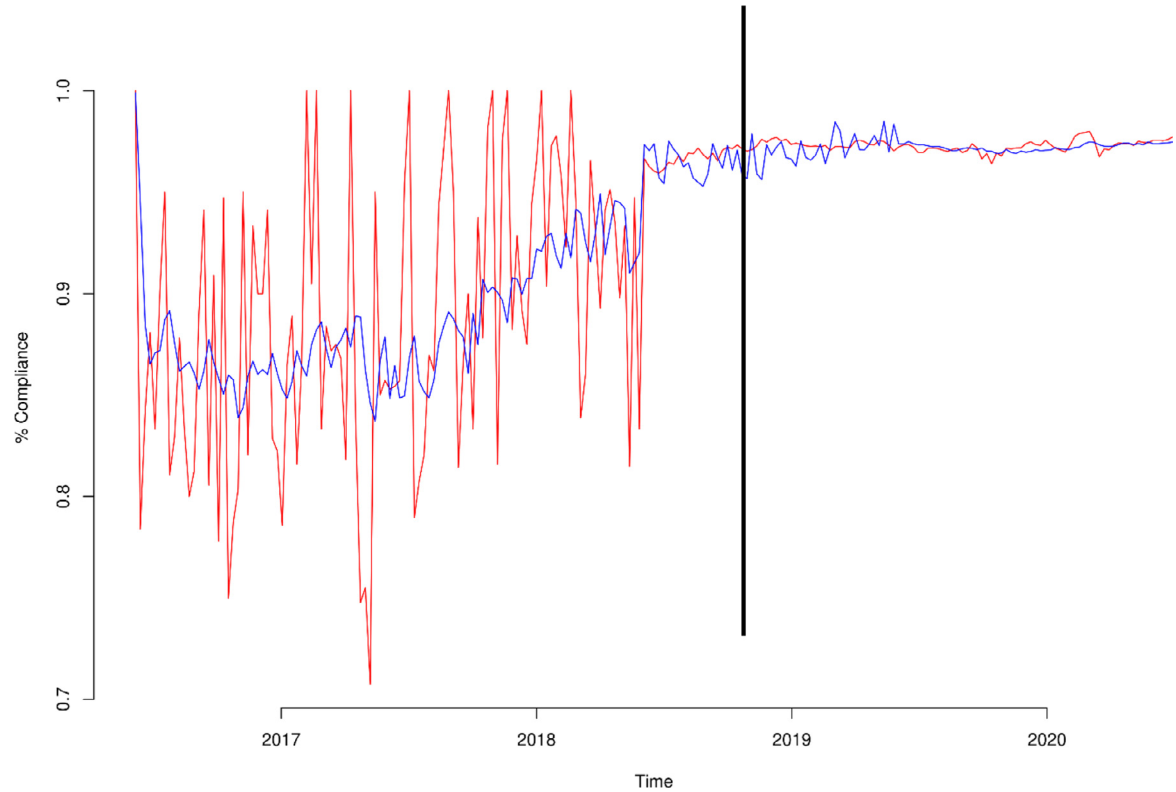

Fig. 2. Interrupted time series analysis. Intervention date June 2018. 5.7% increase in hand hygiene compliance (z = 2.90, *P*= .004).

demonstrates that the 89.9% compliance through direct observation is likely an overstatement. This emphasizes the value of the reminder and the ability of the technology to maintain a postimplementation HH compliance rate of 97.1 and the greater impact of the HH technology versus direct observation. During the study period, the consumption of alcohol-based hand sanitizer more than doubled (2.33) following implementation of the technology. The comparative consumption volume of alcohol-based sanitizer would support other studies concluding there is an overstatement when the direct observation methodology is employed.[25] The HH technology was also able to measure compliance by nonclinical staff, a group which is often not the focus of direct observation and provides additional support for the use of the HH technology.

The implementation of the HH technology had a significant impact on the incidence of *C. difficile*, with periods of zero infections postimplementation experienced by the facility. While the study did not include measures for CLABSI and CAUTI, a similar study utilizing the same BioVigil technology showed a statistically significant reduction in both CLABSI and CAUTI rates. However, the technology implementation occurred over a 3 year time frame in an acute care rather than LTACH setting and reflected the concurrent implementation of both HH technology and updated infection control policies.[12] Important differences in rates of *C. difficile* preimplementation reflect the uniqueness of the LTAC setting. Patients transferred to the facility spent on average 25.9 days in an ICU prior to admission (2019-2020). Of these approximately 60% are admitted with a HAI. The significant ICU days prior to admission combined with the large percentage of infection prior to admission further support the effectiveness of the HH technology to increase HH compliance and significantly decrease infection rates within the facility.

The results of this study may not be generalizable to other postacute facilities. Data collection and metrics reflect the specific parameters applied at the discretion of this facility which may limit the comparative value and generalizability. For example, data collection occurs only when worn by the employee. This could have led to study bias from self-selection. However, the technology's data suite has automated reports that are pushed out to both employees and managers every week showing each employee's usage metrics, including the number of hours a badge was worn. Employees who had low compliance or low badge usage were automatically flagged and reviewed by managers. The effect was an increase in badge compliance over the study period. The ability to monitor badge usage and remind individual employees of individual usage patterns mitigated self-selection bias. In addition, the immediate increase in compliance observed did not change as badge usage increased through this process. An additional informal measure of increased compliance during the study period was the doubling of alcohol-based sanitizer purchases which further supports the increased HH compliance rate observed. There was also no control hospital for comparative data and these results reflect data from a single hospital. The technology tracked only 2 of the 5 moments for HH. Ideally, the technology would be able to sense when the hand sanitizer had lost its effectiveness. It could be assumed that longer times at the bedside would increase the opportunities for exposure to blood/body fluids, for example, during wound or respiratory care.

As with all technology, the badge may also have a relatively short time frame of utility thus limiting the long-term value of some of the findings. Continued development of next generation technology will be important to maintain ongoing relevance and improved HH compliance. For example, the technology currently requires a separate badge worn by HCWs. Future technology could embed identification and sensing capabilities through proximity sensors in the sanitizer dispenser or part of the patient bed. This might also facilitate the timing reminder for the additional moments of HH opportunities and ensuring HCW usage of the HH technology.

CONCLUSION

This study was able to demonstrate a significant increase in HH compliance and a decline in *C. difficile* incidence rates during the study period. HH technology was shown to be effective in both measuring and increasing the compliance and adequacy of HH. Patient involvement incorporated into the implementation process provided an additional element of shared HH compliance. Studies on the importance of patient involvement continue to reinforce the role of patients in HH compliance efforts.[26-30]

The ability of HH technology to identify specific HCW categories provides an opportunity to examine outcomes beyond HH compliance. This could include analysis reflecting the economic impact of: reduced precaution days, savings related to fewer precaution related supplies, associated decreased length of stay, fewer employee nosocomial illnesses, and the cost of penalties associated with readmissions within 30 days for sepsis due to HAIs could be explored.

The extensive data produced through the utilization of HH technology suggest other immediate opportunities. With the recent COVID-19 pandemic, the technology has provided data driven tracing of all patient contact when a staff member (physician, nurse, PT, OT, environmental services, others) has tested positive, as well as instances of cross contamination tracing where patients have tested positive. In each of these cases, the technology provides specific real-time patient, staff, room and movement data to mangers who take immediate action to isolate and test staff and patients for potential exposure risk. The technology has also been utilized in the management and consumption of PPE by staff. The technology allows the tracking of HH opportunities to employee work schedules, and correlating the exact hours worked by an employee using badge hours. There are a host of human resource implications which arise as HH technology is adopted as a standard of care. At the extreme, there might be disciplinary action for staff who refuse to participate in utilizing the technology or, while wearing the badge show clear evidence of cross contamination. If adopted on a wide scale, there could be broader quality implications with the potential of penalties imposed by payors for episodes of cross contamination.

We are in the process of replicating the implementation of this technology across our network due to the success of this initial implementation. These additional settings include an inpatient acute rehabilitation and subacute/skilled nursing facility. Pairing with other providers at each level of postacute care is being considered to provide a control environment to further explore causality between HH compliance and HAI.

Acknowledgments

Samantha Louise Kolbe and Keith Chin RN, BSN, CIC, Spaulding Rehabilitation Network.

SUPPLEMENTARY MATERIALS

Supplementary material associated with this article can be found in the online version at https://doi.org/10.1016/j.ajic.2020.10.018.

References

1. Healthcare-Associated Infections - HAI Report. Available at: https://gis.cdc.gov/grasp/PSA/HAIreport.html. Accessed November 19, 2020.
2. HAI Action Plan - health.gov. Available at: https://health.gov/hcq/prevent-hai-action-plan.asp. Accessed November 19, 2020.
3. *WHO Guidelines on Hand Hygiene in Health Care: First Global Patient Safety Challenge Clean Care Is Safer Care*. Geneva, Switzerland: World Health Organization; 2009.
4. Gould DJ, Moralejo D, Drey N, Chudleigh JH, Taljaard M. Interventions to improve hand hygiene compliance in patient care. *Cochrane Database Syst Rev*. 2017.
5. Centers for Medicare & Medicaid Services. HAC-Reduction-Program. Available at: https://www.cms.gov/Medicare/Medicare-Fee-for-Service-Payment/AcuteInpatientPPS/HAC-Reduction-Program.html. Accessed November 19, 2020.
6. Huis A, van Achterberg T, de Bruin M, Grol M, Schoonhoven L, Hulscher M. A systematic review of hand hygiene improvement strategies: a behavioural approach. *Implement Sci*. 2012;7:92.
7. Luangasanatip N, Hongsuwan M, Limmathurotsakul D, et al. Comparative efficacy of interventions to promote hand hygiene in hospital: systematic review and network meta-analysis. *BMJ*. 2015;351.
8. WHO. Recommendations to Member States to improve hand hygiene practices to help prevent the transmission of the COVID-19 virus. *Interim Guidance*. 2020.
9. CDC. *Coronavirus Disease 2019 (COVID-19)*. Centers for Disease Control and Prevention Available at: https://www.cdc.gov/coronavirus/2019-ncov/hcp/infection-control-recommendations.html. Accessed November 19, 2020.
10. What is GRADE? BMJ best practice. Available at: https://bestpractice.bmj.com/info/us/toolkit/learn-ebm/what-is-grade/. Accessed November 19, 2020.
11. Gould D, Moralejo D, Drey N, Chudleigh J, Taljaard M. Interventions to improve hand hygiene compliance in patient care: Reflections on three systematic reviews for the Cochrane Collaboration 2007–2017. *J Infect Prev*. 2018;19:108–113.
12. McCalla S, Reilly M, Thomas R, McSpedon-Rai D. An automated hand hygiene compliance system is associated with improved monitoring of hand hygiene. *Am J Infect Control*. 2017;45:492–497.
13. Michael H, Einloth C, Fatica C, Janszen T, Fraser TG. Durable improvement in hand hygiene compliance following implementation of an automated observation system with visual feedback. *Am J Infect Control*. 2017;45:311–313.
14. Buckner JB, Read M. Individual monitoring increases hand hygiene compliance in multicenter registry utilizing badge-based locating technology. *Am J Infect Control*. 2016;44:S94.
15. Boyce JM. Measuring healthcare worker hand hygiene activity: current practices and emerging technologies. *Infect Control Hosp Epidemiol*. 2011;32:1016–1028.
16. Marra AR, Edmond MB. New technologies to monitor healthcare worker hand hygiene. *Clin Microbiol Infect*. 2014;20:29–33.
17. Sadeghi M, Leis JA, Laflamme C, et al. Standardisation of perioperative urinary catheter use to reduce postsurgical urinary tract infection: an interrupted time series study. *BMJ Qual Saf*. 2019;28:32–38.
18. Shekelle PG, Wachter RM, Pronovost PJ, et al. Making health care safer II: an updated critical analysis of the evidence for patient safety practices. *Evid Report-technol Assess*. 2013:1.
19. Roy MA, Philip N, Fulwadiya D, Dhabade S. Prevention of catheter associated urinary tract infection (CAUTI). *Indian J Public Health Res Dev*. 2018;9:68–73.
20. Williamson. *BioVigil Tehnology Workflow*. 2018.
21. Hyndman R, Khandakar Y. Automatic time series forecasting: the forecast package for R. *J Stat Softw Artic*. 2008;27:1–22.
22. Wang X, Smith K, Hyndman R. Characteristic-based clustering for time series data. *Data Min Knowl Discov*. 2006;13:335–364.
23. Hagel S, Reischke J, Kesselmeier M, et al. Quantifying the Hawthorne effect in hand hygiene compliance through comparing direct observation with automated hand hygiene monitoring. *Infect Control Hosp Epidemiol*. 2015;36:957–962.
24. Srigley JA, Furness CD, Baker GR, Gardam M. Quantification of the Hawthorne effect in hand hygiene compliance monitoring using an electronic monitoring system: a retrospective cohort study. *BMJ Qual Saf*. 2014;23:974–980.
25. McLaws M-L, Kwok YLA. Hand hygiene compliance rates: fact or fiction. *Am J Infect Control*. 2018;46:876–880.
26. Lastinger A, Gomez K, Manegold E, Khakoo R. Use of a patient empowerment tool for hand hygiene. *Am J Infect Control*. 2017;45:824–829.
27. Lastinger A, Khakoo R, Gomez K, Manegold E. Attitudes towards a patient empowerment tool to improve hand hygiene. *Open Forum Infect Dis.*. 2016;3 (suppl_1):1373.
28. Longtin Y, Sheridan SE, McGuckin M. Patient articipation and empowerment. *Hand Hygiene 206–215*. Hoboken, NJ: John Wiley & Sons, Ltd; 2017.
29. McGuckin M, Govednik J. Patient empowerment and hand hygiene, 1997–2012. *J Hosp Infect.*. 2013;84:191–199.
30. Grota PG, Eng T, Jenkins CA. Patient motivational dialogue: a novel approach to improve hand hygiene through patient empowerment in ambulatory care. *Am J Infect Control*. 2020;48:573–574.