Infection Control & Hospital Epidemiology (2020), **41**, 931–937
doi:10.1017/ice.2020.182

Original Article

Impact of an automated hand hygiene monitoring system combined with a performance improvement intervention on hospital-acquired infections

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Abstract

Objective: Hand hygiene adherence has been associated with reductions in nosocomial infection. We assessed the effect of improvements in electronically measured hand hygiene adherence on the incidence of hospital-acquired infections.

Methods: This quasi-experimental study was conducted in a 555-bed urban safety-net level I trauma center. The preintervention period was January 2015 through June 2016. Baseline electronic hand hygiene data collection took place from April through June 2016. The intervention period was July 2016 through December 2017. An electronic hand hygiene system was installed in 4 locations in our hospital. Performance improvement strategies were implemented that included education, troubleshooting, data dissemination, and feedback. Adherence rates were tracked over time. Rates of hospital-acquired infections were evaluated in the intervention units and in control units selected for comparison. The intervention period was subdivided into the initial and subsequent 9-month periods and were compared to the baseline period.

Results: Electronically measured hand hygiene rates improved significantly from baseline to intervention, from 47% 77% adherence. Rates >70% continued to be measured 18 months after the intervention. Interrupted time series analysis indicated a significant effect of hand hygiene on healthcare facility-onset *Clostridioides difficile* infection rates during the first 9 months of the intervention. This trend continued during the final 9 months of the intervention but was nonsignificant. No effects were observed for other hospital-acquired infection rates.

Conclusions: Implementation of electronic hand hygiene monitoring and performance improvement interventions resulted in reductions in hospital-onset *Clostridioides difficile* infection rates.

(Received 27 January 2020; accepted 10 April 2020; electronically published 28 May 2020)

Effective hand hygiene is associated with reduced nosocomial infection and mortality and is a major focus of infection prevention performance improvement programs.[1] Both the Centers for Disease Control (CDC) and World Health Organization (WHO) have published detailed recommendations for when and how to clean hands most effectively.[2,3] Some studies have indicated that reductions in hospital-acquired infection (HAI) rates such as methicillin-resistant *Staphylococcus aureus* (MRSA) and methicillin-susceptible *Staphylococcus aureus* (MSSA) bacteremia can be achieved when hand hygiene adherence increases.[4-6] The association between hand hygiene behavior and *Clostridioides difficile* infection (CDI) is more complex. Alcohol-based hand rub (ABHR) does not kill *Clostridioides difficile* spores and has been shown to be less efficacious at mechanically removing spores from hands than traditional soap and water.[7] Nonetheless, an association between lower CDI rates and higher rates of handwashing using either soap and water or ABHR has been demonstrated.[8]

Direct observation of hand hygiene practice remains the gold standard for measuring adherence although it is flawed by small sample size, heterogeneous observer training and methodology, and the Hawthorne effect.[9] Intensive efforts to monitor and improve hand hygiene have questionable sustainability.[10-13] Automated hand hygiene monitoring systems (AHHMSs) are increasingly common,[14-16] but they have varying accuracy.[9,17-23] Some AHHMSs record the use of alcohol-based hand rub (ABHR) and soap, while others record the number of times dispensers are used and compare that to an estimated number of hand hygiene opportunities.[24] These systems can accurately estimate an aggregate adherence rate for a hospital, unit, or individual room within a hospital, but they cannot distinguish between healthcare worker (HCW) types or provide individualized HCW data.[9,24] AHHMSs utilizing radio frequency identification (RFID) technology also allow adherence to be tracked in individual rooms, as well as for individual HCWs.[25] However, simply implementing an AHHMS in the absence of interventions intended to improve performance has not been shown to be effective.[26] Interventions that are associated with improved adherence include providing feedback, rewarding positive behavior, encouraging friendly competition, and conducting educational programs to raise awareness.[26-30]

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Cite this article: Knepper BC, Miller AM, and Young HL. (2020). Impact of an automated hand hygiene monitoring system combined with a performance improvement intervention on hospital-acquired infections. *Infection Control & Hospital Epidemiology*, 41: 931–937, https://doi.org/10.1017/ice.2020.182

Table 1. Demographic Characteristics and Mean HAI rates of AHHMS and Non-AHHMS Locations

Variable		Non-AHHMS[a]			AHHMS[b]	
Beds		166			84	
Acuity (average DRG weight)		1.8			2.46	
Average daily census		113			66	
Average daily AHHMS opportunities		. . .			4,080	
		Non-AHHMS			AHHMS	
HAI Type	Period 1[c]	Period 2[d]	*P* Value	Period 1	Period 2	*P* Value
All	1.82	1.26	.04	2.53	2.04	.24
CLABSI[e]	0.24	0.16	.04	0.44	0.19	.19
CAUTI[e]	0.29	0.13	.01	0.87	0.72	.32
HO-MRSA Bacteremia[f]	0.06	0.03	.30	0.08	0.05	.98
HO-CDI[f]	1.23	0.93	.24	1.14	1.07	.58

Note. HAI, hospital-acquired infection; AHHMS, automated hand hygiene monitoring system; DRG, diagnosis-related group; CLABSI, central-line–associated bloodstream infection; CAUTI, catheter-associated urinary tract infection; HO-MRSA, hospital-onset *Staphylococcus aureus*; HO-CDI, hospital-onset *Closridioides difficile* infection; ICU, intensive care unit.
[a]Locations included an ICU and 5 medical/surgical units.
[b]Locations included an ICU, 2 medical/surgical units and a stepdown unit.
[c]Pre-AHHMS period: January 2015–June 2016.
[d]AHHMS period: July 2016–December 2017.
[e]Infections per 1,000 device days.
[f]Infections per 1,000 patient days.

Our institution implemented an RFID-based AHHMS in selected units, coupled with interventions designed to increase hand hygiene adherence. We assessed hand hygiene adherence both electronically and by direct observation, and we studied the effect of AHHMS-measured adherence on HAI rates.

Methods

Study design

This intervention took place at Denver Health Medical Center (DHMC), a 555-bed urban safety-net level I trauma center, for locations with and without AHHMS tracking.

Population

In total, 4 intervention units (2 medical-surgical units, 1 intensive care unit, and 1 step-down unit) were selected to receive both the AHHMS and performance improvement interventions (Table 1). In 6 control units (5 medical-surgical units and 1 intensive care unit), hand hygiene adherence rates were monitored using direct visual observation.

Intervention

At DHMC, directly observed hand hygiene adherence is assessed using the WHO Five Moments of Hand Hygiene methodology.[2] Infection prevention staff, nurse managers, educators, and unit hand hygiene champions collect manual observations in each location (median monthly observations, 194; interquartile range [IQR], 174–241). Unit-level staff members, nurse managers, and hand hygiene champions (N = 1–2 observers) collect manual observations on their units each month. Infection prevention staff collect roaming observations in all areas each month. In total, ~20–25 employees are asked to collect 20 observations per month. Verbal feedback, coaching, and just-in-time training are provided to HCWs by infection prevention staff or by nurse managers. A comparison of staff- or manager-collected hand hygiene adherence data to infection prevention staff-collected hand hygiene adherence data is periodically conducted to ensure validity. Typically, adherence data collected by infection prevention are 5%–10% lower than data collected by dedicated unit personnel (unpublished data). Multiple initiatives intended to reduce the incidence of central-line bloodstream infections (CLABSIs), catheter-associated urinary tract infections (CAUTIs), and hospital-onset MRSA (HO-MRSA) bacteremia were in varying stages of implementation during the study period. These included implementing nursing-directed Foley catheter removal, reducing Foley catheter insertion in the emergency department, and universal mupirocin nasal decolonization and chlorhexidine gluconate (CHG) bed bathing for intensive care unit (ICU) patients with a Foley catheter or a central venous catheter. Several practices were already in place to specifically target risk reduction for hospital-onset *Clostridioides difficile* infection (HO-CDI), including mandatory soap and water handwashing after caring for a CDI patient and using a sporicidal peroxide/peracetic acid cleaning agent. Ultraviolet light is used to disinfect CDI patient rooms upon discharge or transfer. No substantial changes were made to policies or procedures relating to hand hygiene or HAI prevention in either AHHMS or non-AHHMS locations.

The study was divided into 2 periods: preintervention and intervention AHHMS. The preintervention period was divided into 2 sections: pre-AHHMS and baseline AHHMS (Fig. 1). HAI rates were collected by the infection prevention team for both AHHMS and non-AHHMS locations during the entire study. The pre-AHHMS period was January 2015 to June 2016. The AHHMS system was installed in April 2016. The system was comprised RFID badges worn by the HCWs, location sensors at each doorway and in each patient's room, and sensors at each soap or ABHR dispenser. The baseline AHHMS period was defined as April–June 2016. During this period, HCWs were unaware that the system was active. Foot-traffic studies were conducted to determine the rules that would assess adherence versus nonadherence. Accessing an ABHR or soap dispenser during a 2-minute window around each room entry or exit (1 minute prior to room entry or exit to 1 minute after) was considered adherent. Foot-traffic studies

https://doi.org/10.1017/ice.2020.182 Published online by Cambridge University Press

Table 2. Performance Improvement Interventions Implemented in AHHMS and Non-AHHMS Locations

		AHHMS				
			Intervention AHHMS			
Variable	Non-AHHMS	Baseline	ICU	MS 1	MS 2	SD[b]
Verbal feedback	X	X	X	X	X	X
Coaching	X	X	X	X	X	X
Just-in-time training	X	X	X	X	X	X
AHHMS orientation	X	X	X	X	X	X
AHHMS education			X	X	X	X
Troubleshooting			X	X	X	X
Weekly unit reports			X	X	X	X
Monthly unit reports			X	X	X	X
Monthly top performers			X	X	X	X
IP rounding			X	X	X	X
Weekly staff member reports					X	
Low-performer email					X	
Peer-to-peer coaching			X		X	

Note. AHHMS, automated hand hygiene monitoring system; ICU, intensive care unit; MS, medical/surgical unit; SD, stepdown unit; IP, infection prevention.

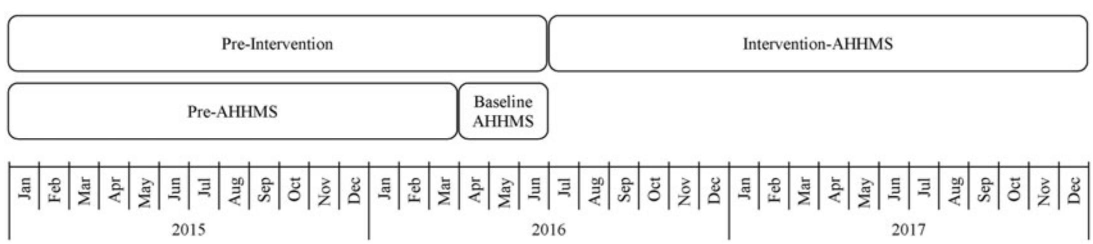

Fig. 1. Study time line.

also helped determine the accuracy of the system in comparison to direct observation hand hygiene opportunities (HHO). Because the system we installed records handwashing upon room entry and exit and our hospital policy mandates that staff follow the WHO Five Moments, it was unknown how well the AHHMS data would compare with directly observed HHOs. During our foot-traffic studies, direct observation of HCW hand hygiene behavior on room entry and exit was observed in real time in tandem with data being recorded by the AHHMS. These data were compared, and ~85% of HHOs were properly identified and recorded by the AHHMS.

The intervention AHHMS period occurred from July 2016 through December 2017. On both AHHMS and non-AHHMS units, direct observation data collection, verbal feedback, coaching, and just-in-time training continued as usual (Table 2). Each AHHMS unit also received a set of AHHMS-focused interventions. These interventions focused on data feedback, troubleshooting, AHHMS orientation and education, and positive reinforcement. On all units, nurse managers and clinical nurse educators received weekly and monthly performance data updates. Performance progress reports were distributed to staff through daily and weekly huddles as well as quarterly staff meetings. Monthly, a list of staff members from each unit with hand hygiene adherence in the top 20% of their unit was distributed at staff huddles and was posted on unit data walls and on the institutional intranet. One of these top performers was selected at random each month to receive a prize. Nurse managers and educators were given access to the data system to facilitate real-time tracking and education. Semiweekly, infection prevention staff conducted roving education, training, and troubleshooting services in the units. Staff were offered a real-time view of data being collected in the system to facilitate discussion, education, and awareness of the system as well as to troubleshoot issues with badge or sensor function.

In addition, the infection prevention team encouraged and assisted nurse managers to design and implement their own additional interventions. Some nurse managers received automated weekly adherence reports stratified by staff member, allowing them to conduct individual coaching and education sessions with below-average performers. Direct e-mail feedback also targeted below-average performers on 1 unit. Selected staff received a weekly e-mail containing their adherence rate, the average rate and the top performer's rate for their unit the previous week. Peer-to-peer coaching and education was implemented in the ICU and on 1 medical-surgical unit.

To varying degrees, physicians and advanced practice providers (APPs) also participated in the system. On the ICU, all attending physicians, resident teams, and APPs wore badges. Ten hospitalists who regularly worked on the medical-surgical units also participated. All physicians and APPs received weekly reports of their adherence rate along with the deidentified adherence rates of the other badged providers to facilitate friendly competition and inspire improvement. Other groups, such as respiratory therapists, physical/occupational

https://doi.org/10.1017/ice.2020.182 Published online by Cambridge University Press

therapists, phlebotomists, environmental services and other support service staff members, did not wear tracking badges.

Definitions

We defined CLABSI, CAUTI, healthcare facility-onset MRSA (HO-MRSA) bacteremia, and healthcare facility–onset *Clostridioides difficile* (HO-CDI) according to National Health Safety Network (NHSN) criteria.[31]

Data analysis

The specific aim of the study was to assess the effect of implementing an AHHMS and performance improvement intervention on HAI incidence. Increased hand hygiene adherence was demonstrated using median tests comparing the baseline period to the intervention period. CLABSI, CAUTI, HO-MRSA bacteremia, and HO-CDI incidence rates were collected. An aggregate incidence rate of these 4 outcomes was calculated. Incidence rates for all outcomes were compared between AHHMS and non-AHHMS units. For the AHHMS units, correlation coefficients were calculated to assess the association between HAI rates and hand hygiene adherence.

On AHHMS units, interrupted time series (ITS) analysis was conducted to detect any changes in incidence rate trends before and after the installation of the electronic hand hygiene system. Autocorrelation was assessed using the Durbin-Watson statistic and was corrected where appropriate. Baseline trends, immediate effect after the baseline, intervention trend, and changes in trend from preintervention to intervention were assessed. The intervention period was subdivided into the initial 9-month and the subsequent 9-month period, and these were evaluated against the preintervention period separately to assess the initial and sustainability effect of the intervention.

All analyses were conducted using SAS version 9.4 (SAS Institute, Cary NC). The study protocol was reviewed by the DHMC's internal quality improvement and research council and was deemed to be a quality improvement project.

Results

In the pre-AHHMS period, directly observed (manually collected) hand hygiene adherence was 77% on the control units (N = 2,347 HHOs) and 77% on the intervention units (N = 1,606 HHOs; $P = .84$). In the intervention period, directly observed hand hygiene adherence in the control units was 86% (N = 1,920 HHOs) and 76% on the intervention units (N = 1,479 HHOs; $P < .001$). During the baseline AHHMS and intervention AHHMS periods, the AHHMS recorded 366,951 and 2,327,636 hand hygiene opportunities, respectively. Baseline AHHMS adherence was 47%. During the intervention period, adherence averaged 69%, and unit-specific increases ranged from 19% to 29%. In the first 9 months of the intervention period, adherence average 67%, and adherence averaged 70% in the second 9 months of the intervention period.

The HO-CDI rate during the intervention AHHMS period was significantly negatively correlated with AHHMS adherence ($r = -0.52$; $P = .03$). No significant differences were detected for the AHHMS units in CAUTI, CLABSI, HO-MRSA bacteremia, or the composite outcome (CAUTI, CLABSI, HO-MRSA bacteremia, and HO-CDI combined) (Table 1). In the control locations, decreases were observed in CAUTI ($P = .01$), CLABSI ($P = .04$), and the composite outcome ($P = .04$) between the preintervention and intervention-AHHMS period, but no other differences were observed.

An ITS analysis of HAI data indicated that the trend in HO-CDI rates in the AHHMS units changed from increasing to decreasing in the intervention period as a whole, but this change was nonsignificant (Fig. 2). Subdivision of the intervention period showed that HO-CDI rates significantly decreased during the early (initial 9 months) period of the intervention ($P = .002$) (Fig. 3), and this trend continued during the latter period (subsequent 9 months) of the intervention but was not significant ($P = .58$). No changes in the trends for CLABSI, CAUTI, HO-MRSA bacteremia, or composite outcome rates were observed between the pre-AHHMS period and the intervention AHHMS period.

Discussion

The primary aim of this study was to assess the effect of implementing AHHMS and performance improvement interventions on HAI rates. In the present study, improved AHHMS-measured hand hygiene adherence was significantly correlated with decreased HO-CDI rates. Our ITS analysis indicated a significant association in the first 9 months of the intervention. The trend persisted 18 months after implementation of the intervention but was not significant in the second half of the intervention AHHMS period (Fig. 3). No effect was detected for CLABSI, CAUTI, or HO-MRSA bacteremia. The association between HO-CDI rates and electronic hand hygiene adherence during the intervention period supports the results of other studies.[8] Notably, in the initial 9 months of the intervention, when hand hygiene adherence increased sharply and reached its peak, the HO-CDI rate declined most severely. The subsequent increases observed in the HO-CDI rate between May and November 2017 may have resulted from a slight decrease in the hand hygiene adherence rate during the same period, but other factors may also have influenced this result. The relatively low rate of infection at our institution causes any increase in infections to appear to have a large effect. Also, as a teaching institution, rotations of medical learners may impact ordering patterns and may result in temporary increases in inappropriate ordering. Random cause variation also cannot be ruled out as a factor. Other studies have shown that improved hand hygiene resulted in significant reductions in hospital-acquired infections other than HO-CDI.[5,6,32-34] but this finding is not supported by the present study, likely due to the study being underpowered for outcomes with lower incidence rates.

Our baseline AHHMS adherence was similar to or perhaps slightly higher than those in other published reports.[26,35] After implementing performance improvement interventions, the AHHMS indicated a sustained increase overall and within each AHHMS unit of ~20%–30% for months after the intervention. This sustained improvement supports the results reported by others.[26,36,37] Our experience with this program reinforced the findings of other studies that a multimodal, team-driven, friendly competition and positive-reinforcement–focused approach is crucial for improving hand hygiene, particularly with respect to peer influence and role modeling.[11,12,28,29,38] It also reflects the assertion outlined in other studies that multimodal interventions are necessary for sustained improvement.[26,39,40] Easing concerns about the system's accuracy and increasing comfort were important considerations. Our primary strategy to mitigate these concerns was to provide personalized coaching by accompanying staff members on their rounds while showing them their data in real time. We felt that this had the effect of building confidence in the system

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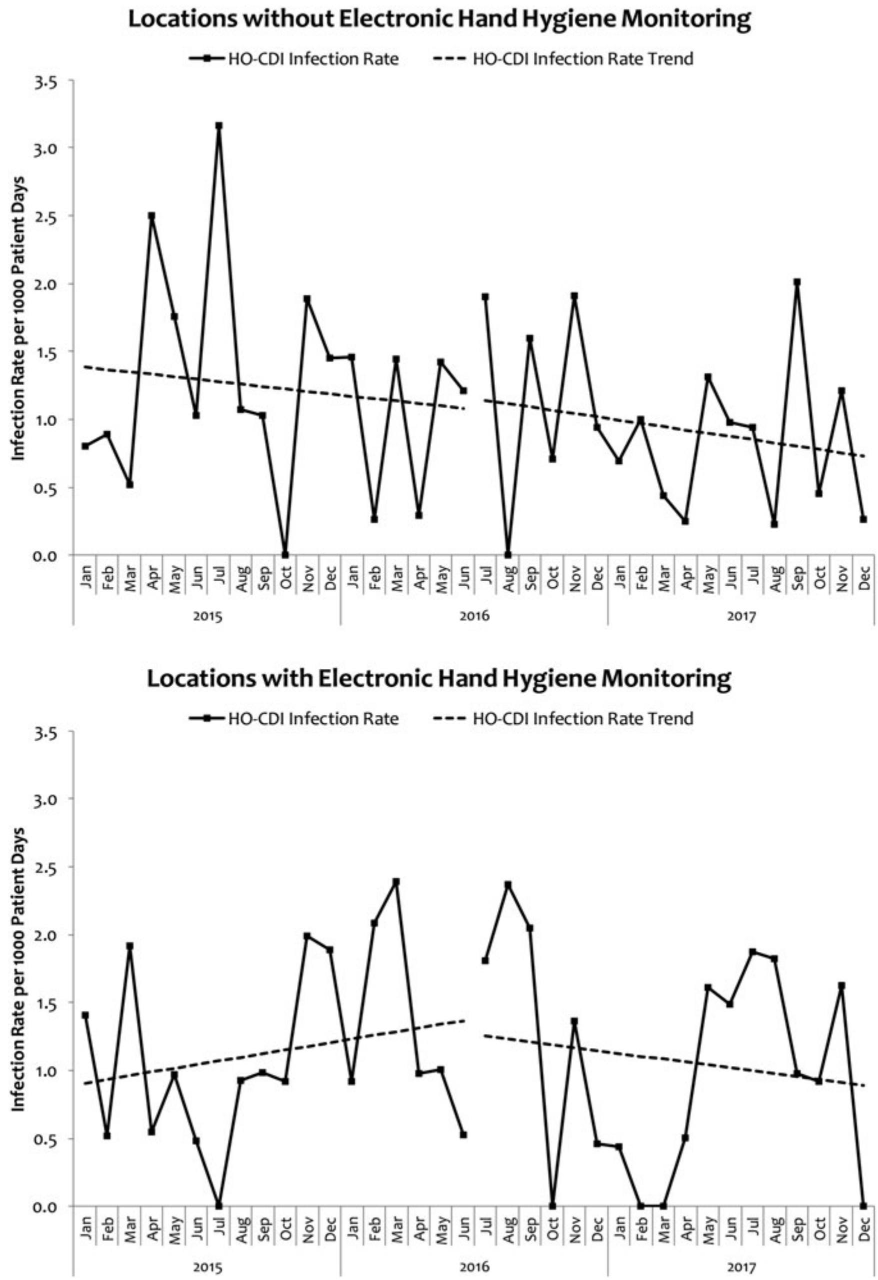

Fig. 2. Hospital-onset *Clostridioides difficile* infection (HO-CDI) rate trend in locations with and without the automated hand hygiene monitoring system (AHHMS).

through transparency, helping the staff member improve with just-in-time education, and identifying AHHMS system issues or barriers to achieving high adherence. We did not measure the staff's attitudes toward the system or the effectiveness of the coaching sessions; this is an opportunity for future research.

We were surprised both that directly observed hand hygiene significantly increased in the non-AHHMS units and that it did not increase in the AHHMS units. Both of these outcomes may have been due to random-cause variation related to small sample size, an effect that others have reported.[9] Direct observation collects <1% of the HHOs collected by the AHHMS. Collecting relatively small samples may magnify biases introduced by the sampling technique and other factors.[9] The group collecting directly observed HHOs was relatively large and the observer pool was subject to turnover, so the training of new members was ongoing. During the intervention-AHHMS period, new observers who did not have the requisite proficiency may have been collecting HHOs. It is reasonable to expect that AHHMS-measured adherence would translate into in observable improvements in manually collected hand hygiene data, and perhaps larger samples sizes will confirm this. We also observed significant decreases in some outcomes in the non-AHHMS units, including CAUTI and CLABSI. Notably, these HAIs were already trending downward at the start of the preintervention period, and this trend simply continued during the intervention period.

An AHHMS is not a panacea, but it can provide robust data that can be used to drive improvements in patient safety. Thousands of observations are recorded at all hours of the day with no Hawthorne effect. The RFID technology enables feedback and accountability at the individual HCW level; accountability requires the system to be as accurate as possible. Some studies have reported high accuracy of AHHMS systems and others have not.[17-21,23] Alignment of the hospital policy that guides how direct observation HHOs are collected with the way in which an AHHMS system

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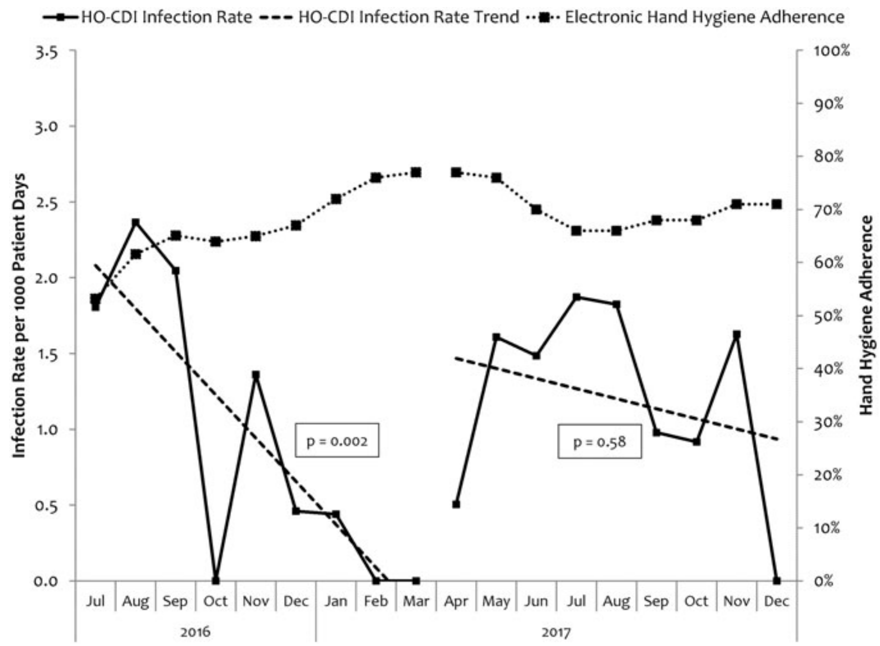

Fig. 3. Subsegmentation of trends related to the effect of an automated hand hygiene monitoring system (AHHMS) intervention on hospital-onset *Clostridioides difficile* infection (HO-CDI).

records HHOs would logically result in the greatest accuracy. The system we implemented simply tracks handwashing in and out of patient rooms. Our institutional policy mandates that staff follow the WHO Five Moments; thus, the AHHMS does not perfectly align with how our direct observers collected HHO data. Nonetheless, our foot-traffic studies, which compared direct observation with the electronic system in real time, suggested that ~85% of HHOs recorded by the electronic system matched direct observer data. Although this rate is higher than those reported in other studies,[17] it is still a limitation of this study and should be explored further.

Another limitation of this study is its quasi-experimental design. Like other studies of this nature, the interventions were implemented gradually. Comparability between AHHMS and non-AHHMS units in unmeasured factors may have differed in important ways. Adherence to other factors related to HO-CDI rates (eg, glove and gown usage, effective cleaning by housekeeping, and exposure to high-risk antibiotics) may have differed significantly between AHHMS and non-AHHMS units. Another factor that may have affected the comparison between the 2 groups is that the assumption that the groups are distinct and independent cannot be assured. In non-AHHMS locations, it is likely that staff and managers had knowledge of the AHHMS system and the interventions being implemented, and this may have affected behavior. Also, many nursing staff float between AHHMS and non-AHHMS areas and thus may have contributed to the manually collected hand hygiene adherence rate in one or both groups, as well as to the AHHMS data. In addition, low baseline incidence rates at our institution likely caused this study to be underpowered to detect any differences that may have been present between preintervention and intervention AHHMS periods for CLABSI, CAUTI, and HO-MRSA bacteremia. Finally, because this was a single-center quality improvement study, its results are not generalizable.

In conclusion, improvement in AHHMS-measured hand hygiene was associated with a reduction in HO-CDI cases. Performance improvement interventions that are multimodal, staff-driven, use positive reinforcement, and encourage friendly competition are effective at building and sustaining improvements in hand hygiene adherence. AHHMS technology is a promising tool for hospitals to both objectively monitor hand hygiene and to promote improvement.

Acknowledgments. We thank the staff, nurse managers, nurse educators, attending physicians, resident and intern teams, information technology and administrative support staff, and other essential contributors to Denver Health's electronic hand hygiene project.

Financial support. No financial support was provided relevant to this article.

Conflicts of interest. All authors report no conflicts of interest relevant to this article.

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