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Major Article

Challenges encountered and lessons learned during a trial of an electronic hand hygiene monitoring system

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Background: Automated hand hygiene monitoring systems (AHHMS) are being developed to supplement direct observations of hand hygiene (HH). We compared compliance rates generated by direct observations and by a badge-based AHHMS.

Methods: Observations of HH compliance were conducted in a surgical intensive care unit (SICU) and a general medical ward (GMW) during a 7-month baseline period and a 13-week intervention period, when compliance was also estimated using an AHHMS. Compliance rates were analyzed using time-series analysis.

Results: During the entire pre- and postintervention period, univariate analysis of observations revealed significant improvement in overall HH compliance in the SICU ($P = .001$) and the GMW ($P = .03$), beginning before implementation of the AHHMS. Initiation of the AHHMS was associated with a transient drop in entry and exit compliance on both units. During the intervention period, observations suggested that compliance on entry and exit continued to increase in the SICU, but not in the GMW. Time series analysis of AHHMS data revealed that entry and exit compliance did not change significantly in the SICU but decreased significantly in the GMW ($P = .001$). The average accuracy of the AHHMS was 60%.

Conclusions: Based on observations, HH compliance increased during the baseline period. Observations and the AHHMS yielded different trends in compliance. The AHHMS's accuracy of HH events and health care personnel location were suboptimal.

Observational surveys conducted by trained observers are currently considered the gold standard method for monitoring health care personnel (HCP) hand hygiene (HH) compliance.[1-3] Despite having a number of unique advantages, direct observational surveys have a number of limitations including the fact that they are time-consuming, are affected by the Hawthorne effect, and sample only a very small fraction of all HH opportunities.[3,4] Electronic HH monitoring systems offer the potential to monitor many more HH events and opportunities with less effort and without the type of Hawthorne effect that occurs with the direct observation method.[4] We describe a study that evaluated an automated HH monitoring system and compared its estimated compliance rates with those obtained by direct observation of HCP.

METHODS

Setting

The study of HH compliance was conducted by the infection control program at a 500-bed university-affiliated teaching hospital in New Haven, Connecticut as a quality improvement initiative. The impact of an automated HH monitoring system on HH compliance was evaluated in a 13-bed surgical intensive care unit (SICU) with

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Funding/support: The manufacturer of the automated monitoring system provided and installed the equipment. GOJO Industries provided an observer to assist with the validation study.

Conflicts of interest: J.M.B. is a consultant to and has received travel support from Diversey and GOJO Industries and has received an honorarium from Sodexo. J.W.A. is an employee of GOJO Industries, the manufacturer of the alcohol-based handrub used in the study.

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single-patient rooms and on a 21-bed general medical ward (GMW) with both single- and 2-bed rooms. The trial was approved by the vice president of nursing service, the chief safety officer, and patient care managers from the 2 study units.

Study design

The before-after study consisted of a baseline period (May 16 through December 11, 2011) and an intervention period (December 12, 2011 to March 4, 2012) during which the automated monitoring system was operational. HH compliance rates obtained by direct observation of HCP during the baseline and intervention periods were compared with those generated by the automated system. Nurses, physicians, physician assistants, and respiratory therapists on the 2 study units were invited to participate in the study. Verbal consent was obtained from HCP who volunteered to participate.

Direct observational surveys

A hospital employee who was trained and validated to observe HH compliance performed observational compliance surveys in the 2 study units during both the baseline and intervention periods. The observer recorded HCP HH compliance on room entry and on room exit, and recorded results using the iScrub app (SwipeSense, Evanston, IL).[5] HH compliance was calculated by dividing the number of HH events, defined as accessing an alcohol-based handrub (ABHR) dispenser, by the number of opportunities, expressed as a percentage.

Automated HH monitoring system

The real-time location system-based HH monitoring system, which was in the alpha testing phase of its development, used a combination of infrared and radio frequency identification for component communication. Wall-mounted touch-free ABHR dispensers compatible with wireless infrared sensors provided by the automated system vendor were placed in rooms and hallways in both study units. ABHR dispensers communicated HH events to electronic badges worn by HCP using a line-of-sight infrared communication protocol. Sensors were not placed in soap dispensers, because they were from a different manufacturer and because the majority of HH events was with ABHR. Installation of the automated monitoring system included placement of an infrared sensor in each single-patient room, "bed-level" sensors over each bed in rooms with 2 patients, and multiple sensors at various locations in hallways and nursing stations of the 2 study units. Each room entry (a proxy for World Health Organization Moment 1 [before touching patient]) and room exit (a proxy for World Health Organization Moments 4 and 5 combined [after touching patient or the environment]) by a badged HCP was defined as an HH opportunity. To accommodate the monitoring system, additional Wi-Fi nodes were placed in the 2 study units. Data from badges and location sensors were sent to a hospital-based server via the hospital's existing Wi-Fi network. Specialized software provided by the automated monitoring system vendor interpreted the data and reported room entry and room exit HH compliance rates for each individual wearing a badge.

Preparatory phase

An experienced infection preventionist and hospital epidemiologist conducted multiple in-service sessions regarding the importance of HH, study goals and how the electronic monitoring system operated. Additional in-services that included instructions on how volunteers should wear electronic badges, and how and where to recharge badges after each work shift were conducted during multiple shifts.

Volunteers were informed that during the first few weeks during which they donned electronic badges, individual data would be checked only for the purpose of determining if they were wearing the badge correctly and that they were approaching dispensers in such a way that their badge would accurately record use of the dispenser. After this break-in period, individual HH compliance rates would be determined but would not be used for annual performance evaluations or shared with the human resources department.

Operational phase

From December 12, 2011 through March 4, 2012 (intervention period), compliance rates were generated by the automated system and HCP were given feedback regarding their compliance rates. During the latter part of the intervention period, a limited planned path validation assessment and a real-life validation survey were conducted by investigators who observed badged HCP entering and exiting rooms and HH events and compared with data recorded by the automated system.

Statistical analysis

The χ^2 test was used to compare overall HH compliance rates between baseline and intervention cohorts on the 2 study units as determined by observational surveys, and between units on room entry and room exit as determined by the automated system.

Compliance rates generated by direct observation over a time period of May 16, 2011 to March 4, 2012, were analyzed using interrupted time series method to assess the intervention effect of implementation of the automated system in each unit. The correlation over time was modeled using an autoregressive correlation structure as appropriate.

Postintervention compliance rates estimated by the automated system were analyzed using autoregressive moving average methods. Automated system data from December 12-18 were removed from the autoregressive moving average analysis. After testing for autocorrelation using the Durbin-Watson test, we fit an autoregressive error model that assumes a second-order autoregressive error to compare different time trends using SAS procedure PROC AUTOREG (SAS Institute, Inc., Cary, NC). If the linear slopes of compliance rates were not statistically significant between comparisons, further analysis was performed to compare overall average rates using PROC ARIMA. Statistical significance was set as P <.05, 2-sided.

RESULTS

Direct observational surveys

The total number of HH opportunities observed in the SICU and GMW was 564 and 595, respectively, during the baseline period, and 131 and 154, respectively, during the intervention period. The number of HH events, opportunities, and compliance rates are shown in Table 1. Univariate analysis revealed that compared to the baseline period, overall HH compliance rates increased significantly after the intervention in the SICU (312 of 564 [55.3%] vs 93 of 131 [71%]; P = .001) and in the GMW (293 of 595 [49.2%] vs 91 of 154 [59.1%]; P = .03). For both wards, the compliance rates on room entry increased after intervention (+32.9% for SICU and +21.1% for GMW; P < .001) but were unchanged on room exit (P = .45, .86, for SICU and GMW, respectively). In addition, during the baseline period, the mean compliance rate for both study wards combined on room entry (137 of 525 [26.1%]) was significantly lower than the rate on room exit (468 of 634 [73.8%]) (P < .0001). Similarly, during the intervention period, the mean HH compliance rate on room entry for both

Table 1
Number of HHE, number of opportunities on room entry and exit, and percent compliance on room entry and exit for SICU and GMW based on direct observational surveys

	Before touching patient			After touching patient		
Unit	Number of HHE	Number of opportunities	Compliance rate	Number of HHE	Number of opportunities	Compliance rate
SICU						
Baseline	80	259	30.9%	232	305	76.1%
Intervention	47	74	63.5%	46	57	80.7%
			P <.0001			P = .45
GMW						
Baseline	57	266	21.4%	236	329	71.7%
Intervention	35	77	45.5%	56	77	72.7%
			P <.0001			P = .86

GMW, general medical ward; *HHE*, hand hygiene events; *SICU*, surgical intensive care unit.

study wards combined (82 of 151 [54.3%]) was significantly lower than on room exit (102 of 134 [76.1%]) (P = .0001).

Interrupted time series analysis of observational data revealed that the compliance rate in the SICU at entry and exit both increased over time significantly before and after intervention (P < .001). There was no difference in the slopes of time trend (P = .94). However, immediately after the implementation of the automated monitoring system the compliance rate dropped 30% on entry (P = .06) and 24% on exit (P = .04) (Fig 1A, 1B). In contrast, in the GMW there was no significant time trend on entry before intervention (P = .20 for time effect) and after intervention (P = .19) (Fig 2A). On exit there was a significant increase over time before intervention (2% increase per week; P < .0001), and a sudden decline right after implementation of automated monitoring (30.4% drop; P = .05). The time trend of post-implementation was not significant (P = .97) (Fig 2B).

Automated HH monitoring

A total of 74 HCP (50 nurses) in the SICU and 52 (43 nurses) on the GMW agreed to participate in the evaluation of the automated monitoring system and received individual badges with their initials on them. During the intervention period, a total of 101,655 HH opportunities were recorded on the 2 study units. The number of HH events and opportunities recorded by the AHHM system are shown in Table 2. The compliance rate on room entry for SICU was 5.9% greater than the rate for GMW (P < .0001). However, the difference in rates on room exit was smaller (2.2% greater in SICU; P < .0001). Mean weekly HH compliance rates on room exit were significantly higher than at room entry in both the SICU and GMW (Table 2) (P < .0001 for both), with considerable variation from week to week in both units.

Time series analysis on postintervention automated data revealed that the compliance rate in the SICU on room entry and exit both did not change significantly over time (Fig 3). However, on average the compliance rate on exit was 5.2% greater than the rate at entry (P = .02). The compliance rate in the GMW on entry and exit both declined over time significantly (−2.4% per week on entry, P = .001; −1.4% per week on exit, P = .02) (Fig 4). Similar to the SICU data, the average rate on exit over time was 5.6% higher (absolute %, not relative %) than the rate on entry (P = .06). However, there was no difference in terms of rate decline between entry and exit (P = .19). Comparison of rates in the GMW to those in the SICU revealed that the decline of the compliance rate on entry in the GMW was significantly greater (P = .005), and the rate on exit was marginally significant (P = .08).

Validation studies

A small planned path validation study was conducted at the end of the intervention period. The system correctly recorded 18 of 29 (62%) HH events on room entry and exit, and 28 of 30 (93.3%) room entry and exit opportunities.

During the real-life validation study conducted in both units, 158 of 265 (59.6%) HH events were accurately recorded by the automated system with nearly identical results on the 2 units. The HH event

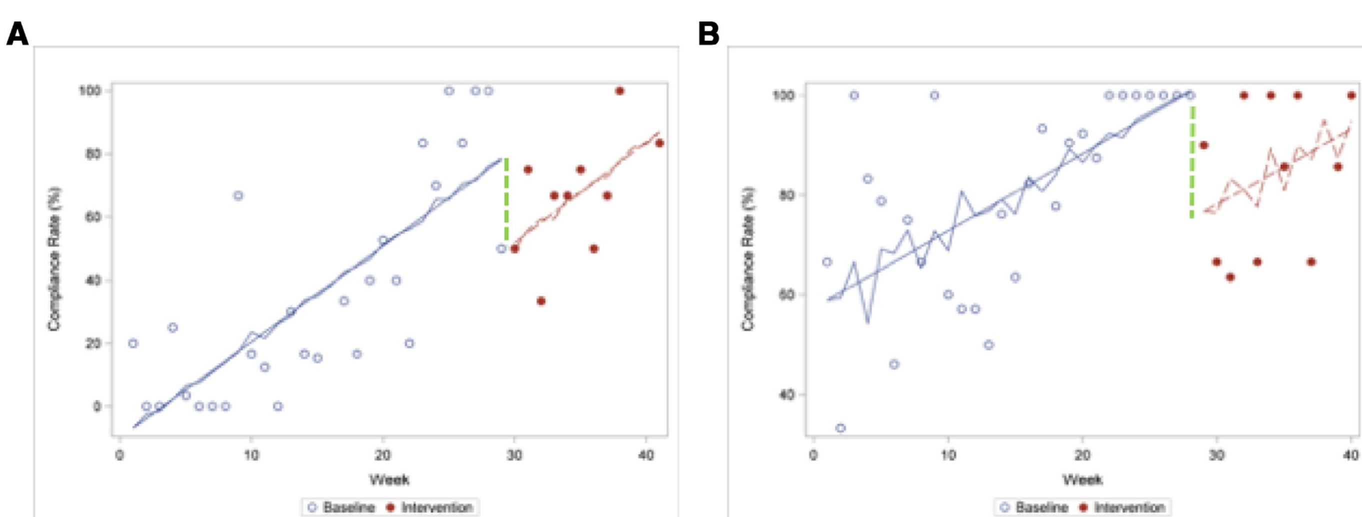

Fig 1. Time trend of hand hygiene compliance rate during pre- and postintervention in surgical intensive care unit: (A) on entry, (B) on exit, as determined by observational surveys.

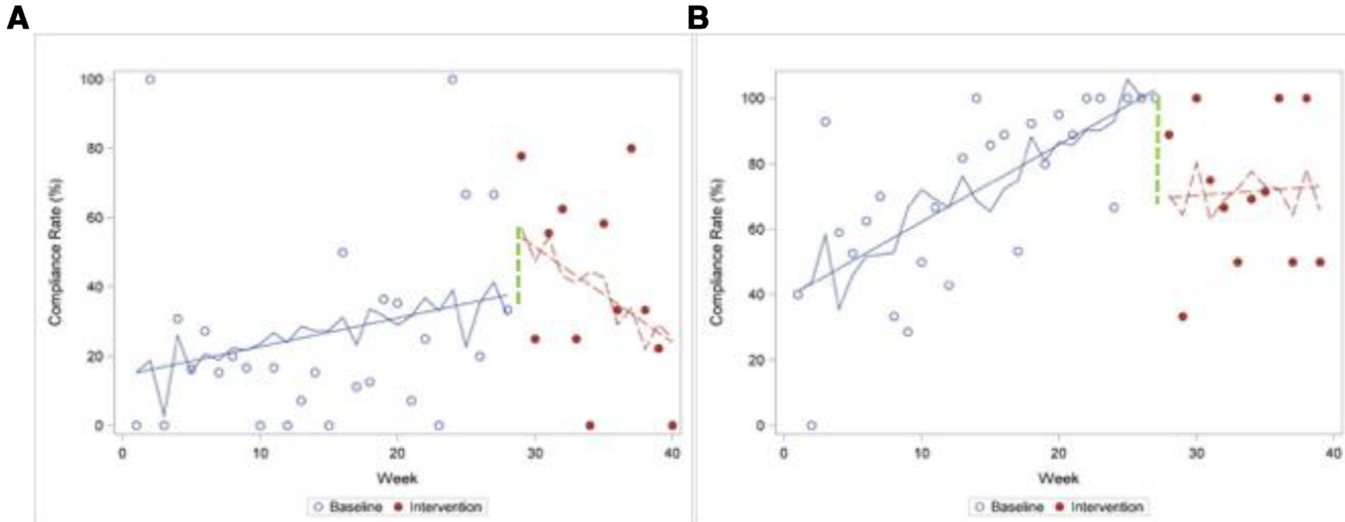

Fig 2. Time trend of hand hygiene compliance rate during pre- and postintervention in general medical ward: (A) on entry, (B) on exit, based on observational surveys.

Table 2
Number of HHE, number of room entries and exits (opportunities), and percent compliance on room entry and exit for SICU and GMW during the intervention period based on automated monitoring system

	Room entries			Room exit		
Unit	HHEs	Number of room entries	Compliance rate	HHEs	Number of room entries	Compliance rate
SICU	13,157	37,165	36.4%	14,821	37,135	39.9%
GMW	4,166	13,679	30.5%	5,150	13,676	37.7%
			P <.0001			P <.0001

GMW, general medical ward; *HHE*, hand hygiene events; *SICU*, surgical intensive care unit.

accuracy for individual HCP ranged from 32%-83%. The wide range appeared to be multifactorial and was not explained by individual behavior alone. A total of 245 of 308 (79.5%) observed room entries and exits were correctly recorded by the system, with no significant difference between entry and exit accuracy. However, additional analysis revealed that when HCP remained in or near doorways, they were sometimes attributed with multiple entries and exits when they in fact did not enter or exit the room. Room sensors in several rooms did not record entries and exits despite proper badge function. Quick repeated compliant HH events often resulted in misreads.

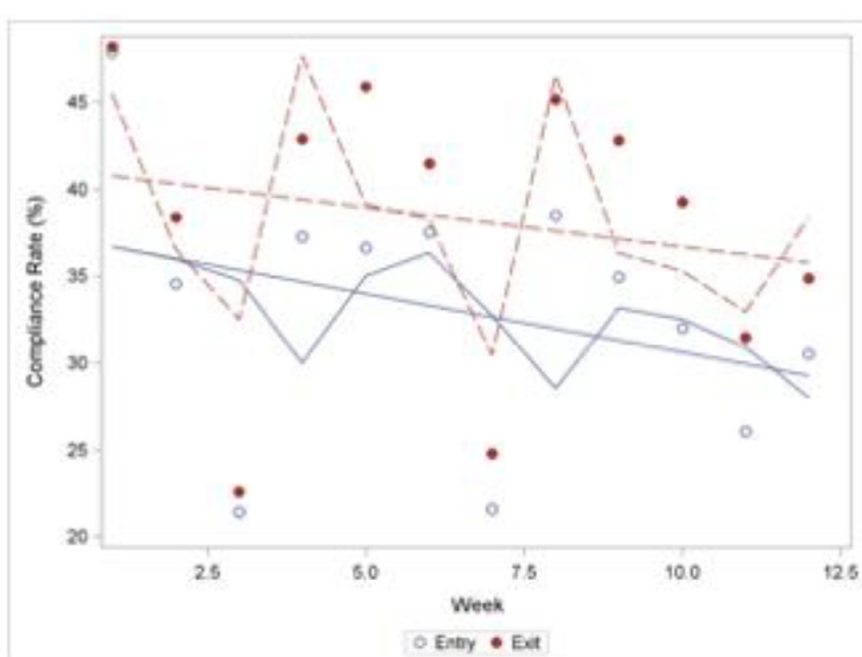

Fig 3. Comparison of compliance rate on entry and exit using automated data in surgical intensive care unit.

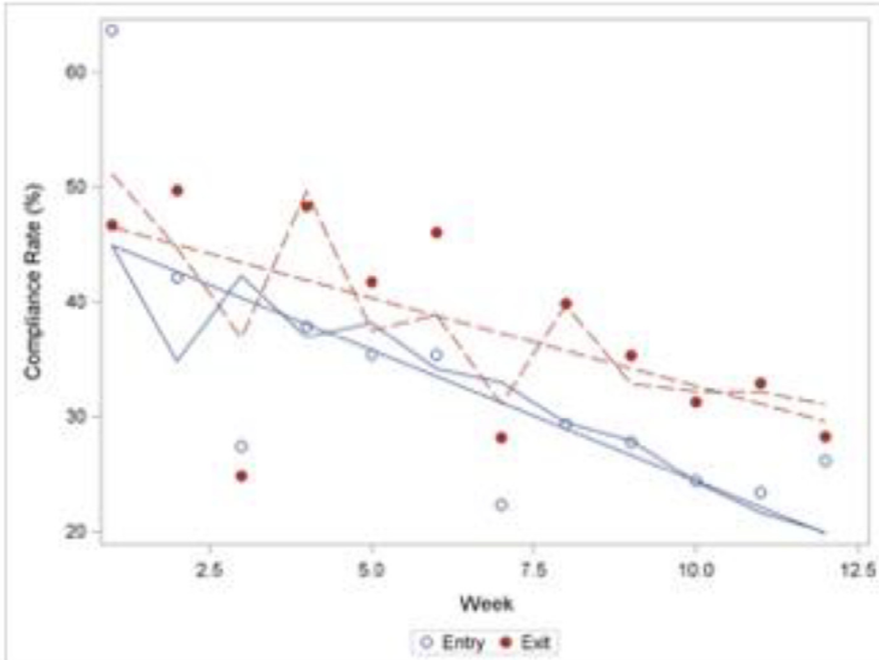

Fig 4. Comparison of compliance rate on entry and exit using automated data in general medical ward.

Other challenges experienced with the automated monitoring system

Several infrared sensors that were attached to walls by using an adhesive fell off the walls within 24 hours of installation. This delayed implementation of the system while the vendor revised the sensors so they would remain attached to various wall surfaces in the study units. To improve the accuracy of HCP location (entry or exit of patient rooms), several changes in the position of infrared sensors were required during the early weeks of the installation phase. HH events were not reliably recorded by the system when nurses walked quickly past a dispenser while accessing it with their badge pointed away from the dispenser, and when nurses of short stature wore badges at waist level. These issues arose owing to the line-of-site communication protocol between dispensers and HCP badges.

On a number of occasions, workflow-related issues required modification of the system software by the vendor. Because nurses sometimes exited patient rooms with both hands occupied (eg, holding a bedpan that required emptying in a dirty utility room), changes in the system software rules were necessary so that nurses were not classified as noncompliant when they could not be expected to perform HH within a short time on exiting the room. Interference with the hospital's WiFi network occurred when all volunteers on the GMW were wearing electronic badges. Some HCP refused to wear badges because of concerns over how the data might be used by hospital administration although individual compliance rates were not reported to hospital administrators. Additionally, some HCP who volunteered to wear badges did not wear their badge during each work shift.

DISCUSSION

In this study, direct observational surveys revealed that during the entire pre- and postobservation period, there were significant trends in improved HH compliance in both the SICU and the GMW after touching the patient, which started prior to the beginning of the intervention period. A similar trend also appeared in the SICU before touching the patient, but not in the GMW. Improvements in compliance prior to implementing automated monitoring may have been due the multiple in-service educational sessions during the baseline period that emphasized the importance of HH in preventing health care–associated infections and described the forthcoming trial of the badge-based automated monitoring system. Some earlier short-term trials of systems that tracked individual HCP reported improvements in HH compliance rates,[6-12] whereas others found little impact of automated monitoring on compliance rates.[13,14]

Interrupted time series analysis found that shortly after the implementation of the automated system, there was a sharp drop in compliance rate, whereas an upward trend started earlier. On the GMW, both observational and automated data suggested the lack of sustained improvement, similar to the findings reported during the trial of another automated system.[15] This was most likely due at least in part to failure of the current system to accurately record HH events, which has been reported with some other automated systems.[11,15,16] This issue resulted in a loss of confidence in the system by the nursing staff, a problem identified in earlier studies.[9,13] However, in the SICU the observation data showed a recovering increase trend (Fig 1), whereas automated data showed no significant decline postimplementation, indicating SICU HCP were more likely to maintain a high level of compliance.

Lack of acceptance of the system by the nursing staff may also have been due in part to inability of the system to accurately record room entries and exits (ie, the number of HH opportunities) that occurred when HCP were near room doors, which contributed to inaccurate compliance rates. Approximately 20% of actual (true-positive) entries and exits were not recorded by the system, a technical shortcoming also reported with some other automated systems.[14]

Both direct observation and the automated system established that HCP performed HH more frequently after patient care than before caring for patients, a phenomenon observed in multiple previous studies.[2,17-19] Both methods revealed that estimated compliance rates were somewhat higher in the SICU than on the GMW, and that there was substantial variation in compliance rates from week to week, similar to findings reported by Cheng et al.[14] However, the estimated compliance rates generated by the 2 monitoring strategies differed in several respects. For both study units combined, observational compliance rates before and after touching patients (54.3% and 76.1%, respectively) were significantly higher than automated compliance rates on room entry and exit (34.1% and 39.3%, respectively) ($P < .001$ for both comparisons), a finding reported in multiple other studies.[14,20]

The present study has a number of limitations, including the small number of HH opportunities observed, particularly during the intervention period. The planned path and real-life validation studies were also small. Not all HCP on the study units agreed to participate, and those who did, did not always wear their badge, a behavior noted by others.[15] We were unable to determine how these issues might have affected the overall results. The automated system (which is no longer being marketed by the manufacturer) was in the alpha testing phase of its development, and as a result, some of the technical challenges encountered are not representative of newer automated systems that do not rely on similar line-of-sight communication protocols between dispensers and HCP badges and that have improved location granularity.

Another limitation of the study is that only 1 automated system was evaluated, and the results cannot be considered presentative of other automated HH monitoring systems. Other automated HH monitoring technologies include systems that monitor only dispenser activations (HH events), a system that combines electronic dispenser counters with an algorithm for estimating HH opportunities, group monitoring systems that record both HH events plus entry and exit of persons entering patient rooms, badge-based systems that can provide data on individual HCP, and systems based on video cameras.[4,10,12,14-16,19-22] Such systems use a variety of wireless technologies including radio frequency identification, Wi-Fi, ZigBee, Bluetooth, proprietary wireless systems, infrared, or ultrasound.[10,14-16,21-25]

CONCLUSIONS

Both direct observation and the automated monitoring system revealed that HCP sanitized their hands more often after touching a patient in both units, and that estimated compliance rates were higher in the SICU than on the GMW. Based on observational surveys, HH compliance increased during the baseline period but decreased somewhat shortly after automated monitoring was in use. The communication protocol between dispensers and electronic badges and suboptimal location granularity of the automated system were problematic. HCP frustration with system accuracy highlights the importance of minimizing perceived false-negatives with automated monitoring systems. Continued refinements of current technologies and the introduction of newer ones should result in improved and acceptably high accuracy of automated HH monitoring systems. Improved systems, combined with direct observation for qualitative HH feedback and additional data on their ability to sustain improved HH compliance rates and reduce health care−associated infections, should facilitate wider adoption of such systems as a valuable component of multimodal HH promotion programs.

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