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Impact of a Novel Antimicrobial Surface Coating on Health Care–Associated Infections and Environmental Bioburden at 2 Urban Hospitals

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Background. Approximately 1 in 25 people admitted to a hospital in the United States will suffer a health care–associated infection (HAI). Environmental contamination of hospital surfaces contributes to HAI transmission. We investigated the impact of an antimicrobial surface coating on HAIs and environmental bioburdens at 2 urban hospitals.

Methods. A transparent antimicrobial surface coating was applied to patient rooms and common areas in 3 units at each hospital. Longitudinal regression models were used to compare changes in hospital-onset multidrug-resistant organism bloodstream infection (MDRO-BSI) and *Clostridium difficile* infection (CDI) rates in the 12 months before and after application of the surface coating. Incidence rate ratios (IRRs) were compared for units receiving the surface coating application and for contemporaneous control units. Environmental samples were collected pre- and post-application to identify bacterial colony forming units (CFUs) and the percent of sites positive for select, clinically relevant pathogens.

Results. Across both hospitals, there was a 36% decline in pooled HAIs (combined MDRO-BSIs and CDIs) in units receiving the surface coating application (IRR, 0.64; 95% confidence interval [CI], .44–.91), and no decline in the control units (IRR, 1.20; 95% CI, .92–1.55). Following the surface application, the total bacterial CFUs at Hospitals A and B declined by 79% and 75%, respectively; the percentages of environmental samples positive for clinically relevant pathogens also declined significantly for both hospitals.

Conclusions. Statistically significant reductions in HAIs and environmental bioburdens occurred in the units receiving the antimicrobial surface coating, suggesting the potential for improved patient outcomes and persistent reductions in environmental contamination. Future studies should assess optimal implementation methods and long-term impacts.

Keywords. health care-associated infections; hospital environment; cleaning; infection prevention; patients' rooms.

Health care–associated infections (HAIs) pose substantial risks to patients and an economic burden to health-care systems. Approximately 1 in 25 patients admitted to a hospital will acquire a HAI, which can lead to longer hospital stays, readmissions, and death [1]. The estimated direct medical cost of HAIs exceeds $30 billion annually in the United States [2], and hospitals face financial penalties from regulators for exceeding HAI thresholds [3]. The frequent use of broad-spectrum antimicrobial drugs has hastened the emergence of *Clostridium difficile* infections (CDIs) and multidrug-resistant organisms (MDROs) in health-care settings [4]. Decreasing the transmission of these pathogens is a priority for health-care providers and public health officials. To this end, the US Department of Health and Human Services has set ambitious 2020 HAI reduction targets, including 30% and 50% reductions in HAIs caused by CDI and invasive methicillin-resistant *Staphylococcus aureus* (MRSA), respectively [5].

Recent systematic reviews have emphasized the role of environmental contamination of hospitals in the transmission of HAIs [6–8]. Pathogens causing HAIs can survive on inanimate surfaces for months and can serve as persistent sources of transmission in the absence of control measures. Further, health-care personnel can contaminate their hands and gloves with MDROs, *C. difficile*, and other common HAI pathogens after touching contaminated surfaces [9, 10]. Few products offer persistent efficacy, so surfaces can be re-contaminated immediately after cleaning [11]. Even with protocols in place for terminal cleaning of patient rooms, patients face elevated risks of HAIs from organisms left on surfaces by prior room occupants [12, 13]. In addition, terminal cleaning does not prevent the room from becoming re-contaminated with microbes within 24 hours of rooming a new patient [14, 15]. These

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challenges have led to a call for research on innovative technologies that confer persistent antimicrobial activity, with evaluations of the clinical impacts on patient outcomes [16].

Such an emerging technology is a transparent, antimicrobial surface (AMS) coating that can be applied by an electrostatic spray procedure. The mechanism for persistent antimicrobial activity is a quaternary ammonium polymer coating that disrupts the cell membranes of microbes, leading to cell lysis. The coating can minimize bacterial survival on surfaces for up to 15 weeks by bonding to the surface and creating a protective antimicrobial barrier [17]. This product can be applied to most surfaces—including bedframes, mattresses, medical equipment, furniture, walls, ceilings, windows, doors, hallways, and curtains—after a room is cleaned. The active ingredient reduces both bacteria and fungus [18, 19]; although it does not kill spores, it influences both surface charge and hydrophobicity, which enhance adhesion to surfaces and could make spores less likely to be aerosolized or transferred to other surfaces [20, 21].

In this study, we used a multicenter, nonrandomized, pre-post study design with contemporaneous control groups to assess the impact of AMS coating application on HAIs and surface contamination. Our objectives were: (1) to assess changes in hospital-onset HAIs in the year before and after application of the AMS coating; and (2) to identify changes in microbial burdens and clinically relevant pathogen presences on surfaces, relative to the AMS coating application.

METHODS

Study Sites

The study was conducted in 2 hospitals in a large, American city, hereafter referred to as Hospital A and Hospital B. Hospital A has 250–300 licensed beds, a case mix index of 1.43, and certification for Level III trauma care. Hospital B has over 350 licensed beds, a case mix index of 1.80, and certification for Level I trauma care. Both hospitals have cardiac, emergency, surgical, and intensive care unit (ICU) services. Only Hospital B has neonatal ICU (NICU), oncology, and solid organ transplant services. At each hospital, 3 units were nonrandomly selected for AMS coating application. Non-application units were considered control units. At Hospital A, 1 medical ICU and 2 medical wards were selected for AMS coating application; at Hospital B, 1 medical ICU, 1 neurological ICU, and 1 transplant step-down unit were selected for AMS coating application.

The Western Institutional Review Board reviewed the study protocol and determined the study to be exempt from full human subjects review as a quality improvement initiative. The company that invented and produces the AMS coating initiated the study with both hospitals. All environmental sampling and microbiology testing were performed by an independent laboratory. All analyses of HAI data were conducted by independent researchers.

Product Application

Certified technicians followed a uniform protocol for the surface preparation and application of AMS coating, and a manufacturer representative monitored all applications for quality control. Prior to an application, the surfaces were prepared with a solution containing a mild emulsifying agent on all hard, high-touch surfaces—including keyboards, countertops, railings, and chairs—to remove any buildup of organic matter. Technicians then applied the AMS coating with an electrostatic spray applicator to all hard and soft surfaces in the selected treatment units. Common areas were treated at night, when minimally staffed and free from visitors. For patient rooms, technicians coordinated with hospital personnel to enter rooms immediately following a discharge and terminal cleaning. For mobile items—including patient beds, intravenous poles, and wheelchairs—a barcode was placed on the item to indicate when the AMS coating had been applied.

Technicians applied the surface coating 3 times over the course of the study, approximately once every 4 months. The treatment of "fixed" items occurred each time, while mobile items were treated if they were in the select room or common area at the time of application. At Hospital A, technicians applied AMS coating to 104 single-patient rooms and 54 common areas, including nurses' stations, staff lounges, and family waiting rooms. In Hospital B, technicians applied the product to 108 single-patient rooms and 114 common areas. All fixed and mobile items in the room were treated as they were positioned in each room. A complete application took approximately 4 weeks (20 business days). Prior to and following the application of the AMS coating, hospital staff maintained their normal, daily cleaning schedule in all areas, which involved using reusable cloths and disinfecting with hospital-grade disinfectants, such as bleach or quaternary ammonium compounds.

Health Care–Associated Infections

To quantify the impact of the AMS coating on HAIs, we assessed changes in the incidences of hospital-onset MDRO bloodstream infections (BSI) and hospital-onset CDIs. Specifically, we examined monthly incidences (infections/1000 patient days) in the 12-month pre- and post-application periods for units receiving AMS coating (application units) and units not receiving AMS coating (control units). Control units accounted for underlying HAI trends not associated with AMS coating. Total patient days for the 12 months pre- and post-application were similar at Hospitals A and B (Table 1).

As part of routine HAI monitoring, infection preventionists at each hospital tracked HAIs per National Healthcare Safety Network (NHSN) protocols [22]. The NHSN protocols specify laboratory identification, de-duplication, and internal validation procedures for the monthly collection of MDRO-BSI and CDI metrics [23]. We used hospital-onset MDRO-BSI and CDI data collected from October 2015 through December 2017 at Hospitals A and B (Figure 1). We considered rates

Table 1. Distribution of Units, Rooms, and Patient Days Relative to Antimicrobial Surface Coating Application at Hospitals A and B

Hospital	Unit Status	Units	Rooms	Patient days (Pre)	Patient days (Post)
A	Application	3	104	29 345	29 627
	Control	5	>150	42 616	43 810
B	Application	3	108	28 451	28 991
	Control	6	>250	52 019	53 090

Abbreviations: Post, 12-month post-application periods; Pre, 12-month pre-application period.

of hospital-onset MDRO-BSI and CDI for 12-month pre-application and 12-month post-application periods. We excluded a 2-month application period at Hospital A and a 3-month application period at Hospital B, because these periods could not be categorized cleanly as pre- or post-application periods. Also, we excluded 1 control unit at Hospital B—the NICU—since NICUs do not track CDI per NHSN protocols. No changes in infection prevention or cleaning protocols occurred throughout the pre- and post-application study periods.

We calculated incidence rate ratios (IRRs) to quantify changes in the incidences of hospital-onset MDRO-BSI, CDI, and pooled infections (MDRO-BSI + CDI) relative to product application periods for application and control units at each hospital. We used general estimating equation regression modeling to generate IRRs, 95% confidence intervals (CIs), and *P* values. We specified the general estimating equation models to accommodate a Poisson distribution with patient-days as an offset, repeated observations over time by unit, and a first-order autoregressive correlation structure to account for nonindependence of observations by month. To generate separate IRRs for application and control units, we modeled monthly infection rates by their pre-post application status. We ran separate models for each outcome (both MDRO-BSI and CDI) at each hospital, as well as combined models (pooled MDRO-BSI and CDI). Finally, we created models including both application and control units, with interaction terms to assess whether pre-post application differences were significantly different by unit type (ie, a difference-in-difference analysis). In the following equation, the interaction term is characterized as $\beta 3$ and interpreted as an IRR.

$$\gamma HAI = \beta 0 + \beta 1\,(Pre - Post\ application\ period) + \beta 2(Application - Control\ Unit) + \beta 3\ (Pre - Post * Application - Control) + \varepsilon$$

Environmental Sampling

A technician from an independent laboratory conducted all pre-application and post-application environmental sampling at Hospitals A and B in application units only. Sampling of surfaces and items in patient rooms occurred following patient discharges but prior to terminal cleaning and a subsequent AMS coating application. Post-application sampling took

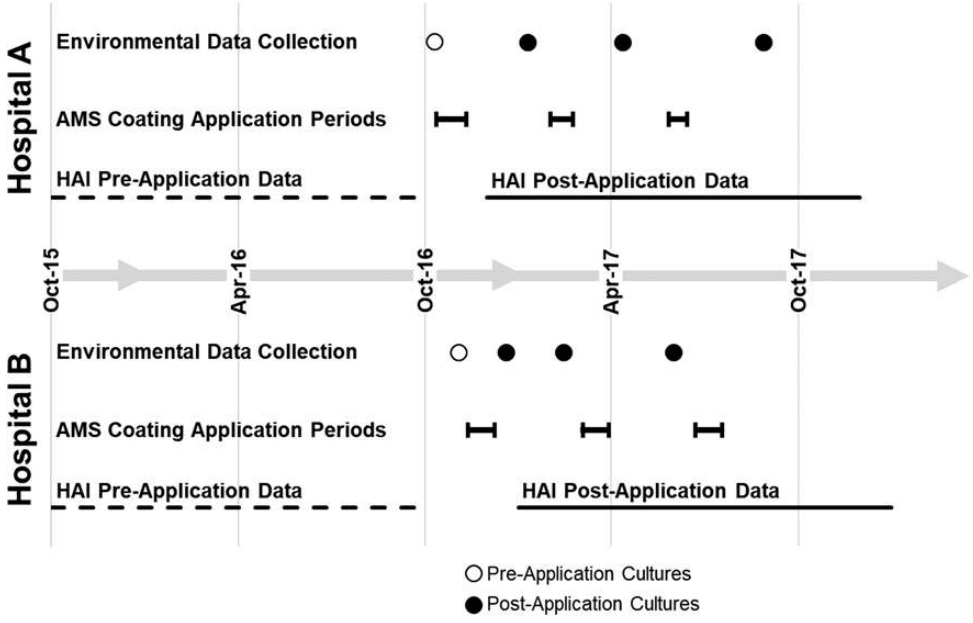

Figure 1. Timeline for application of product, collection of environmental data, and collection of hospital-onset multidrug-resistant organism and *Clostridium difficile* data at Hospitals A and B. Abbreviations: AMS, antimicrobial surface; HAI, health care–associated infection.

place at approximately 11 weeks following each AMS coating application. This post-application sampling interval was determined based on previous efficacy studies of AMS coating [17]. At Hospital B, the technician also sampled at 4 weeks post-treatment during the first application and did not sample at 11 weeks following the third application (Figure 1). Prior to the surface coating application, the technician collected 32 environmental samples at Hospital A and 133 at Hospital B. Over 3 post-application collection periods at each hospital, the technician collected 342 samples at Hospital A and 399 at Hospital B.

The laboratory technician sampled areas of 100 cm^2 using a sponge stick containing Letheen broth (3M, St Paul, MN) to neutralize any residual disinfectant. After collection, the samples were immediately placed on ice packs and sent overnight to the MicroChem Laboratories (Round Rock, TX). Upon receipt, the broth was extracted from the sponge stick by manual agitation, and extracted broth was assayed using selective media for isolation of the various bacteria. Samples were cultured for total aerobic bacteria on Trypticase Soy Agar (Hardy Diagnostics, Santa Maria, CA) by the pour plate method.

The plates were incubated for 5 days at 24 ± 5°C and the resulting colonies were counted. Vancomycin-resistant *Enterococcus* (VRE) and carbapenem-resistant *Enterobacteriaceae* (CRE) were assayed using Chrom agar media, as previously described [24, 25]. MRSA was assayed according to the methods described by May [26], and *Clostridium difficile* was assayed on brain-heart infusion agar (Hardy-Criterion, Santa Maria, CA) with yeast extract (Van Waters and Rogers Company, Seattle, WA) and horse blood agar (Hemostat Laboratories, Dixon, CA) [27]. The limit of detection for total bacteria was 1.00E+01. The lower limit for the selective plates was dependent on the sample volume and ranged from 1.40E+01 to 2.6E+01.

Environmental samples were evaluated for total bacterial colony forming units (CFUs) and for the presence of 4 clinically relevant pathogens: CRE, MRSA, VRE, and *C. difficile*. For mean CFU counts of total heterotrophic bacteria, arithmetic means were calculated and nonparametric (Mann-Whitney) statistical tests were used to compare means. To determine the percent of samples positive for select pathogens, the number of surfaces positive for a clinically relevant pathogen was divided by the total number of sites sampled. A Student's *t* test was used to determine differences in percentages of positive sites in the pre- versus post-application periods.

RESULTS

Health Care–Associated Infections

Across both hospitals, there was a 36% decline in pooled HAIs (hospital-onset MDRO-BSI and CDI) following an application of ABS coating (IRR, 0.64; 95% CI, .44–.91). In control units, there was no decline in HAIs over the same period (IRR, 1.20; 95% CI, .92–1.55). The difference in IRRs for application and control units for pooled HAI was significant ($P = .005$).

In application units at Hospital A, there were significant HAI reductions following applications of ABS coating, including a 52% reduction in pooled HAIs (IRR, 0.46; 95% CI, .38–.61), a 54% reduction in MDRO-BSIs (IRR, 0.46; 95% CI, .28–.77), and a 47% reduction in CDIs (IRR, 0.53; 97% CI, .38–.74); there were no reductions in HAIs in control units (Table 2; Figure 2A). The differences in IRRs for application and control units were significant for pooled HAIs (0.002) and borderline significant for MDRO-BSIs (0.125) and CDIs (0.119).

In application units at Hospital B, there was a 37% reduction in CDIs following AMS coating (IRR, 0.63; 95% CI, .45–.88) and were nonsignificant reductions in MDRO-BSIs and pooled HAIs (Table 2; Figure 2B). In control units, there were no statistically significant differences in MDRO-BSIs, CDIs, or pooled HAIs during the same time period. For each of these outcomes, there were greater reductions of infection rates in application

Table 2. Number and Rate of Hospital-onset Infections in the Surface Application and No Application Units at Hospitals A and B

Hospital	Unit Status	Outcome	Number of Cases (Pre)	Rate Per 1000 Pt. Days (Pre)	Number of Cases (Post)	Rate Per 1000 Pt. Days (Post)	*P* Value for Pre-post Difference
Hospital A	Application	Pooled	47	1.60	23	.78	<.001
		MDRO-BSI	32	1.09	15	.51	.003
		CDI	15	.51	8	.27	<.001
	Control	Pooled	24	.56	26	.59	.794
		MDRO-BSI	14	.33	13	.30	.775
		CDI	10	.23	13	.30	.649
Hospital B	Application	Pooled	75	2.64	57	1.97	.192
		MDRO-BSI	42	1.48	36	1.24	.574
		CDI	33	1.16	21	.72	.007
	Control	Pooled	52	1.00	61	1.15	.196
		MDRO-BSI	25	.48	37	.70	.066
		CDI	27	.52	24	.45	.545

The *P* values were on incidence rate ratios generated by general estimating equation regression models controlling for nonindependence and autocorrelation.
Abbreviations: BSI, bloodstream infection; CDI, *Clostridium difficile* infection; MDRO, multidrug-resistant organisms; Pooled, combined MDRO-BSI and CDI; Post, 12-month post-application periods; Pre, 12-month pre-application period; Pt., patient.

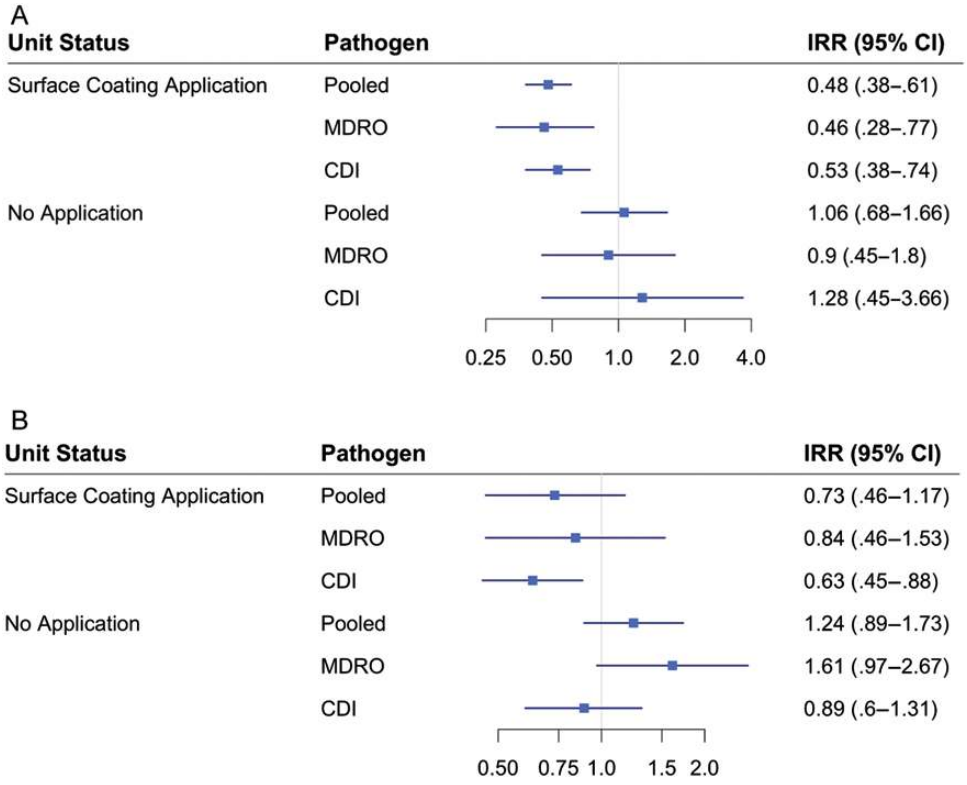

Figure 2. IRRs and 95% CIs are displayed on a forest plot for MDRO, CDI, and pooled health care–associated infection rates at (*A*) Hospital A and (*B*) Hospital B. IRRs less than 1 indicate reductions in the post-application period. Abbreviations: CDI, *Clostridium difficile* infection; CI, confidence interval; IRR, incidence rate ratio; MDRO, multidrug-resistant organism.

versus control units, although these differences were borderline significant ($P = .065$ for pooled HAIs; $P = .120$ for MDRO-BSIs; $P = .162$ for CDIs).

Environmental Bioburden

There were statistically significant decreases in total CFU levels at both hospitals following applications of the AMS coating (a 79% decrease for Hospital A and a 75% decrease in Hospital B). At Hospital A, sampling occurred at baseline and at 11 weeks following each of the 3 applications. For total bacterial CFUs, the mean baseline level of 208.0 CFU/cm^2 decreased to 74.6 CFU/cm^2 following the first application. That decrease continued following the second application (40.4 CFU/cm^2) and third application (15.3 CFU/cm^2; $P < .0001$, comparing the baseline to all post-application periods combined).

At Hospital B—which used a slightly different sampling protocol than Hospital A, with sampling at 4 and 11 weeks after the first application and 11 weeks after the second application—the total bacterial CFU level had decreased from a mean baseline level of 221.9 CFU/cm^2 to 30.3 CFU/cm^2 at 11 weeks after the first application and decreased further, to 16.91 CFU/cm^2, at 11 weeks after the second application.

At both hospitals, the percent of sites positive for clinically relevant pathogens decreased (Figure 3). For Hospital A, of the 32 samples collected at baseline, the number of positive sites ranged from 2 (*C. difficile*) to 12 (MRSA). When all post-application sampling results were combined and compared to the pre-application levels, the percentage of positive sites decreased for each pathogen (Figure 3). In Hospital A, *C. difficile* decreased from 6.3% of sites positive to 0.0% positive; CRE decreased from 15.6% to 4.3% ($P < .0001$); VRE decreased from 12.5% to 4.3% ($P = .042$); and MRSA decreased from 37.5% to 12.4% ($P = .0001$). For Hospital B, *C. difficile* decreased from 3.0% positive sites at baseline to 0.4% at follow-up ($P = .005$); CRE decreased from 10.5% to 4.6% ($P = .009$); VRE decreased from 15.0% to 3.1% ($P < .0001$); and MRSA decreased from 18.1% to 14.4% ($P > .05$).

DISCUSSION

In this first study to assess the impact of AMS coating on HAI rates, we observed significant HAI reductions in units receiving the AMS coating and no impact in control units across both hospitals. Hospital A showed a clearer distinction in HAI rates between application and control units than Hospital B, suggesting a variable impact across facilities. The increase in hospital-onset MDRO rates in control units at Hospital B suggests that other factors may have increased the overall infection risk during the application period, despite noted decreases

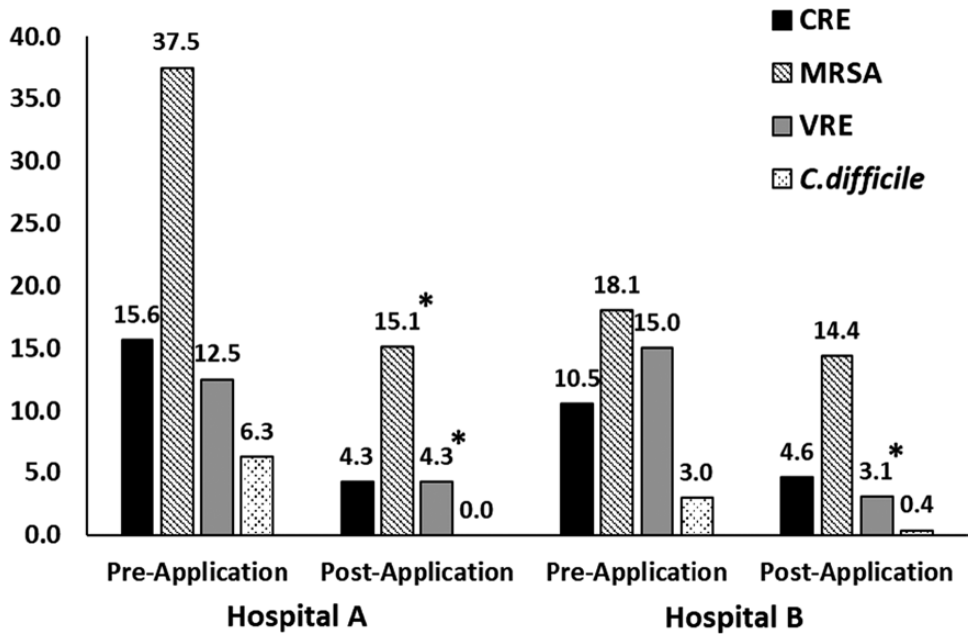

Figure 3. Percent of sites positive for select, clinically relevant pathogens before the application of AMS coating (labeled as "Pre-Application"), compared to sites positive after the application of coating (labeled as "Post-Application") at Hospitals A and B. *Indicates a statistically significant difference from baseline at the $P < .05$ level. Abbreviations: AMS, antimicrobial surface; *C. difficile, Clostridium difficile*; CRE, carbapenem-resistant *Enterobacteriaceae*; MRSA, methicillin-resistant *Staphylococcus aureus*; VRE, vancomycin-resistant *Enterococcus*.

in the environmental bioburden. Overall, decreases in HAIs in application units were accompanied by decreases in environmental bioburdens and clinically significant pathogens in those units treated with the ABS coating.

Inanimate surfaces are known to play a role in the transmission of HAIs in the health-care environment [16, 28]. Cleaning and disinfection of surfaces is an effective approach to reducing the spread of pathogens; however, surfaces are often not adequately cleaned, and recontamination can occur within minutes [16]. Many commercial products demonstrate the ability to reduce the bacterial load in clinical settings, yet the clinical translations of these products have not been well described [29]. In this study, we demonstrated a reduction in HAIs, concurrent with a reduction in bacterial loads, following the application of the AMS coating. While the association between a reduced bacterial load and reduced HAIs might appear obvious, the determination of the bacterial presence in a clinical setting is imperfect due to several factors (ie, sampling error, bacterial load limits of detection, persistence of bacteria in/on under-treated areas of the clinical setting, variability in cleaning protocol adherence, variability in clinical practices). Thus, a patient might still be at risk for acquiring a HAI despite an apparent reduction of the bacterial load in a clinical setting.

A limitation of this study is that no environmental data were collected in control units. Another potential limitation is the possibility that lower baseline HAI rates in control units would require a longer study period to demonstrate significant HAI reductions. However, this study did demonstrate statistically significant reductions in both environmental contamination and HAIs in the application units, while the HAI rates in the control units appeared to increase, though not significantly. Finally, at Hospital B, the decreases in MDRO-BSIs were not significant in the application units, although MDRO-BSIs increased nonsignificantly in the control units. Several explanations may account for these findings. First, we encountered mobility of such items as hospital beds, patient-assist devices, intravenous poles, and pumps and monitoring devices. Attempts to track and treat mobile assets were compromised by a lack of protected time and space for the assets when not in use. Finally, this study design prioritized patient care over the study implementation, which impacted the precision of the timing for treatments and sampling in some cases.

Our study is further limited by a lack of monthly, unit-specific infection prevention and antimicrobial use data, which could have affected hospital-onset MDRO-BSI and CDI rates during the pre- and post-application periods. However, at Hospital A, we did obtain hospital-wide hand hygiene data, which showed that hand hygiene decreased from 90% in the pre-application period to 56% in the post-application period. This finding suggests that unmeasured increases in hand hygiene did not account for infection declines noted in the study; in fact, declines in hand hygiene should bias findings towards the null in the application units. At Hospital B, unit-specific infection prevention process data demonstrated declines in hand hygiene and isolation precaution adherence for both the application and control units. These declines could explain the

limited impact of the ABS coating at Hospital B, and suggest that unmeasured enhancements in infection practices do not explain declines in CDI rates at Hospital B relative to the ABS coating application.

Future studies should incorporate the knowledge gained in this study to more directly focus the benefits, scalability, and cost-effectiveness of AMS coating applications. Future studies need to better define changes in other sources of HAI risk and to better quantify the independent impacts of products like AMS coating in complex health-care environments. Also, studies of applications in high-touch, key patient entry points, such as the emergency department, urgent care centers, and long-term care facilities, will be important in understanding the potential of antimicrobial surface coating in preventing HAIs.

Notes

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Disclaimer. The study design was developed by ABS and the technology is the sole property of ABS. The study was executed in collaboration with clinical and administrative leaders at Methodist. Environmental sampling and testing were conducted by a third party GLP-certified lab. The Infection data were collected, aggregated, and provided by the Methodist Infection Prevention staff as part of their ongoing infection rate monitoring processes.

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Potential conflicts of interest. C. P. G. has served as an unpaid advisor to ABS. K. P.-B. and K. E. received consulting fees for statistical analyses from ABS. All other authors report no potential conflicts of interest. All authors have submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest. Conflicts that the editors consider relevant to the content of the manuscript have been disclosed.

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