ORIGINAL ARTICLE

Frequency of Hand Decontamination of Intraoperative Providers and Reduction of Postoperative Healthcare-Associated Infections: A Randomized Clinical Trial of a Novel Hand Hygiene System

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BACKGROUND. Healthcare provider hands are an important source of intraoperative bacterial transmission events associated with postoperative infection development.

OBJECTIVE. To explore the efficacy of a novel hand hygiene improvement system leveraging provider proximity and individual and group performance feedback in reducing 30-day postoperative healthcare-associated infections via increased provider hourly hand decontamination events.

DESIGN. Randomized, prospective study.

SETTING. Dartmouth-Hitchcock Medical Center in New Hampshire and UMass Memorial Medical Center in Massachusetts.

PATIENTS. Patients undergoing surgery.

METHODS. Operating room environments were randomly assigned to usual intraoperative hand hygiene or to a personalized, body-worn hand hygiene system. Anesthesia and circulating nurse provider hourly hand decontamination events were continuously monitored and reported. All patients were followed prospectively for the development of 30-day postoperative healthcare-associated infections.

RESULTS. A total of 3,256 operating room environments and patients (1,620 control and 1,636 treatment) were enrolled. The mean (SD) provider hand decontamination event rate achieved was 4.3 (2.9) events per hour, an approximate 8-fold increase in hand decontamination events above that of conventional wall-mounted devices (0.57 events/hour); $P < .001$. Use of the hand hygiene system was not associated with a reduction in healthcare-associated infections (odds ratio, 1.07 [95% CI, 0.82–1.40], $P = .626$).

CONCLUSIONS. The hand hygiene system evaluated in this study increased the frequency of hand decontamination events without reducing 30-day postoperative healthcare-associated infections. Future work is indicated to optimize the efficacy of this hand hygiene improvement strategy.

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Intraoperative bacterial transmission from healthcare provider hands has been directly linked to postoperative infection development, and improved hand hygiene compliance has been associated with a reduction in 30-day postoperative infections.[1–6] Increasing the proximity of hand hygiene devices and solutions to healthcare providers and performance feedback are evidence-based hand hygiene improvement strategies.[7–10] Prior work has strongly suggested that provider hand decontamination event (HDE) rates of 4–8 per hour are associated with reductions in healthcare-associated infections (HAIs).[6,7] This 2-center, cluster randomized, and controlled clinical trial aimed to more rigorously evaluate whether increasing intraoperative HDEs via a novel, multimodal hand hygiene system is an efficacious strategy for reducing 30-day postoperative HAIs.

METHODS

Overview

This was a randomized, prospective study conducted at Dartmouth-Hitchcock Medical Center in New Hampshire and UMass Memorial Medical Center in Massachusetts. Approval

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was obtained at each study site from the respective institutional review boards for the protection of human subjects with a waiver for informed consent.

Study Recruitment Process

Operating room enrollment occurred from September 30, 2013, to June 17, 2014, at Dartmouth-Hitchcock Medical Center and from January 8, 2014, to August 21, 2014, at UMass Memorial Medical Center. Five to 10 operating rooms were enrolled Monday-Friday for each of 20 working days per month at each site. A computer program was utilized to generate a list of operating rooms randomly selected for observation and associated with their randomized assignment to treatment or control (study days were randomly assigned to treatment or control observations, and rooms were randomly selected for observation according to that treatment assignment from a computer generated list). Randomization assignments included usual intraoperative hand hygiene (standard wall-mounted devices and anesthesia machine and/or anesthesia cart–based dispensers) or a personalized, body-worn hand hygiene system (Sage Products; Online Supplementary Appendix 1) in addition to usual hand hygiene. In the intervention group, providers outside of the surgical field (certified-registered nurse anesthetists, resident and attending physician anesthesiologists, circulating nurses, and break providers or observers) were assigned a personalized body-worn dispenser that delivered an alcohol-based hand rub (64% ethanol, 1.03 g dispensed per depression, and 29 doses per cartridge). Three refills (1.25 oz/refill) were placed on the anesthesia cart before case start. Additional refills were available. In the control group, routine wall-mounted, cart-based, or machine-based devices were assessed to ensure that they were in proper condition and available for use. Providers were instructed to use the devices to wash their hands at every available opportunity.[6] Wall-mounted devices in both the treatment and control groups were electronically monitored (separately from the healthcare provider) when operational in order to assess overall frequency of use of conventional devices. Research assistants tracked and recorded changes in provider assignments. In some instances (see below) changes in provider assignments resulted in exclusion (Fig. 1).

Tracking Hand Hygiene Performance

Continuous wireless monitoring linked HDEs to device/provider identification numbers (IDs) during device exposure. Only events occurring in the patient care arena (operating room environment) were recorded. At least 20 seconds between decontamination events were required for an HDE to count towards the total HDE. This time lapse was chosen to prevent "gaming" of the system. This information was also utilized to generate daily performance feedback displayed on electronic monitors (Online Supplementary Appendix 2). Individual and group level performance was compared with a benchmark of 4–8 HDEs per hour, a goal set by work evaluating a similar device.[6,7] Overall group and individual performance (HDE) along with top performers were communicated via work-addressed email delivered after every 2 completed shifts (providers were given individual feedback regarding performance averaged over 2 device exposures, or work days) and then at quarterly intervals (individual and group performance feedback provided at this time) during the study period (Online Supplementary Appendix 2).

Device Management

Devices were distributed in the morning and collected and decontaminated (disinfectant wipes) at the end of each day. Every provider had an assigned device with a unique ID that was linked to all data, and this device was collected and reassigned to the same provider when enrolled at a later date. Devices were tracked to prevent contamination of control rooms with treatment devices.

Linking Hand Hygiene Performance to Patient Outcomes

Each patient in each operating room was assigned a unique barcode (case-log ID) that was linked to the provider hand hygiene IDs (hand hygiene database) and to all patient, procedural, and provider demographic information and outcomes (infection, hospital duration, and readmission) listed below in a separate database. All enrolled patients were followed up prospectively for 30 days as described below.

Inclusion Criteria

Operating rooms considered eligible for enrollment included at least 2 consecutive surgical cases for patients undergoing elective, urgent, or emergent orthopedic, plastic, neurosurgical, cardiothoracic, urologic, general abdominal, gynecologic, vascular, or ear/nose/throat procedures. Procedures could require general anesthesia or monitored anesthesia care with or without regional anesthetic approaches (epidural catheters and/or peripheral nerve blocks). Use of a peripheral and/or central intravenous catheter was required.

Exclusion Criteria

Pediatric or pregnant patients, lack of an intravascular catheter, or a surgical procedure outside of the classes listed above were considered reasons for exclusion. In addition, operating rooms where one or more primary providers (anesthesia attending if a solo anesthesia provider, anesthesia resident or certified-registered nurse anesthetist otherwise) were assigned to provide care in operating rooms with and without the hand hygiene system, adjacent operating rooms for example, were excluded from enrollment and another was randomly selected as described above. Operating rooms that involved primary providers with previously documented refusal or with an allergy/intolerance to alcohol were also

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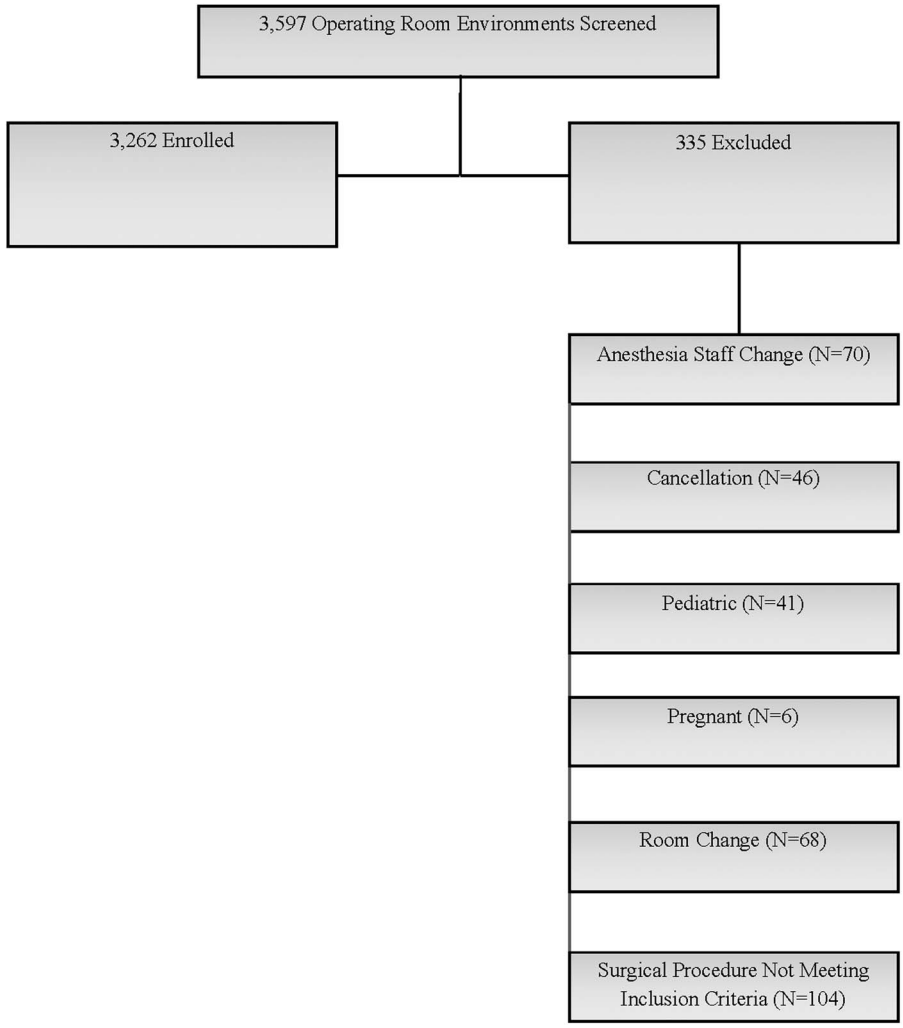

FIGURE 1. Patient enrollment and exclusions in randomized clinical trial of a novel hand hygiene system.

excluded from enrollment. If a primary provider developed an allergy/intolerance during the study period, subsequent operating rooms involving those providers were excluded from enrollment. In operating rooms where one or more providers outside of the primary provider had a history of or developed a complication as above, the operating room and associated patients would still be enrolled, the intervention deployed, and the patients followed up prospectively. Excluded cases and the rationale for exclusion were tracked and recorded (Fig. 1).

Prospective HAI Assessment

Patient electronic medical records were screened by a research nurse at each site for the presence or absence of an elevated white blood cell count, fever, anti-infective order, office visit documenting signs of infection, and/or the acquisition of bacterial cultures for 30 days following the surgical procedure. A patient positive for one or more of these initial criteria underwent an extensive medical chart review by the principal investigator at each institution (masked to the treatment assignment) in order to determine whether the patient met criteria for the diagnosis of a HAI according to National Healthcare Safety Network definitions.[11]

Prospective Assessment of 30-Day Postoperative Hospital Duration and Readmission Rates

The length of hospital stay (days) was recorded and entered into a database (Access; Microsoft), linked to the randomization assignment and unique barcode. All readmissions (as documented in the electronic medical record) were identified and systematically recorded.

Demographic Information

Basic patient, procedure, and provider demographic information was collected for all patients including age, sex, American Society

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of Anesthesiology health classification status, comorbidities (cardiovascular, neurologic, pulmonary, renal, endocrine, infectious disease, hematologic, rheumatologic, gastrointestinal, other), urgency, >2 comorbidities, general abdominal surgery, dirty or infected site, duration 2 hours or longer, anesthesia duration, surgical duration, Study on the Efficacy of Nosocomial Infection Control[12] score (an index predicting the probability of postoperative HAI development for a given patient), case order (eg, first case, second case, third case), procedure (orthopedic or cardiovascular), anesthesia type (general, monitored anesthesia care), more than 1 visit, patient origin (same day, hospital ward, the intensive care unit, or other), patient decolonization procedures (chlorhexidine bath or nasal mupirocin ointment), prophylactic antibiotic(s), and providers involved in care (attending and resident physicians, certified-registered nurse anesthetists, circulating nurses, other).

Data Handling

Basic information (eg, operating room, date of surgery, age, sex) was compiled on source documents and linked by unique barcodes to all demographic and outcome data in a database. The unique patient barcodes were linked by device/provider IDs to hand hygiene performance data in a separate database. Finally, patient identifiers such as medical record numbers and date of surgery were compiled in a separate binder and linked to demographic/outcome and hand hygiene databases via patient barcode and device IDs.

Data Analysis

Power calculations. The primary outcome in this study was the presence of a HAI occurring within 30 days after surgery. We hypothesized a potential 66% reduction from a baseline incidence of 0.16 on the basis of prior interventions,[6] but we assumed for power considerations a more conservative reduction of 40% from a baseline incidence of 0.12 averaged across all patients in each arm. Assuming a 10% loss to follow-up, we required 1,600 patients per group for a power of 0.9 with a type 1 error of .05. Because we had no loss to follow-up, we were powered to detect a 31% reduction from a baseline incidence of 7%.

Analysis. Baseline patient and disease characteristics were compared using the χ^2 test for discrete data and the *t* test for continuous data. The primary outcome, 30-day HAI, was evaluated first by fixed effects univariable analysis. Fixed effects multivariable logistic regression models adjusting for nasal mupirocin, chlorhexidine, case order, case urgency, surgical and anesthesia duration, anesthesia type, procedure type, age, sex, American Society of Anesthesiology health classification status, more than 2 comorbidities, renal comorbidity, origin, discharge location, dirty or infected site, and with or without site were then run. Additional analyses included 2 separate 2-level mixed effects XTMELOGIT (categorical outcomes) models, one clustering to patient and site and another clustering to patient and operating room number, a multivariate XTMELOGIT adjusting for the covariates listed above, and an assessment of all first-order interactions. All first-order interactions were nonsignificant and therefore not included in the final regression models. Logistic regression analysis was used to examine the effect of provider (by unique ID) on HAIs.

Hand hygiene device usage rates (intervention group) were summarized by mean and standard deviation. Each device rate was aggregated to an average monthly rate and plotted on statistical process control charts, XmR, to evaluate usage during the trial with calculated central tendency (mean), upper and lower control limits, and a moving range plot with the average and upper control limit. HAI rates were then plotted with the monthly device rate using a time series plot. We reported 95% confidence intervals and considered $P < .05$ to indicate statistical significance for the primary outcome.

RESULTS

A total of 3,256 operating rooms and patients (1,620 control group and 1,636 treatment group) were randomized for observation during the study period. The enrollment process is summarized in Figure 1. As shown in Table 1, the overall randomization was effective with similar proportions.

There was an 8-fold increase in HDEs for the treatment group (device use in the treatment group compared with mean wall-mounted dispenser use in the control group, $P < .001$) (Table 2). The mean (SD) HDE for the treatment group was 4.3 (2.9), whereas the mean (SD) wall-mounted dispenser use in the control group was 0.54 (0.34) events per hour. HDEs were similar across provider types (Table 3), and while HDEs decreased over time, there was a sustained increase in HDEs in the treatment group compared with the control group throughout the study period (Online Supplementary Appendix 3 a-d). The average number of cartridges used per clinician (device) per day was 1.2.

The overall 30-day postoperative HAI rate was 6.9% (224/3,256). Forty-one percent (92/224) of HAIs were superficial and deep surgical site infections, 10.3% (23/224) healthcare-associated pneumonia, 26.8% (60/224) urinary tract infections (catheter-associated and symptomatic urinary tract infections combined), 10.7% (24/224) deep organ space infections, 2.7% (6/224) *Clostridium difficile*, 3.6% (8/224) bloodstream (central line–associated, peripheral intravenous catheter–associated, and primary bloodstream infections combined), and 6.3% (other) infections according to National Healthcare Safety Network definitions.[11] The overall rate of surgical site infections (superficial and deep) was 3.6%.

Approximately 6.7% (108/1,620) and 7.1% (116/1,636) of patients experienced HAI development in the control and treatment groups, respectively. There was no difference in the likelihood for 30-day HAIs between groups using fixed-effects univariable analysis (odds ratio [OR], 1.07 [95% CI, 0.82–1.40]) or multivariable logistic regression analysis with

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TABLE 1. Patient and Procedural Characteristics

Variable	Control group (N = 1,620)	Treatment group (N = 1,636)	*P* value
Age, mean, years	57.29	56.75	.3433
Male sex, %	49.75	52.04	.191
ASA score, %			
1	5.43	5.48	.103
2	44.14	48.32	
3	43.70	40.22	
4	6.73	5.97	
Comorbidities, %			
Cardiovascular	54.88	51.13	.032
Neurologic	14.14	13.89	.842
Pulmonary	14.94	14.08	.485
Renal	10.74	11.21	.666
Endocrine	23.33	23.58	.866
Infectious disease	6.79	6.09	.418
Hematologic	5.12	6.52	.089
Rheumatologic	4.63	4.51	.869
Gastrointestinal	11.73	10.97	.494
Other	13.40	13.65	.831
Urgency, %			
Elective	90.43	90.25	.844
Urgent	8.95	9.26	
Emergent	0.62	0.49	
Infection risk			
Prophylactic antibiotics, %	0.1	0.1	.645
>2 comorbidities, %	22.28	21.27	.482
General abdominal surgery, %	14.14	14.02	.922
Dirty or infected site, %	10.86	8.59	.029
Duration ≥2hours, %	37.47	41.38	.022
Anesthesia duration, hours	3.131595	3.305972	.0389
Surgical duration, hours	2.077634	2.196687	.1010
SENIC score >2, %	3.27	3.23	.946
Case order			
First case, %	43.33	45.22	.617
Second case, %	34.94	33.27	
Third case, %	17.35	16.51	
Procedure			
General abdominal	14.01	13.77	.451
Orthopedic	23.52	26.33	
Vascular	16.42	16.09	
Gynecologic	4.57	5.61	
Ear, nose, and throat	10.19	9.81	
Urologic	3.15	3.60	
Plastic	7.72	6.34	
Cardiothoracic	3.58	3.17	
Neurosurgical	11.91	10.73	
General other	4.94	4.57	
Anesthesia type (general), %	89.01	91.59	.050
>1 visit	2.60	3.17	.501
Patient origin, %			
Same day	83.02	83.73	.467
Floor	12.47	12.25	
Catheterization laboratory	0.06	0.00	
Other	0.19	0.12	
Postanesthesia care unit	0.86	0.61	
Emergency department	0.86	1.40	
Intensive care unit	2.53	1.89	
Patient discharge location, %			
Same day	34.01	31.38	
Floor	25.99	26.69	
Other	0.31	0.37	
Postanesthesia care unit	31.85	34.49	
Emergency department	0.06	0.00	
Intensive care unit	7.78	7.07	
Patient decolonization procedures, %			
Chlorhexidine bath[a]	45.68	47.78	.230
Nasal mupirocin[a]	6.42	7.68	.160
Patients who received any prophylactic antibiotics, %	99.81	99.88	.644
Providers[b]			.308

NOTE. ASA, American Society of Anesthesiology physical status classification system (I-IV), SENIC, Study on the Efficacy of Nosocomial Infection Control.
[a]Use of agent before surgery.
[b]Providers included attending and resident anesthesiology physicians, certified-registered nurse anesthetists, and circulating nurses.

(1.05 [0.79–1.39]) or without (1.08 [0.82–1.43]) site (Table 4). The results were unchanged in mixed-effects models clustering patient and site (OR, 1.03 [95% CI , 0.79–1.36]) or patient and operating room number (1.06 [0.81–1.39]). Deep organ space infections and other infections showed a strong trend toward increased infection in the treatment group compared with other subgroups (Table 4; Online Supplementary Appendix 4). There was no effect of provider on HAI (OR, 0.99 [95% CI, 0.99–1.00], $P = .676$).

There was no difference between treatment groups in terms of hospital duration (adjusted OR, 1.25 [95% CI, 0.7–2.23], $P = .447$), 30-day readmission rates (adjusted OR, 1.03 [95% CI, 0.7–1.53], $P = .876$), or all-cause 30-day mortality (control group, 0.37% [6/1,620] and treatment group, 0.43% [7/1,636], $P = .793$).

DISCUSSION

The World Health Organization,[13] the Centers for Disease Control and Prevention,[14] and the White House[15] have urged researchers to investigate new ways to improve basic preventive measures. We hypothesized that a novel hygiene system combining 2 evidence-based strategies, proximity of hand hygiene devices to provider and performance feedback, would reduce the incidence of postoperative HAIs via increased intraoperative HDEs.[6–10]

The most robust study to date evaluating the efficacy of hand hygiene improvements in reducing hospital-acquired infections was conducted by Rupp et al.[16] The authors found

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TABLE 2. Hourly Hand Decontamination Event Summary and Comparison

	Hourly use, mean (SD)		Comparison *P* value	
Variable	Control	Treatment	Conventional	Treatment
Wall-mounted device	0.54 (0.34)	0.34 (0.27)	<.001[a]	
Personalized device	N/A	4.30 (2.90)		<.001[b]

[a]Comparison of mean hourly device use for wall-mounted dispensers in the control compared with mean hourly device use for wall-mounted dispensers in the treatment group (usual care was continued in both groups).
[b]Comparison of hourly personalized body-worn dispenser use in the treatment group compared with hourly use of conventional wall-mounted dispensers in the control group.

TABLE 3. Provider Hand Hygiene Rates With Device

	Rate, HDE/hour	
Provider type	Mean	SD
Attending anesthesia physician	5.8	6.9
Resident anesthesia physician	5.5	5.5
Certified registered nurse anesthetist	6.0	6.3
Circulating nurse	5.3	7.0
Overall clinician	4.3	2.9

NOTE. HDE, hand decontamination event. Control hand hygiene rates were determined by continuous monitoring of standard wall-mount use during the study period for nonintervention days, and device rates were determined by continuous, wireless monitoring of the device in patient care areas including the operating room, preoperative patient care areas, and postanesthesia care units.

no decrease in HAIs despite a 2-fold increase in hand hygiene compliance. Primary study limitations included a low overall infection rate, making it difficult to show a difference, combined with an increase in hand hygiene compliance to 70% that was likely not high enough.

The results of this similarly robust, randomized, 2-center study support those of Rupp et al, [16] but there are important considerations. The current study employed an evidence-based approach targeting an hourly HDE rate of 4–8 per hour to reduce HAIs instead of an opportunity-based approach.[6] In this study, providers achieved an average rate of 4 HDE, amounting to a greater than 8-fold increase in overall HDEs. Yet, there was no difference in the overall HAI rate or across various HAI subtypes. Thus, the current study, a robust, prospective, randomized, 2-center study conducted over an 8-month period, accounting for seasonal variation, employing a comprehensive strategy involving all providers outside of the sterile field, and leveraging real-time feedback to augment hand hygiene compliance, failed to validate prior study results involving a similar hand hygiene system.[6]

There are several viable explanations for system failure. There are 50–300 World Health Organization–based hand hygiene opportunities for every hour of patient care in the operating room environment.[4,5] Assuming an average of 175 opportunities per hour during the study period, this translates to 267,575 opportunities during the 1,529 study hours. With 9,237 events, this equates to a calculated hand hygiene opportunity rate of 3%, at most. Thus, achieving 4 or even 8 HDEs, a 3%–6% opportunity-based compliance rate if every HDE was opportunity-based, is simply not likely to be enough to show an effect in HAI reduction, especially when the event rate is fairly low. Further, whereas the study design recorded only HDEs that occurred in the patient care environment and were separated by at least 20 seconds in order to increase the

TABLE 4. The Impact of the Novel Hand Hygiene System on 30-Day Postoperative Healthcare-Associated Infections (HAIs)

	Crude			Adjusted[a]		
	OR	*95% CI*	*P value*	*OR*	*95% CI*	*P value*
Any HAI	1.07	(0.82–1.40)	.626	1.05	(0.79–1.39)	.735
Subgroup						
SSI	0.95	(0.63–1.43)	.800	0.96	(0.62–1.46)	.832
HCAP	0.91	(0.40–2.06)	.818	0.74	(0.32–1.77)	.497
UTI	0.99	(0.59–1.65)	.973	0.97	(0.57–1.66)	.916
DOSI	1.99	(0.85–4.67)	.113	2.26	(0.90–5.69)	.082
CDI	0.20	(0.02–1.69)	.139	0.03	(0.0003–3.04)	.139
BSI	0.99	(0.25–3.97)	.990	1.01	(0.21–4.88)	.994
Other	2.49	(0.78–7.95)	.124	3.03	(0.88–10.41)	.079

NOTE. BSI, peripheral and central bloodstream infections; CDI, *Clostridium difficile* infection; DOSI, deep organ space infection; HCAP, healthcare-associated pneumonia; OR, odds ratio; Other, other subtypes of infections defined by the National Healthcare Safety Network[11]; SSI, deep and superficial surgical site infections; UTI, catheter-associated and symptomatic urinary tract infections.
[a]Adjusted for nasal mupirocin, chlorhexidine, case order, case urgency, surgical and anesthesia duration, anesthesia type, procedure type, age, sex, American Society of Anesthesiology health classification status, >2 comorbidities, renal comorbidity, origin, discharge location, dirty or infected site, and with or without site.

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likelihood that recorded events were tied to hand hygiene opportunities, an automated electronic monitoring system does not definitively capture opportunity-based hand hygiene compliance. Although it is unlikely that the events were not opportunity-based, it is not certain that they were.

One approach to improve this system would be to set a higher HDE target. However, it is important to consider whether providers in the operating room could ever wash their hands enough to prevent infections via this approach. In this study, providers washed their hands 4.3 times per hour on average, or every 13 minutes. To achieve a 70% compliance rate with this system based on HDEs, providers would have to wash their hands at least every 30 seconds. Thus, achieving a 70% opportunity-based hand hygiene compliance rate in the operating room with this system does not seem feasible.

An alternative, evidence-based approach would be to link use of the device with target hand hygiene opportunities. An excellent starting point would be to target World Health Organization–defined hand hygiene opportunities.[6,7] Also, since intraoperative environmental contamination peaks following induction and emergence of anesthesia, time points that correlate with nadirs in hand hygiene compliance,[4] targeting hand hygiene opportunities with the system during emergence and induction of anesthesia are additional opportunities to improve patient safety. Recent work also suggests that use of the system could be augmented with additional measures. For example, double gloving during induction of anesthesia with removal of the outer glove immediately following patient intubation and before environmental contact, followed by use of the outer glove to sheath the contaminated laryngoscope blade and handle, has been shown to reduce environmental contamination.[17,18] In addition, separation of clean and dirty work areas is a useful intervention for reducing environmental contamination.[19] These are potentially very important interventions because environmental contamination has been linked to high-risk intraoperative bacterial transmission events that have been directly linked by molecular typing to postoperative infection development.[1] Additional work is required to better characterize hand hygiene opportunities in the fast-paced operating room environment and to potentially link use of this system with those opportunities.

The authors recognize potential limitations of this study. With regard to contamination, there were 2 "rogue" devices during the study period that were collected the next day from providers not enrolled in the study. To account for a potential Hawthorne effect, electronic monitoring of wall-mounted use occurred in both the treatment and control groups. With regard to a device vector of transmission, devices were decontaminated at shift end on a daily basis. One potential limitation was lack of sustained exposure to the intervention; there remained a significant increase in HDEs above that of control. Concerning the 20-second time interval, although a provider could wash hands in less than the 30 seconds required for air drying, this limitation also applied to conventional devices. Also, although there are a multitude of factors that can affect HAI development, the randomized, controlled study design accounts for these known and unknown variables. The study was designed to rigorously assess the efficacy of a specific hand hygiene system in a specific window of patient care, the operating room.

In conclusion, the hand hygiene system evaluated in this robust study increased provider HDEs, but the increase in HDEs was not associated with a reduction in 30-day postoperative HAIs. Future work is indicated to optimize the efficacy of this hand hygiene improvement strategy.

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Potential conflicts of interest. R.W.L. reports that he has received research funding from Sage, has provisional patents unrelated to hand hygiene or this study, and is a partner of RDB Bioinformatics. All other authors report no conflicts of interest relevant to this article. Sage assisted in the installation of hand hygiene monitoring system and monitoring of hand hygiene. Sage did not participate in the development of the study design, nor did they have access to or participate in the analysis of infection control outcomes data or the writing of the manuscript. Sage did have the opportunity to review the completed manuscript before its submission.

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SUPPLEMENTARY MATERIAL

To view supplementary material for this article, please visit http://dx.doi.org/10.1017/ice.2016.106

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