Introduction of Group Electronic Monitoring of Hand Hygiene on Inpatient Units: A Multicenter Cluster Randomized Quality Improvement Study

Jerome A. Leis MD MSc[1,2,7,8], Jeff E. Powis MD[3,7,8], Allison McGeer[4,7], Daniel R. Ricciuto[5], Tanya Agnihotri[1], Natalie Coyle[1], Victoria Williams[1], Christine Moore[4], Natasha Salt[1], Louis Wong[4], Liz McCreight[4], Sajeetha Sivaramakrishna[2], Shara Junaid[6], Xinghan Cao[2], Matthew Muller MD PhD[6,7]

[1]Sunnybrook Health Sciences Centre, Toronto, Canada
[2]Sunnybrook Research Institute, Toronto, Canada
[3]Michael Garron Hospital, Toronto, Canada
[4]Sinai Health Systems, Toronto, Canada
[5]Lakeridge Health, Oshawa, Canada
[6]St. Michael's Hospital, Toronto, Canada
[7]Division of Infectious Diseases, Department of Medicine, University of Toronto
[8]Centre for Quality Improvement and Patient Safety, University of Toronto

Corresponding author:

Jerome A. Leis, MD MSc FRCPC
Sunnybrook Health Sciences Centre
2075 Bayview avenue, B103
Toronto, Ontario M4N 3M5
tel: 416 480-4243
email: Jerome.leis@sunnybrook.ca

Summary

In this cluster-randomized quality improvement study of 26 inpatient units across five hospitals, introduction of electronic monitoring of hand hygiene resulted in nearly doubling of hand hygiene adherence associated with a trend toward reduced healthcare-associated transmission of methicillin-resistant *Staphylococcus aureus*.

Abstract

Background: The current approach to measuring hand hygiene (HH) relies on human auditors who capture less than 1% of HH opportunities and rapidly become recognized by staff, resulting in inflation in performance. Group electronic monitoring is a validated method of measuring HH adherence but data demonstrating the clinical impact of this technology are lacking.

Methods: A stepped-wedge cluster randomised quality improvement study was performed on 26 inpatient medical and surgical units across five acute care hospitals in Ontario, Canada. The intervention involved daily HH reporting as measured by group electronic monitoring to guide unit-led improvement strategies. The primary outcome was monthly HH adherence (percentage) between baseline and intervention. Secondary outcomes included transmission of antibiotic resistant organisms such as methicillin resistant *Staphylococcus aureus* (MRSA) and other healthcare-associated infections.

Results After adjusting for the correlation within inpatient units and hospitals, there was a significant overall improvement in HH adherence associated with the intervention (IRR 1.73, 95% CI, 1.47-1.99; p<0.0001). Monthly HH adherence relative to the intervention increased from 29% (1395450/4544144) to 37% (598035/1536643) within 1-month, followed by consecutive incremental increases up to 53% (804108/1515537) by 10-months (p<0.0001). There was a trend toward reduced healthcare-associated transmission of MRSA (0.74, 95% CI, 0.53-1.04; p=0.08).

Conclusions The introduction of a system for group electronic monitoring led to rapid, significant improvements in HH performance within a two-year period. This method offers significant advantages over direct observation for measurement and improvement of HH.

Keywords: hand hygiene, healthcare-associated infection, nosocomial infection, electronic monitoring, quality improvement

Introduction

Healthcare-associated infections (HCAIs) affect 3-8% of hospitalized patients, resulting in prolonged hospital stay, increased healthcare expenditure, high cost for patients and their families and preventable deaths [1,2]. Hand Hygiene (HH) is widely considered one of the most important interventions for prevention of HCAIs and is recognized as one of the top 10 patient safety strategies that should be encouraged for adoption [3].

Direct observation remains the gold standard for measurement of HH adherence as recommended by the World Health Organization (WHO), yet the limitations of this method for benchmarking performance are well recognized [4]. First, direct observation is subject to sampling bias since auditors capture less than 1% of all HH opportunities and generally only measure daytime weekday activities [5, 6]. Second, results of these audits are inflated due to changes in behavior that occur when healthcare workers know they are being audited known as the Hawthorne effect [5-9]. Many hospitals reporting adherence rates above 85% in reality have rates of 10-50% and the limitations of direct observation make it an invalid method for benchmarking performance [5, 6, 9, 10].

Inflated HH adherence rates have given hospitals and front-line staff little reason to invest in further improvements, even though true HH performance remains suboptimal [4]. There is an urgent need for a more accurate method for measuring HH adherence to prevent HCAI. Group electronic monitoring is a validated method that works by measuring 100% of all HH events by counting hand sanitizer and soap dispenser activations via a wireless signal to a wireless hub. The HH adherence is calculated per 24-hours using estimates of the number of daily HH opportunities per patient bed multiplied by the hourly census of patients on the unit which have been derived and validated across many countries including the United States, Australia and Canada [11-14].

We hypothesized that this system, which provides ward-level estimates of HH adherence on a daily basis could be used to facilitate unit-led improvements. We conducted the following multicenter quality improvement to assess the impact of electronic monitoring driven improvement on HH adherence and incidence of HCAIs.

Methods

Study setting and design

Five hospitals participated in this stepped-wedge cluster-randomized quality improvement study including three university academic hospitals (Sunnybrook Health Sciences, Sinai Health System, St. Michael's Hospital) and two community academic hospitals (Michael Garron Hospital, Lakeridge Health). Prior to the intervention, all participating hospitals had established multifaceted hand hygiene programs in accordance with Canadian provincial guidelines [15] with a mean HH adherence of 83.0% (63.2-93.6%) using the direct observation method during 2016-17.

In April of 2017, group electronic HH monitoring (DebMed SC Johnson) was installed on 26 in-patient units (14 medicine, 10 surgery, 1 mixed, 1 chronic care) including all alcohol and soap-based dispensers associated with 746 inpatient beds across the five hospitals. Units were selected for inclusion based on stability of the patient population admitted on these units across the entire study period in order to minimize confounding of secondary outcomes. Initially, HH was monitored without reporting performance. Each unit was then randomly assigned to one of three possible dates when reporting of results and program interventions would begin: June-July 2017, October-November 2017, or January-February 2018. One hospital (St. Michael's Hospital; 8 units) only randomized units to the first two dates due to tighter timeline for implementation. The intervention was continued until December 31st, 2018 when all units had completed a minimum 10-months of the intervention. Research Ethics Board approval was received at each participating hospital.

Intervention

The study intervention included re-enforcing the multimodal strategy recommended by the World Health Organization [15], using group electronic HH monitoring instead of direct observation, including the 5 recommended components: (1) System change where healthcare providers could modify the location of alcohol-based hand rub anywhere on the unit to facilitate access; (2) Training and education where each unit received a brief presentation on how the group electronic HH system works and how many HH opportunities are being missed; (3) Measurement and feedback where the group electronic monitoring system provided minimum of weekly email push reports to unit managers and any interested staff on their HH performance; (4) Visual reminders that included posting of weekly results on a quality board on the unit that was visible to staff, patients and families; (5) Creation of a safety climate within the institution through corporate reporting of each unit's monthly HH performance where hospital leaders sent congratulatory communications when improvements were observed.

In addition to this established multimodal HH improvement strategy, inpatient units were encouraged to organize a minimum of weekly unit huddles to review and discuss their HH results to come up with their own change ideas. Finally, leadership, educators and HH champions from all participating units were strongly encouraged to attend weekly 20-miniute webinars which provided education on Quality Improvement methodology and an opportunity to share successes, challenges and lessons learned across all the hospitals.

Outcome measures

The primary outcome was the absolute change in monthly HH adherence (percentage) between control and intervention months after adjusting for the correlation within inpatient units. The baseline was defined as the period from April, 2017 where group electronic monitoring was installed but not reported to units until the first day the unit was informed of their monthly HH adherence measured by group electronic monitoring based on the date randomly assigned. Intervention period was defined as the start of the intervention until December 31st, 2018.

Other pre-specified secondary outcomes included incidence of healthcare-associated acquisition of antibiotic resistant organisms (AROs) including methicillin resistant *Staphylococcus aureus* (MRSA) and vancomycin resistant enterococci (VRE), as well as HCAIs including the development of hospital-acquired *Clostridioides difficile* infection (CDI) and nosocomial bloodstream infection (BSI). For these analyses, the control period consisted of April 1st, 2014 to the start of the intervention for each unit, while the intervention period extended from the start of the randomly assigned intervention start date to December 31st, 2018. Nosocomial MRSA, VRE, and CDI was prospectively adjudicated by each hospital's Infection Prevention & Control program throughout both baseline and intervention periods based on epidemiologic exposure and typing by pulsed-field gel electrophoresis when available [16]. Nosocomial MRSA and VRE included both colonization and infection combined. The definition of hospital-acquired CDI was based on Society of Healthcare Epidemiology of America surveillance definition [17]. BSIs were identified retrospectively using hospital microbiology databases with chart abstraction to identify those meeting a standard surveillance definition [18].

Process measures

To assess the degree to which each unit engaged in Quality Improvement, process measures were recorded prospectively including the number of huddles held, and the content of these discussions. Two independent reviewers (NC and TA) reviewed documented discussions to determine the number of completed Plan-Do-Study-Act (PDSA) cycles during the 10-months following the intervention. Since all units were actively studying (S) their HH performance, minimum evidence of PDSA was defined additionally as at least two of the following: (P) Formulating a prediction to improve Hand Hygiene, (D) Implementing a test of change, or (A) Making an iterative change or new prediction based on the results [19,20]. Where any disagreement existed (n=8) regarding whether units met minimum evidence of PDSA, consensus was reached after discussion with a third reviewer (JAL).

Statistical Analysis

Descriptive statistics were calculated for all variables of interest. Continuous measures were summarized using means and standard deviations whereas categorical measures were summarized using counts and percentages.

Aggregate HH adherence (percentage) and incidence of healthcare-associated ARO acquisition or HCAI per 1000 patient days in baseline and intervention periods were compared using a generalized estimating equation (GEE) model adjusting for the correlation within inpatient units and hospitals. Overall monthly HH adherence relative to the start of the intervention was also assessed for the minimum number of months of baseline for all units (3-months) out to the minimum number of intervention months for all units (10-months).

Finally, to assess for factors associated with the greatest improvements in HH adherence, bivariate regression analysis was performed between the overall unit-level change in HH adherence and the following covariates: hospital, academic or community, patient population (medical, surgical, mixed), unit size (<20 beds, 20-30 beds, >30 beds), order of randomization, change in unit leadership during intervention period, and number of minimum PDSA cycles based on pre-specified criteria. To further assess the association between the number of minimum PDSA cycles and change in HH adherence, a scatter plot was generated with calculation of Pearson correlation coefficient (r).

Results

Characteristics of the 26 inpatient units and overall HH adherence in control and intervention periods is summarized in Table 1. Each unit improved its HH adherence significantly with a median relative and absolute improvement of 52% (interquartile range, IQR 36-113%) and 18% (IQR 11-20%), respectively. After adjusting for the correlation within inpatient units and hospitals, there was a significant overall improvement in HH adherence associated with the intervention (IRR 1.73, 95% CI, 1.47-1.99; p<0.0001).

Figure 1 depicts monthly aggregate HH adherence relative to start of the intervention. At baseline, overall HH adherence was 29% (1395450/4544144) and did not change during 3 consecutive months pre-intervention. Within 1-month of intervention, aggregate HH adherence improved to 37% (598035/1536643, p<0.0001) followed by consecutive monthly incremental increases up to 53% (804108/ 1515537) by 10-months following the intervention (p<0.0001).

Daily HH adherence by hospital is depicted in Figure 2 which showed improvement following each stepped introduction of group electronic monitoring.

Table 2 summarizes the infection rates before and after the intervention. After adjusting for the correlation between inpatient units, a trend was noted in reduction in nosocomial MRSA transmission (0.74, 95% CI, 0.53-1.04; p=0.08). There was no significant decrease in the rates of healthcare-associated VRE transmission or the incidence of healthcare-associated BSI or *C. difficile* infection.

Examples of PDSA cycles meeting pre-specified criteria are included in Supplemental Material. One hospital was excluded due to incomplete documentation. The number of PDSAs completed by the unit was significantly associated with greater improvement in HH adherence (p=0.0001). Figure 3 depicts the positive correlation between the number of PDSA cycles completed and the degree of improvement observed in HH adherence (r=0.74, 95% CI, 0.42-0.90, p<001). Conversely, changes in unit leadership (n=18) was associated with a trend toward reduced improvement (p=0.07) while there was no significant association identified between hospital, patient population, unit size, or order of randomization.

Discussion

In this multicenter quality improvement study, we measured nearly a doubling in HH adherence within two years of introducing group electronic monitoring to drive unit-led improvement strategies. We also observed a trend towards reduced healthcare-associated MRSA transmission which was 26% lower compared to baseline consistent with the expected reduction resulting from significant improvements in HH adherence [21,22].

Due to the inherent flaws in directly observed HH measurements, many automated methods of measuring HH adherence are under development to overcome these limitations but few have been validated and systematically evaluated to assess their feasibility for measuring HH adherence and preventing HCAIs. Group electronic monitoring of HH was validated and adopted at one centre in the United States where a significant reduction in nosocomial MRSA was observed [12, 13, 23]. Our study involved five different hospitals spanning community and academic institutions in the Canadian healthcare context where rates of MRSA are much lower at baseline. This approach was adopted over solutions that measure individual HH performance because of implementation challenges associated with providing feedback to individual healthcare providers [10].

Every unit participating achieved improvements in HH adherence owing to the ability of this technology to provide accurate feedback on HH performance. The speed of the improvement observed occurred over months rather than over years which differs from prior studies that have relied primarily on direct observation methods [24,25]. Observational HH audits are labour-intensive and require many weeks to months to accrue a sufficient sample size to be fed back to units on their performance whereas group electronic HH monitoring allowed each unit to be continuously monitored with next day results available. This near real-time feedback created more meaningful feedback to units and also facilitated rapid-cycle changes to practice [26].

Some units achieved greater improvements in their HH performance than others. In our analysis of unit-led improvement activities, we found that the magnitude of improvement was positively correlated with the number of PDSA cycles performed. This finding highlights the role of rapid-cycle change methodology in achieving HH improvement [19]. Other factors may have also played a role including staff engagement and patient safety culture on the unit but these were not formally measured. Our experience suggests that, while accurate measurement of HH adherence is necessary for improvement, the largest improvements are seen on units with stable engaged leadership that are actively implementing a formal quality-improvement approach.

While the role of HH in interrupting the transmission of healthcare-associated infection is indisputable, its relative impact varies based on pathogen and type of HCAI. Nosocomial acquisition of MRSA is most commonly the result of transmission from patient to patient via the hands of healthcare workers and prior systematic reviews have demonstrated that the MRSA transmission rate decreases inversely with the volume of hand sanitizer used [22]. Similarly, we identified a trend toward a decrease in rate of nosocomial MRSA transmission. In contrast, we did not identify any reduction in nosocomial VRE or *Clostridioides difficile* infection, which may reflect the role of environmental contamination and antimicrobial use in the spread of these organisms [17,27].

Our study has a number of strengths including being a multicenter evaluation where improvements in HH adherence were seen across both university and community-associated hospitals. The group electronic monitoring system captured HH activity continuously during the study period including over 1.5 million HH opportunities per month and over 19 million throughout the study period. The prospective data collection regarding unit huddle content, healthcare-associated transmission and infection surveillance allowed us to assess the relationship between unit-led PDSA cycles and the magnitude of HH improvement, and improvements in patient outcomes.

Our study also has several important limitations. First, group electronic monitoring generates an overall unit-level estimate of hand hygiene compliance that does not discern adherence to specific WHO moments of hand hygiene. Second, the intervention was deployed during a limited time horizon which likely prevented us from assessing the full impact of HH improvement on healthcare-associated transmission and HCAI. Month over month improvement in HH continued until the end of the study period, suggesting that the maximum improvement achievable through this approach had not yet been reached. Third, the assessment of infection-related outcomes was limited to before-after comparisons which are subject to the potential for confounding by other factors including changes in patient characteristics and other infection control practices that were not accounted for. However, the trend towards reduced healthcare-associated MRSA transmission observed is consistent with what has been seen associated with hand hygiene improvement in other studies [21,22]. Fourth, there are many other HCAIs that may be prevented through improved HH that were not assessed in this study which may lead to underestimate of the overall benefit of the HH improvements achieved. Finally, study findings should not be applied beyond acute care inpatient units as the impact may differ across other healthcare settings.

Introduction of a group electronic HH monitoring system coupled with unit-led quality improvement resulted in a rapid improvement in HH adherence. This method offers significant advantages over direct observation for measurement and improvement of HH.

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Disclaimer

The vendor of the group electronic monitoring system played no role in the development of the study protocol, data collection, analysis or interpretation of the results.

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Conflicts of interest

J.P. reports grants from Gilead, outside the submitted work. All other authors have no conflicts to declare.

References

1. Magill SS, O'Leary E, Janelle SJ, Thompson DL, Dumyati G et al. Changes in Prevalence of Health Care-Associated Infections in U.S. Hospitals. *N Engl J Med* 2018; 379: 1732-44.
2. Mitchell R, Taylor G, Rudnick W, Alexandre S, Bush K et al. Trends in health care-associated infections in acute care hospitals in Canada: an analysis of repeated point-prevelance surveys. *CMAJ* 2019; 191: E981-88.
3. Shekelle PG, Pronovost PJ, Wachter RM et al. The top patient safety strategies that can be encouraged for adoption now. *Ann Intern Med* 2013; 158: 365-8.
4. Muller MP, Detsky AS. Public reporting of hospital hand hygiene compliance – helpful or harmful? *JAMA* 2010; 304: 1116-7.
5. Eckmann, Bessert J, Behnke M, Gastmeier P, Ruden H. Compliance with antiseptic hand rub use in intensive care units: the Hawthorne effect. *Infect Control Hosp Epidemiol* 2006;27: 931-4.
6. Hagel S, Reischke J, Kesselmeier M, Winning J, Gastmeier P 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: 957-62.
7. Kohli E, Ptak J, Smith R, et al. Variability in the Hawthorne effect with regard to hand hygiene performance in high- and low-performing inpatient care units. *Infect Control Hosp Epidemiol* 2009; 30:222 -5.

8. 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: 974-80.
9. Kovacs-Litman A, Wong K, Shojania KG, Callery S, Vearncombe M, Leis JA. Do physicians clean their hands? Insights from a covert observational study. *J Hosp Med* 2016; 11: 862-4.
10. Armellino D, Hussain E, Schilling ME, Senicola W, Eichorn A et al. Using high technology to enforce low-technology safety measures: the use of third-party remote video auditing and real-time feedback in healthcare. *Clin Infect Dis* 2012; 54: 1-7.
11. Nayyar D, Moore C, McCreight L, Garvida C, Xu E, Kiss A, Ricciuto DR, McGeer A, Leis JA. Hand hygiene opportunities on Canadian acute-care inpatient units: A multicenter observational study. *Infect Control Hosp Epidemiol* 2018; 39: 1378-80.
12. Steed C, Kelly JW, Blackhurst D, Boeker S, Diller T et al. Hospital hand hygiene opportunities: where and when (HOW2)? The HOW2 Benchmark Study. *Am J Infect Control* 2011; 39: 19-26.
13. Diller T, Kelly JW, Blackhurst D, Steed C, Boeker S et al. Estimation of hand hygiene opportunities on an adult medical ward using 24-hour camera surveillance: validation of the HOW2 Benchmark Study. *Am J Infect Control* 2014; 42: 602-7.
14. Azim, S, Juergens, C, Hines, J, McLaws, M-L. Introducing automated hand hygiene surveillance to an Australian hospital: mirroring the HOW2 Benchmark Study. *Am J Infect Control* 2016;44:772–776.

15. Best Practices for Hand Hygiene in All Health Care Settings, 4th Edition. April 2014. Provincial Infectious Diseases Advisory Committee. Available at: https://www.publichealthontario.ca/-/media/documents/bp-hand-hygiene.pdf?la=en (accessed 21 March 2019).

16. Tenover FC, Arbeit RD, Goering RV, Mickelsen PA et al. Interpreting chromosomal DNA restriction patterns produced by pulsed-field gel electrophoresis: criteria for bacterial strain typing. *J Clin Microbiol* 1995; 33: 2233-39.

17. Cohen SH, Gerding DN, Johnson S, Kelly CP, Loo VG et al. Clinical Practice Guidelines for Clostridium difficile infection in adults: 2010 Update by the Society for Healthcare Epidemiology of America (SHEA) and the Infectious Diseases Society of America (IDSA). *Infect Control Hosp Epidemiol* 2010; 31(5): 431-55.

18. Bloodstream Infection Event (Central Line-Associated Bloodstream Infection and Non-central Line Associated Bloodstream infection). Centre for Disease Control. Update January, 2019. Available at: https://www.cdc.gov/nhsn/PDFs/pscManual/4PSC_CLABScurrent.pdf (accessed April 5th, 2019).

19. Taylor MJ, McNicholas C, Nicolay C, Darzi A, Bell D, Reed JE. Systematic review of the application of the plan-do-study-act method to improve quality in healthcare. *BMJ Qual Saf* 2014; 23: 290-8.

20. Leis JA, Shojania KG. A primer on PDSA: executing plan-do-study-act cycles in practice, not just in name. *BMJ Qual Saf* 2017; 26: 572-7.

21. Raschka S1, Dempster L, Bryce E. Health economic evaluation of an infection prevention and control program: are quality and patient safety programs worth the investment? *Am J Infect Control* 2013; 41:773-7.

22. Sroka S, Gastmeier P, Meyer E. Impact of alcohol hand-rub use on meticillin-resistant Staphylococcus aureus: an analysis of the literature. *J Hosp Infect* 2010;74(3):204–211.

23. Kelly JW, Blackhurst D, McAtee W, Steed C. Electronic hand hygiene monitoring as a tool for reducing health care-associated methicillin-resistant Staphylococcus aureus infection. *Am J Infect Control* 2016; 44: 956-7.

24. Pittet D, Hugonnet S, Harbarth S, Mourouga P, Sauvan V et al. Effectiveness of a hospital-wide programme to improve compliance with hand hygiene Infection Control Programme. *Lancet* 2000; 356: 1307-12.

25. Kirkland KB, Homa KA, Lasky RA, Ptak JA, Taylor AE, Splaine ME. Impact of a hospital-wide hand hygiene initiative on healthcare-associated infections: results of an interrupted time series. *BMJ Qual Saf* 2012; 21: 1019-26.

26. Walker JL, Sistrunk WW, Higginbotham MA et al. Hospital hand hygiene compliance improves with increased monitoring and immediate feedback. *Am J Infect Control* 2014; 10: 1074-8.

27. Lee AS, White E, Monahan LG, Jensen SO, Chan R, van Hal SJ. Defining the Role of the Environment in the Emergence and Persistence of vanA Vancomycin-Resistant Enterococcus (VRE) in an Intensive Care Unit: A Molecular Epidemiological Study. *Infect Control Hosp Epidemiol* 2018; 39: 668-75.

Table 1. Baseline characteristics and hand hygiene performance of units randomized to introduction of group electronic Hand Hygiene monitoring.

Order	Hospital	Patient population	Beds	Unit leader-ship change	No. of PDSA	Control Hand Hygiene adherence (num/denom, %)	Intervention Hand Hygiene adherence (num/denom, %)
June-July 2017							
1	C	Medical	20	Yes	-	14958/82096 (18%)	201610/780251 (26%)
2	C	Mixed	33	Yes	-	20966/165338 (13%)	350390/1076498 (33%)
3	C	Mixed	26	No	-	12153/70375 (17%)	145869/505114 (29%)
4	E	Surgical	24	Yes	15	25366/88413 (29%)	422893/878552 (48%)
5	A	Medical	26	No	3	58837/176381 (33%)	507204/1035962 (49%)
6	D	Surgical	30	Yes	12	49911/137617 (36%)	503825/925097 (54%)
7	C	Mixed	40	No	-	43850/244346 (18%)	741079/1065897 (70%)
8	B	Surgical	30	Yes	9	34859/166176 (21%)	382289/938686 (41%)
October-November 2017							
9	C	Surgical	36	Yes	-	58530/374649 (16%)	391561/1118426 (35%)
10	C	Medical	20	Yes	-	21813/191846 (11%)	159327/548743 (29%)
11	C	Medical	15	Yes	-	19561/82080 (24%)	124231/218442 (57%)
12	A	Surgical	38	No	6	264202/504590 (52%)	797081/1287202 (62%)
13	A	Mixed	36	No	5	174818/444264 (39%)	615848/1166303 (53%)
14	C	Medical	24	Yes	-	23854/236358 (10%)	160198/559209 (29%)
15	E	Medical	42	Yes	8	152455/410656 (37%)	579443/1276534 (45%)
16	E	Medical	32	Yes	9	161063/469868 (34%)	462099/1089508 (42%)
17	D	Medical	30	Yes	13	131318/393725 (33%)	436271/871074 (50%)
18	D	Medical	30	Yes	6	124378/313897 (40%)	456592/901554 (51%)
19	E	Medical	28	Yes	8	142178/492140 (29%)	309952/735662 (42%)
January-February 2018							
20	D	Medical	30	Yes	4	193611/551200 (35%)	307335/727069 (42%)
21	A	Surgical	36	No	9	369938/722854 (51%)	694142/994109 (70%)
22	E	Medical	27	Yes	4	137414/453843 (30%)	213109/565639 (38%)
23	D	Chronic care	24	No	17	112140/342932 (33%)	257383/422149 (61%)
24	A	Medical	17	Yes	11	131890/369489 (36%)	279069/477126 (58%)
25	E	Medical	30	Yes	11	166686/572140 (29%)	308700/708584 (44%)
26	B	Surgical	22	No	16	112219/510749 (22%)	237478/450840 (53%)

Table 2. Incidence of nosocomial transmission of Antibiotic Resistant Organisms (AROs) and Healthcare-Associated Infection (HAI) before and after introduction of group electronic hand hygiene monitoring.

	Control (per 1000 patient days)	Intervention (per 1000 patient days)	Incidence Rate Ratio* (95% Confidence Interval)	p-value*
Antibiotic Resistant Organism				
Methicillin-Resistant Staphylococcus aureus	0.26	0.19	0.74 (0.53-1.04)	0.08
Vancomycin Resistant Enterococcus	0.23	0.24	1.03 (0.67-1.55)	0.88
Healthcare Associated Infection				
Clostridioides difficile infection	0.34	0.33	0.95 (0.68-1.33)	0.78
Nosocomial bloodstream infection	0.61	0.70	1.15 (0.93-1.43)	0.19

* Based on generalized estimating equation model comparing baseline versus intervention periods adjusting for the correlation within inpatient units.

Figure 1. Monthly Hand Hygiene adherence relative to start of intervention, as measured using group electronic monitoring across 26 inpatient medical and surgical units.

Figure 2. Daily Hand Hygiene adherence by hospital captured by group electronic monitoring from control to launch of unit-led quality improvement intervention.

Figure 3. Association between the number of unit-led Plan-Do-Study-Act Cycles performed and absolute change in Hand Hygiene adherence.

Figure 1

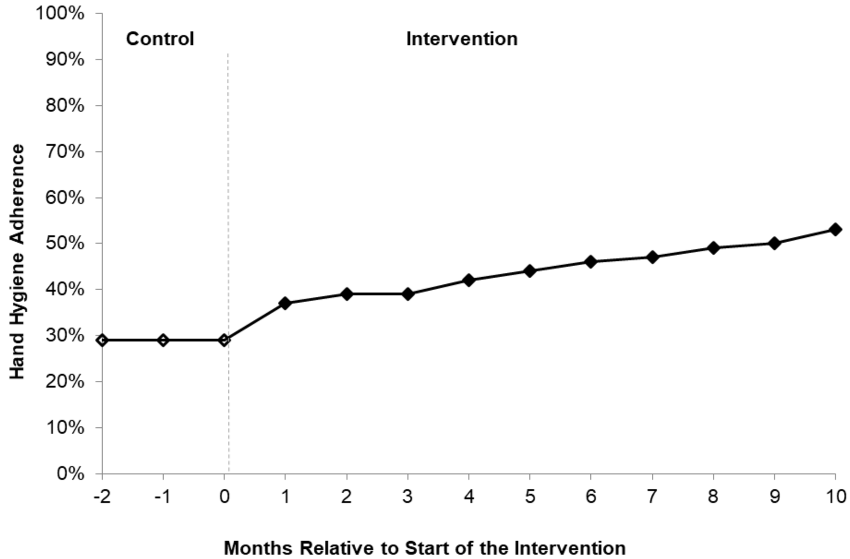
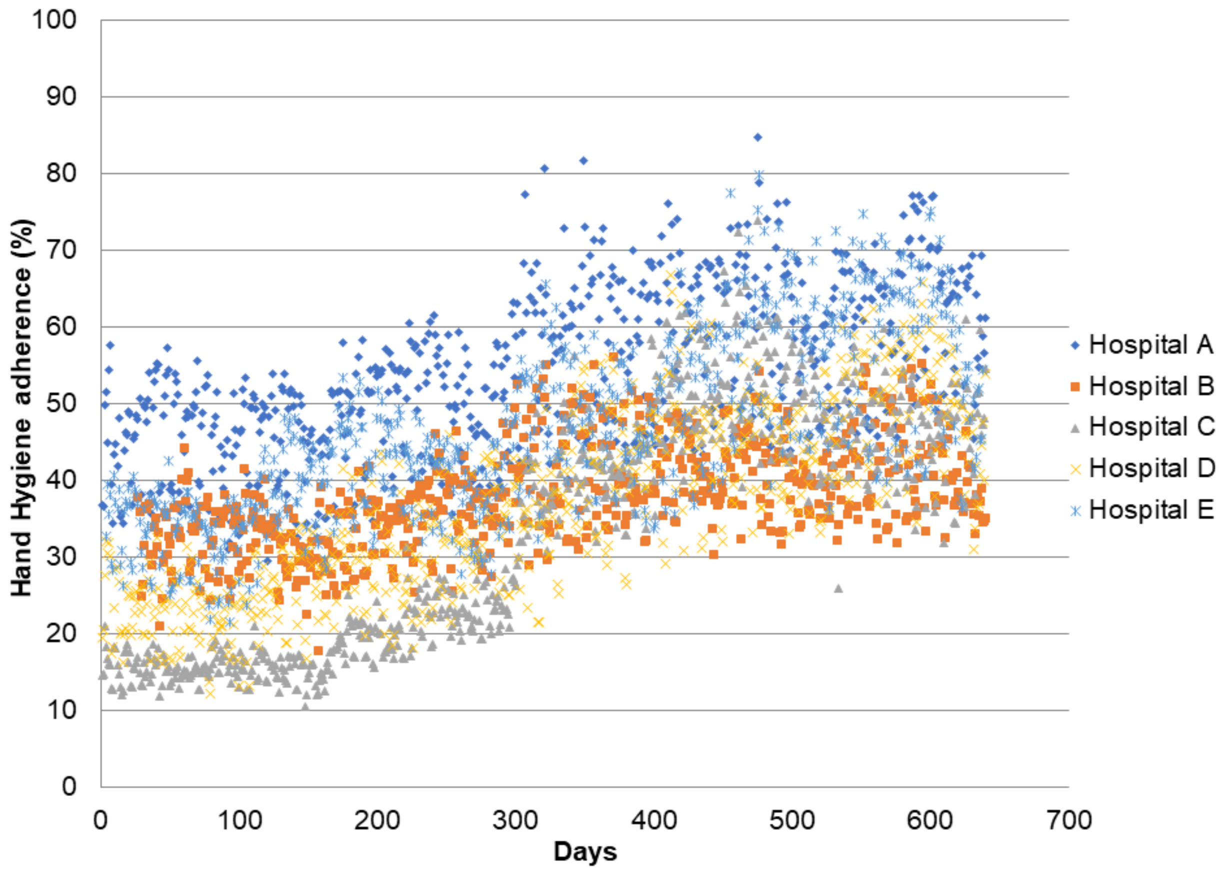
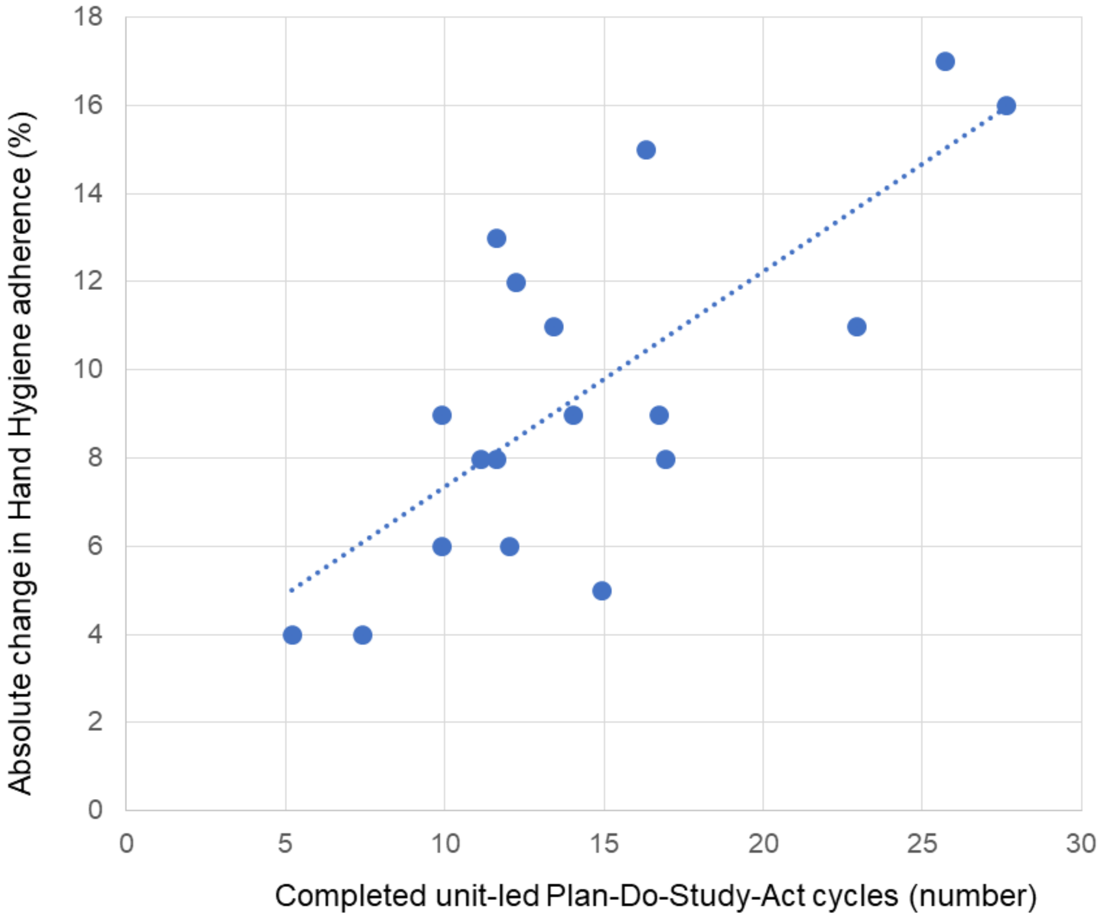

100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Control
Intervention
Hand Hygiene Adherence
-2
-1
0
1
2
3
4
5
6
7
8
9
10
Months Relative to Start of the Intervention

Figure 2



Hand Hygiene adherence (%)
100
90
80
70
60
50
40
30
20
10
0
0
100
200
300
400
500
600
700
Days
Hospital A
Hospital B
Hospital C
Hospital D
Hospital E

Figure 3



18
16
14
12
10
8
6
4
2
0
0
5
10
15
20
25
30
Absolute change in Hand Hygiene adherence (%)
Completed unit-led Plan-Do-Study-Act cycles (number)