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Major Article

Copper (Cu) for Reducing Environmental Healthcare Associated Infections (CuRE HAI): A 10-year pragmatic copper surface implementation study

Marjory D. Williams RN, PhD [a], Angelia Bridges RN, MPH [a], John D. Coppin MPH [a], Piyali Chatterjee PhD [a], Hosoon Choi PhD [a], Thanuri Navarathna MPH [a], Morgan Bennett BS [a], Richard E. Nelson PhD [b,c], Emma Brackens MT [a], Lynn Mayo MT [a], Chetan Jinadatha MD, MPH [d,e,*]

[a] Department of Research, Central Texas Veterans Health Care System, Temple, TX
[b] IDEAS Center, VA Salt Lake City Healthcare System, Salt Lake City, UT
[c] Department of Internal Medicine, University of Utah, Salt Lake City, UT
[d] Department of Medicine, Central Texas Veterans Health Care System, Temple, TX
[e] Department of Medical Education, Texas A&M University, College Station, TX

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Background: Health care-associated infections are a major cause of morbidity and mortality among hospitalized patients. Our Copper for Reducing Environmental Healthcare-Associated Infections (CuRE HAI) study evaluated the effectiveness of introducing a novel copper-oxide infused polymer resin surface in the immediate environment surrounding a hospitalized patient.
Methods: The study was conducted between January 2014 and December 2023. Several high-touch surfaces were replaced with 16-20% copper-oxide-infused surfaces. All hospital admissions each month were monitored for onset of HAIs using predefined criteria. A Bayesian hierarchical Poisson model was used to estimate the effect of the intervention on monthly HAI rates.
Results: There were 543 HAIs and 231,752 bed days of care (BDOC) in the 120-month study period, a mean of 27.6 HAIs per 10,000 BDOC and 20.8 HAIs per 10,000 BDOC in the pre- and post-copper installation periods, respectively. The estimated incidence rate ratio for copper across all infections was 0.51 (0.25, 0.95).
Conclusions: The CuRE HAI study suggests that implementation of novel copper components in a patient care environment may prevent HAIs. The continuous antimicrobial and antisporicidal activity provided by the copper surfaces likely explains at least some of the observed decline in HAI rates.

BACKGROUND

Health care-associated infections (HAIs) are a major cause of illness and death for hospitalized patients across the globe.[1,2] While multiple factors contribute to HAI occurrence, the role that contaminated hospital surfaces play in the transmission and spread of infection, either directly or via hands of health care workers, has garnered substantial attention.[3] Numerous pathogens of clinical importance, including methicillin-resistant *Staphylococcus aureus* (MRSA), *Clostridioides difficile* (*Cl difficile*), *Acinetobacter baumannii*, *Klebsiella pneumoniae*, *Escherichia coli*, and *Candida auris*, have been documented to live on surfaces for weeks or up to several months.[4,5] Of particular concern is evidence that multidrug-resistant organisms (MDROs) live on surfaces for extended periods of time and remain capable of causing disease despite surface disinfection efforts.[1] Studies have shown that improved surface disinfection can decrease environmental contamination of health care-associated pathogens and decrease the likelihood of patients acquiring HAIs.[6]

To reduce risk for HAIs, manual disinfection with hospital-grade spray or wipe disinfectants is routinely used, but organisms might

* Address correspondence to Chetan Jinadatha, MD, MPH, Central Texas Veterans Health Care System, 1901 South 1st Street, Temple, TX 76504.
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persist due to inadequate cleaning or residual contamination.[7] Possible reasons for residual contamination include lack of properly trained staff, use of the wrong disinfectants for the microorganisms present, insufficient dwell times, cross-contamination, and human error.[8] Novel no-touch disinfection (NTD) technologies such as ultraviolet (UV) light, have been incorporated into the episodic cleaning protocols to further minimize left over contamination. NTD that utilizes UV light is effective at reducing microbial burden, possibly with greater consistency than is achieved with manual methods[7]; however, UV light lacks the ability to reach around corners and beneath beds and tables, and its use is episodic. In addition, UV light devices cannot be used while a patient is occupying the room. Prevention of microbial burden accumulation between episodic cleaning and disinfection is important to prevent cross transmission of MDROs and *Cl difficile* from surfaces onto patients.[3] Technologies that provide continuous disinfection of high-touch health care surfaces can address the limitations described of both manual and NTD cleaning protocols.

Copper has antimicrobial properties that can be applied in the health care setting to provide continuous disinfection as an adjunct to the current intermittent strategies. Copper-clad or brass (copper-zinc alloy) surfaces have shown efficacy against many MDROs and *Cl difficile*.[9-12] The main drawbacks preventing wider implementation of copper in health care settings include tarnishing of the metal, inability to easily mold the metal, and cost.

One novel copper-oxide impregnated polymer resin-based surface provides antimicrobial killing power while being easily moldable and resistant to tarnishing.[13] This surface has been shown to reduce microbial contamination of both antibiotic-resistant and nonresistant organisms, including *Cl difficile*, within 2 to 4 hours of contact time.[13,14] While successful microbial reduction has been demonstrated,[15,16] its effectiveness in reducing HAIs has not yet been thoroughly evaluated. In this long-term study, copper-oxide infused polymer resin-based surfaces were retrofitted across major high-touch surfaces in an acute care hospital and its effectiveness on HAI reduction was studied over a 10-year period.

METHODS

Study setting

The CuRE HAI study was a prospective intervention that compared HAI rates before, during, and after the installation of copper-impregnated surfaces in a patient care environment. It was conducted at the Central Texas Veterans Health Care System (CTVHCS) in Temple, TX, a 120 bed, level 1a multispecialty acute care facility, which averages approximately 6,000 to 7,000 admissions per year. During the study period, we had 18 ICU beds and the rest were acute care beds. The study period was from January 2014 to December 2023, spanning 10 years inclusive of pre- and post-installation periods. The primary outcome collected across the 10-year study period was the incidence of HAIs among veterans admitted to the acute care facility who met the 2017 Centers for Diseases Control and Prevention National Health and Safety Network (CDC-NHSN) definition for HAIs. Data was collected retrospectively for the 3-year pre-installation period using the 2017 NHSN definition.[17] The study protocol was approved by the CTVHCS Institutional Review Board. Review of hospital records indicates that routine pre-intervention infection prevention practices included written protocols for the use of NTD devices for environmental disinfection, contact isolation precautions, active MRSA nares screening, and hand hygiene and were maintained throughout the entire study period.

Study material and design

Copper components were installed in all 120 acute care and critical care beds in the hospital. The intervention included transformation of critical components that surround the patient and are typically involved in the HAI transmission[18] with copper-oxide infused polymer-based material (EOSCu Surfaces LLC). The experimental solid surface has uniform properties (16%-20% copper-oxide) throughout the depth of its material and needs to be destroyed completely to be rendered ineffective, as opposed to sheeted copper surfaces which may be pierced or worn through.[9-13] This surface can be poured into molds as a polymer-resin and cast into any required shape, allowing its use in numerous places where uniquely shaped surfaces are needed. The transformed components included the nurses' station countertops, sinks in the patient room and bathroom, tray tables, and bedrail components (siderails, footrails, and headrails) (Fig. 1). Some of the earlier copper tray tables and bedrail components failed due to the brittle nature of the copper polymer material initially used during the early part of the trial. Over time, tray tables were replaced with a less brittle version (impact-resistant polymer), a potential implementation limitation.

The installation was completed in phases as these surfaces were retrofitted into existing/working patient care units. The bedrails and tray tables were transformed between October 2016 and December 2017 (Fig. 2) while sinks and nurses' stations were transformed between October 2016 and December 2019. The hospital already used a multifaceted infection prevention program that included robust hand hygiene guidance, environmental cleaning protocol, usage of UV irradiation following terminal cleaning, active surveillance for MRSA positive carriers/patients and contact barrier precautions for patients with MDROs. Censuses of the number of various copper surfaces were taken periodically throughout the installation and post-installation periods.

Study sample

All patients admitted to the acute care medical-surgical unit and the intensive care units were included in the analysis. There was no exclusion criteria for patients admitted to the units that contained copper components. During the COVID-19 pandemic, a separate COVID-19 unit was constructed. Patients admitted to the COVID-19 ward were not included in the study as the new unit lacked copper components and a baseline HAI rate. HAIs were identified using an extensive manual chart review process that started with reviews of all microbiology culture reports, *Cl difficile* PCR results, and the inpatient records for all hospital admissions for each month from January 2014 to December 2023 (120 months of data). The HAI cases were determined using case definitions published by CDC-NHSN for 2017. The 2017 HAI criterion was used to determine infections for all years of the study (2014-2023). A single experienced infection preventionist collected all the data to maintain consistency. Locking in the 2017 definitions decreased the potential for over-calling or under-calling HAIs due to definition changes. The CDC-NHSN criteria consists of 52 separate infection case definitions including device-related infections (eg, central line-associated bloodstream infections, catheter-associated urinary tract infections). HAI categories were combined into 5 main categories for analysis: blood infections (including Laboratory-Confirmed Bloodstream Infection and Central Line-Associated Bloodstream Infection), urine infections (Symptomatic Urinary Tract Infection [SUTI], Catheter-Associated Urinary Tract Infection [CAUTI], SUTI-NON-CAUTI), site-specific infections, pneumonias, and *Cl difficile* infections.

Fig. 1. Copper-oxide infused polymer-based material surfaces installed on sinks, tray tables, and bedrails in patient rooms.

Statistical analysis

A Bayesian Poisson multivariate structural times series model was fit to the 5 categories of HAIs. The autoregressive structure of this approach models the process in which the number of infections in the current month may directly influence the number in the next month, a realistic modeling assumption in a hospital environment susceptible to outbreaks and correlated infection control responses. In addition to the autoregressive structure, parameters for average length of stay (LOS), bed days of care (BDOC), pre-/post-COVID period, and the proportion of hospital beds, tray tables, sinks, and nurses' stations that were transformed to copper, were also included in the model. Information for these parameters was partially pooled across the models for the 5 HAI categories by modeling parameters hierarchically. The advantage to this approach is that sparse outcomes in some of the HAI categories (such as site-specific infections) are partially informed by categories with more data. Any missing data in between censuses for the level of copper bedrails and tray tables were inferred as parameters in the model, and for the copper beds, constrained to be monotonically decreasing. This constraint ensured that the inferred proportion of copper beds decreased between censuses, as no copper bedrails were replaced after initial installation. Potential month-to-month seasonal variation in HAIs was also incorporated into the model via varying intercepts for the month of the year. These results are presented as parameter estimates for the intervention on each HAI category and as the estimated number of HAIs prevented by the intervention over the course of the study for each HAI category.

The model was written and fit in the probabilistic programming language Stan in rstan version 2.32.6 in R version 4.4.2.[19–21] Visualizations were coded in R using ggplot2 and a Markov Chain Monte Carlo (MCMC) visualization tool suite.[22,23] Numerical results from the model are presented as means or medians and 95% central quantiles of the MCMC samples from the posterior probability distribution for the parameters or estimates.

RESULTS

Monitoring adherence to the intervention

The census of copper intervention components shown in Figure 2 illustrates a period without copper followed by an intervention period where the copper components of beds (A) initially increase then decline to 0% presence prior to the end of the study period, while the copper components of tray tables (B), sinks (C), and nurses' station counters (D) increased and sustained the increased presence over the lifecycle of the study. The decline in beds with copper elements was due to the hospital upgrading to newer bed models that did not get replacement copper railings. After January 2021 most of the acute care beds did not have any copper components, and after May 2021 there were no acute care beds with copper components left.

Health care-associated infections

There were 543 HAIs and 231,752 BDOC in the 120-month study period, resulting in a mean of 27.6 HAIs per 10,000 BDOC prior to the installation of any copper surfaces (January 2014-September 2016) and a mean of 20.8 HAIs per 10,000 BDOC (Table 1) after the commencement of installation of copper surfaces (October 2016-December 2023).

The estimated incidence rate ratio (IRR) from the Poisson model for a full copper intervention was 0.40 (0.12, 0.86) (mean and 95% central quantiles) for blood infections, 0.48 (0.19, 0.98) for urine infections, 0.65 (0.21, 1.55) for site-specific infections, 0.45 (0.18, 0.95) for pneumonias, and (0.46 0.19, 0.97) for *Cl difficile* infections,

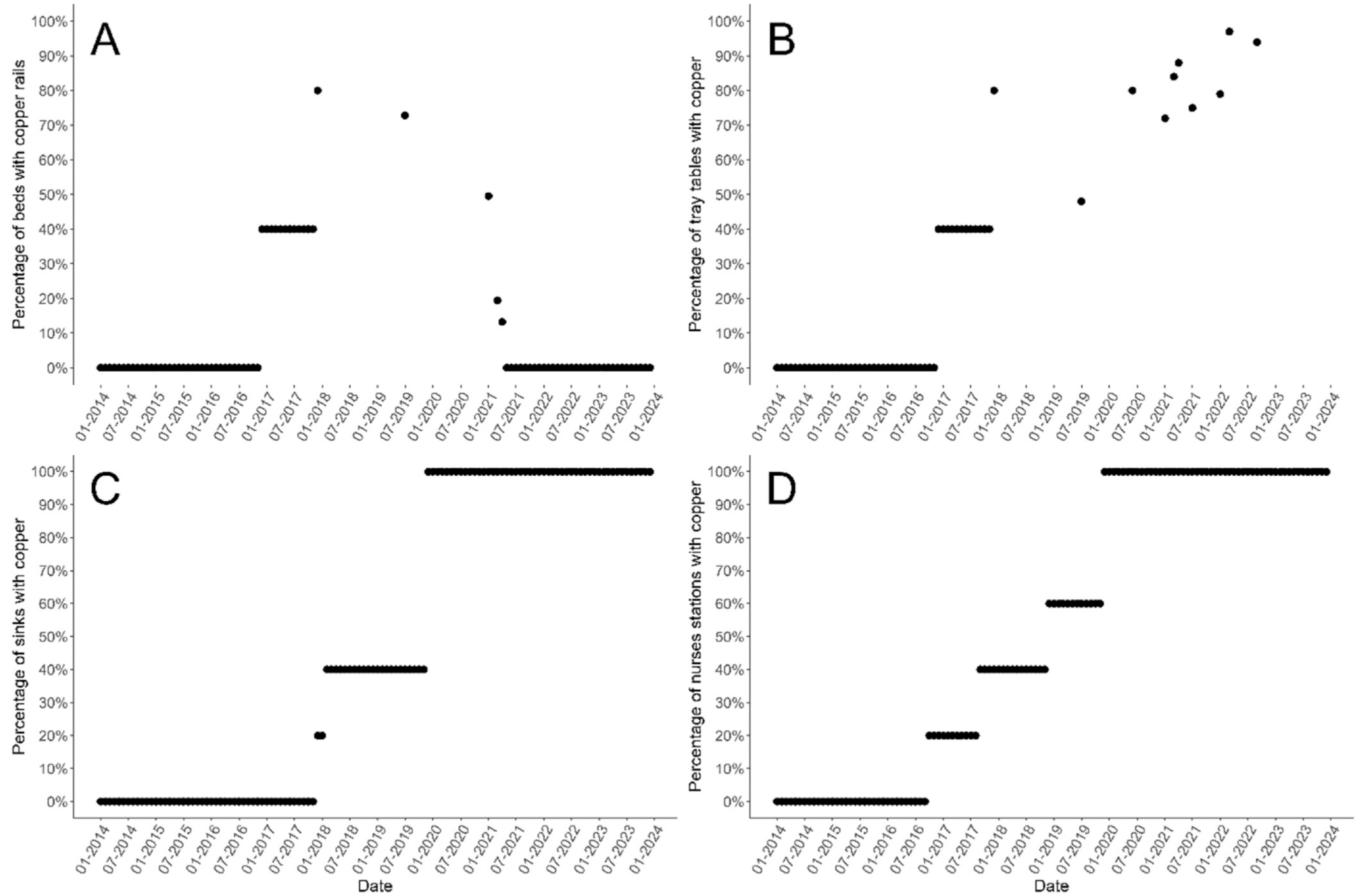

Fig. 2. Percentage of intervention components in the hospital that were converted to copper over the course of the study period. Data for beds (A) and tray tables (B) after installation were based on periodic censuses of the components in the hospital during the intervention period. (A) The percentage of hospital beds with at least one copper bedrail. (B) The percentage of tray tables that were with copper. (C) The percentage of patient rooms with copper sinks. (D) The percentage of nurses' stations with copper countertops.

Table 1
The rate of each category of HAI in the pre- and post-installation timeframe

Infection	Pre-install rate*	Post-install rate†
All infections	27.6 (28.2)	20.8 (18.5)
Blood	6.7 (7.8)	3.8 (0.0)
Urine	4.9 (4.4)	3.5 (0.0)
Site-specific	1.3 (0.0)	2.4 (0.0)
Pneumonias	3.6 (4.3)	3.1 (0.0)
Clostridioides difficile	11.0 (8.8)	8.1 (7.5)

HAI, health care-associated infection.
*Mean (median) number of infections per 10,000 bed days of care for the time-period prior to any copper installation (months 1-33).
†Mean (median) number of infections per 10,000 bed days of care for the time-period after any copper installation (months 34-120).

indicating some beneficial effect of the copper intervention within the 95% credible interval for all but site-specific infections. The estimated IRR for copper across all infections was 0.51 (0.25, 0.95). The estimated IRR for average LOS increasing 1 day was 0.99 (0.91, 1.08), for BDOC increasing by a SD was 1.17 (0.90, 1.45), and for post versus pre-COVID pandemic was 1.31 (0.80, 2.05), indicating uncertainty about both the magnitude and direction of effect as each of the 95% credible intervals were compatible with null effect.

Figure 3 shows the model fit (blue shades), model estimated number of monthly infections had no intervention been implemented (red shades) and observed monthly infections (black dots) over the course of the study period. The model-based results are more interpretable if provided on the scale of the outcome variables as opposed to the model parameters given above. Therefore, we estimated the difference between the model estimated number of infections over the course of the study had the copper intervention not been included (red shades in Fig. 3) and the number of infections observed (black dots in Fig. 3). This counterfactual estimate provides information on the number of infections that were potentially prevented due to the intervention (Fig. 4), which is far more meaningful information to practitioners than estimates of model parameters.[24]

The estimated number (median and 95% central quantiles) of total HAIs prevented over the course of the study due to the copper intervention was 199.0 (40.0, 474.0). Thus, the estimated number of total HAIs prevented over the course of the study was 12.7 (2.6, 30.2) HAIs per 10,000 BDOC. This estimate is conservative in the sense that it reflects the intervention as implemented in this study (Fig. 2) and not the estimated number of HAIs prevented had a full installation been in place for the entire post-install period.

The estimated number of blood infections prevented was 43.0 (−4.0, 150.0), 31.0 (−7.0, 100.0) for urine infections, 8.0 (−16.0, 63.0) for site-specific infections, 27.0 (−7.0, 91.0) for pneumonias, and 78.0 (−11.0, 236.0) for *Cl difficile* infections. Figure 4 shows these results as histograms of samples from the posterior probability distribution for each estimate, which allows visualization of the most probable estimates. For the estimated number of total HAIs prevented 3,972 out

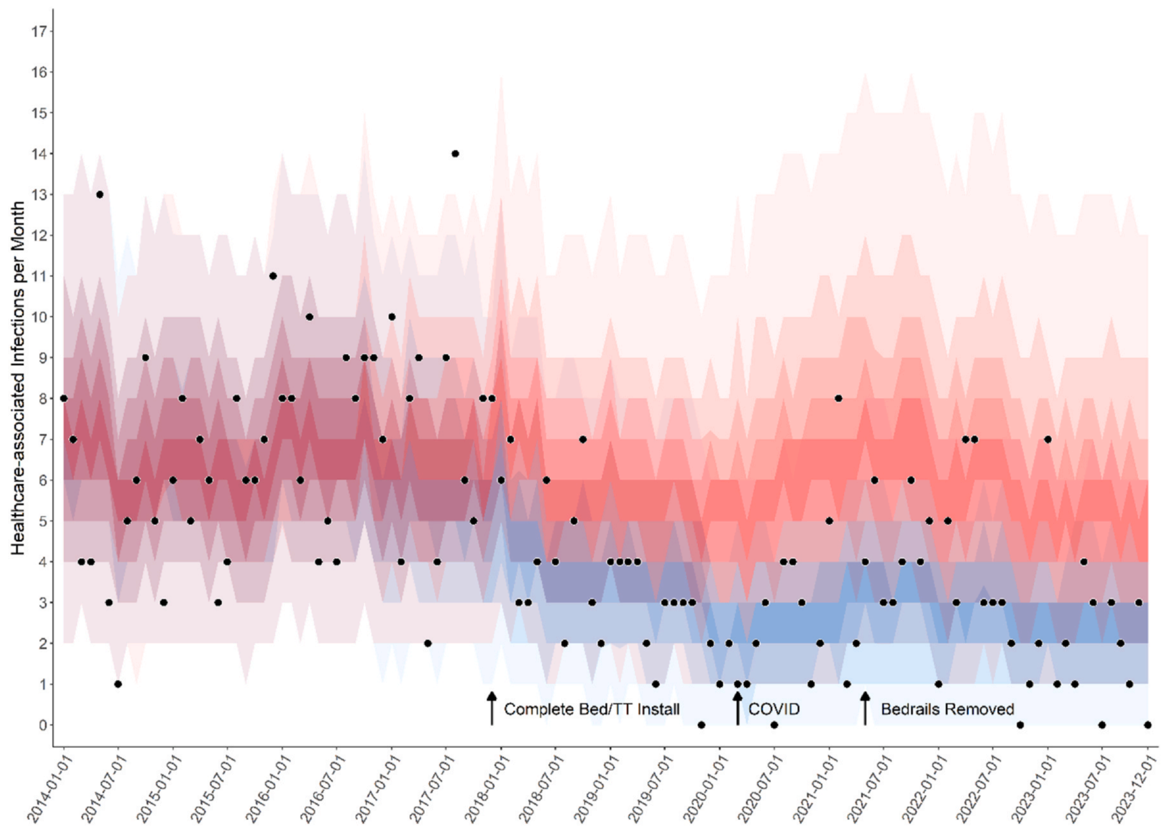

Fig. 3. HAIs per month over the course of the entire study period. Black dots indicate the observed number of HAIs. Blue shades denote the 10%-90% quantiles for the posterior probability distribution for predictions from the model fit to the observed data. Red shades denote the 10%-90% quantiles for the posterior probability distribution for predictions from the model for the hypothetical counterfactual scenario had the intervention not been installed. Darker shades indicate higher probability. The difference between the counterfactual predictions (red shades) and the actual observations (black dots) represents the estimated effect of the intervention on HAIs for each month (summarized for each infection type in Fig. 4). HAIs, health care-associated infections.

of 4,000 MCMC samples (99%) were greater than zero, indicating a 99% estimated probability that the copper intervention had at least some benefit, conditional on the assumptions in our model and study design. In addition, 97% of MCMC samples were greater than 50 HAIs. For the estimate of blood infections prevented, 96% of MCMC samples were greater than zero, for urine infections 93%, for site-specific infections 68%, for pneumonias 93%, and for *Cl difficile* infections 95%.

Among the organisms that caused the most HAIs during the entire study period were *S aureus, E coli, K pneumoniae, Pseudomonas aeruginosa, Proteus mirabilis, Enterococcus faecalis, S epidermidis, Ca albicans, and Cl difficile* (Supplementary Table S2). But by far many of the cultures were mixed organisms attributable to 2 or more microorganisms being present at the same time on a culture plate.

DISCUSSION

Previously, copper and its alloys have been used with varying success in preventing HAIs.[25,26] In the CuRE HAI study, implementation of a novel copper-oxide impregnated polymeric surface in an acute care setting showed reduction in HAIs over the post-implementation period, with a model estimated 99% chance that at least one HAI was prevented and a 97% chance that greater than 50 HAIs were prevented during the intervention period. However, the credible intervals for the IRRs and the estimated number of HAIs prevented are wide, indicating a high degree of uncertainty in the effect size. It is worth noting that the IRRs for the effect of copper are for a full copper intervention, as the model coefficients give the effect of full installation versus no installation, and thus more optimistic, while the estimated number of infections prevented are for our imperfect intervention with less than 100% of copper components always present. Previous efficacy testing of this copper-impregnated surface had already demonstrated a significant reduction in bacterial load in both antibiotic-resistant and nonresistant organisms including vancomycin-resistant *Enterococcus*, *K pneumoniae* carbapenamase, and multidrug-resistant *A baumannii*, *Enterobacter aerogenes*, *E coli*, MRSA, and *P aeruginosa*.[13] Another study showed significant *Cl difficile* spore reduction at 4 hours.[14] We measured the efficacy of copper on environmental contamination (aerobic colony counts) before and after copper surface installation during the initial study period and found that copper significantly lowered environmental contamination.[15,16] This study combined with other pilot studies as well as the *Cl difficile* spore study provides a potential explanation for the observed HAI reduction.[13-16]

Pragmatic trials such as ours are often challenged by real-world events that are beyond the control of the researcher. The COVID-19 pandemic occurred during this trial, altering the hospitalized population through a general decline in elective admissions or procedures and an increase in patients with acute respiratory illness. Copper trials aimed at reducing HAI are particularly difficult to design and test due to a major challenge: the need to transform the built environment. Retrofitting an existing operational infrastructure is especially challenging because as in our case, the installation may span several years. This makes it difficult to establish a clear pre-installation and post-installation period, which is more feasible in other HAI trials such as UV light or spray disinfectants. Care was taken in the analysis of this

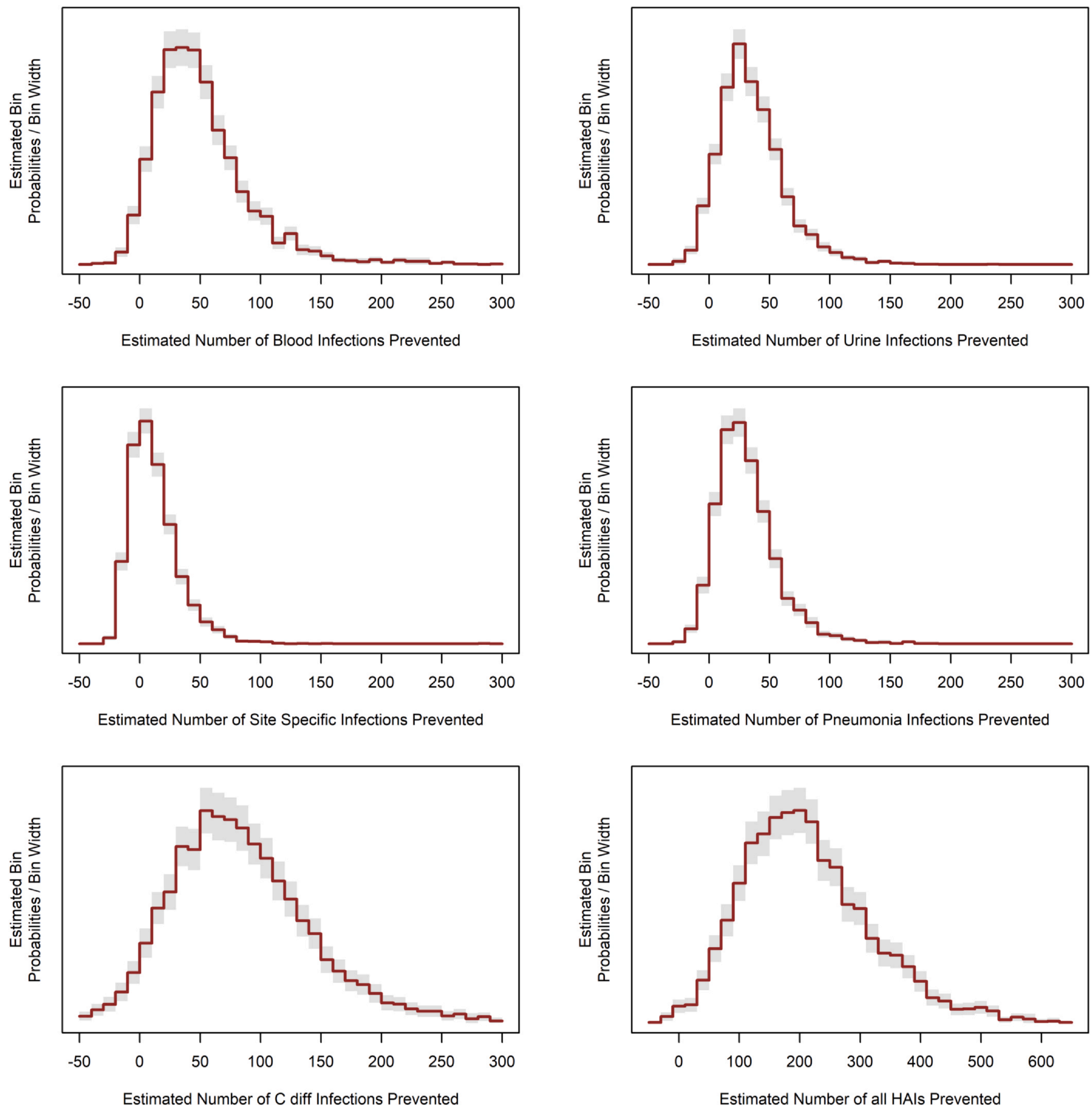

Fig. 4. Histograms of the MCMC samples from the posterior probability distribution for the estimated difference between the counterfactual model predictions and observations, summed over the entire post-install period, for each infection category. This is an estimate of the total number of infections prevented by implementing the copper surface intervention. The x-axis indicates the estimate for the number of infections prevented. The y-axis is the bin probabilities normalized by the bin width, which is comparable to probability density. Thus, taller bin heights indicate increased probability for the corresponding x-axis value. Shades indicate standard errors for the bin heights. MCMC, Markov Chain Monte Carlo.

data by including relevant confounders our model. Parameters such as the COVID-19 pandemic, BDOC, average LOS, and seasonal monthly effects were incorporated. Additionally, the installed amount of each copper component was treated as the intervention variable, rather than relying on a specific time period. Even in randomized trials, such as the one conducted by Salgado et al, the movement of copper surfaces on wheels such (eg, tray tables or beds) along with lack of blinding, can dilute the strengths of the study conclusions even when the results appear effective.[26] While our analysis was designed to account for potential confounding variables, the estimated number of HAIs prevented remained highly uncertain, consistent with findings from other studies. Another trial, a single-site quasi-experimental study at the Sentara Leigh Hospital in Norfolk, Virginia,[27] which used the same copper surface material as our study, showed a significant decline in HAIs following the introduction of solid copper surfaces and copper-infused linens. This study, which incorporated both copper hard surfaces and copper-infused linens, showed significantly greater reductions on HAIs compared to trials that have used copper hard surfaces alone. Additionally, the solid copper surfaces were not a retrofit but were outfitted in a new wing potentially confounding the results. These differences in study design and implementation could help explain the variability and uncertainties observed across various copper trials. Cost of installation, difficulties in retrofitting an active patient care area, maintenance and long-term survival of polymer material in high-impact and high-traffic areas of the hospital can create additional implementation and sustenance challenges.

Limitations of this study, beyond the inherent challenges of real-world pragmatic trials, include a single health care setting and a specific formulation of the copper surface tested. Strengths of this study include the length of HAI data collection, manual chart reviews of every single patient admission, and the advanced statistical modeling. These considerations and disclosures make this study a useful contribution to the field and provide evidence of the effect of self-sanitizing environmental surfaces on HAIs. Although we have included figures highlighting the various types of HAI groups (Fig. 4) and a table (Supplementary Table S2) showcasing the various organisms responsible for the HAIs, our study was not powered to assess the differential effectiveness of copper by organism.

CONCLUSIONS

The CuRE HAI study, a copper surface implementation trial, demonstrated that novel copper components in the patient care environment may have contributed to the prevention of HAIs. However, the wide uncertainty intervals suggest that the magnitude of the intervention's effect is far from established. These findings are consistent with previously published studies involving similar materials, as well as copper surfaces composed of other copper alloys.[25-27] Despite challenges related to implementation and cost, as well as the challenges related to the COVID-19 pandemic, the continuous reduction in microbial and spore burden as shown in our previous studies, along with the probable prevention of at least some HAIs as demonstrated in this trial, support the potential consideration of copper surfaces as an additional tool to fight ongoing battle to reduce HAIs.

APPENDIX A. SUPPLEMENTARY DATA

Supplementary data related to this article can be found at doi:10.1016/j.ajic.2026.02.239.

References

1. Jabłońska-Trypuć A, Makuła M, Włodarczyk-Makuła M, et al. Inanimate surfaces as a source of hospital infections caused by fungi, bacteria and viruses with particular emphasis on SARS-CoV-2. *Int J Environ Res Public Health.* 2022;19:8121.
2. Chaoui L, Mhand R, Mellouki F, Rhallabi N. Contamination of the surfaces of a health care environment by multidrug-resistant (MDR) bacteria. *Int J Microbiol.* 2019;2019:3236526.
3. Otter JA, Yezli S, Salkeld JAG, French GL. Evidence that contaminated surfaces contribute to the transmission of hospital pathogens and an overview of strategies to address contaminated surfaces in hospital settings. *Am J Infect Control.* 2013;41(5_suppl):S6–S11.
4. Kramer A, Schwebke I, Kampf G. How long do nosocomial pathogens persist on inanimate surfaces? A systematic review. *BMC Infect Dis.* 2006;6:130.
5. Porter L, Sultan O, Mitchell BG, et al. How long do nosocomial pathogens persist on inanimate surfaces? A scoping review. *J Hosp Infect.* 2024;147:25–31.
6. Weber DJ, Rutala WA, Miller MB, et al. Role of hospital surfaces in the transmission of emerging health care-associated pathogens: norovirus, *Clostridium difficile*, and *Acinetobacter* species. *Am J Infect Control.* 2010;38(5_suppl 1):S25–S33.
7. Jinadatha C, Quezada R, Huber TW, et al. Evaluation of a pulsed-xenon ultraviolet room disinfection device for impact on contamination levels of methicillin-resistant *Staphylococcus aureus*. *BMC Infect Dis.* 2014;14:187.
8. Jinadatha C, Villamaria FC, Ganachari-Mallappa N, et al. Can pulsed xenon ultraviolet light systems disinfect aerobic bacteria in the absence of manual disinfection? *Am J Infect Control.* 2015;43:415–417.
9. Weaver L, Michels HT, Keevil CW. Survival of *Clostridium difficile* on copper and steel: futuristic options for hospital hygiene. *J Hosp Infect.* 2008;68:145–151.
10. Noyce JO, Michels H, Keevil CW. Potential use of copper surfaces to reduce survival of epidemic meticillin-resistant *Staphylococcus aureus* in the healthcare environment. *J Hosp Infect.* 2006;63:289–297.
11. Karpanen TJ, Casey AL, Lambert PA, et al. The antimicrobial efficacy of copper alloy furnishing in the clinical environment: a crossover study. *Infect Control Hosp Epidemiol.* 2012;33:3–9.
12. Grass G, Rensing C, Solioz M. Metallic copper as an antimicrobial surface. *Appl Environ Microbiol.* 2011;77:1541–1547.
13. Monk AB, Kanmukhla V, Trinder K, Borkow G. Potent bactericidal efficacy of copper oxide impregnated non-porous solid surfaces. *BMC Microbiol.* 2014;14:57.
14. Navarathna T, Chatterjee P, Choi H, et al. Efficacy of copper-impregnated antimicrobial surfaces against *Clostridioides difficile* spores. *Infect Control Hosp Epidemiol.* 2024;46:1–7.
15. Coppin JD, Villamaria FC, Williams MD, et al. Self-sanitizing copper-impregnated surfaces for bioburden reduction in patient rooms. *Am J Infect Control.* 2017;45:692–694.
16. Chatterjee P, Williams MD, Coppin JD, et al. Effectiveness of copper-impregnated solid surfaces on lowering microbial bio-burden levels in an acute care hospital. *Open Forum Infect Dis.* 2020;7:ofaa238.
17. Division of Healthcare Quality Promotion, National Center for Emerging and Zoonotic Infectious Disease, Centers for Disease Control and Prevention. 2017 NHSN Patient Safety Component Manual [Internet]; 2017 [cited December 23, 2016]. Accessed December 23, 2016. ⟨https://www.cdc.gov/nhsn/pdfs/validation/2025/pcsmanual_2025.pdf⟩.
18. Jinadatha C, Villamaria FC, Coppin JD, et al. Interaction of healthcare worker hands and portable medical equipment: a sequence analysis to show potential transmission opportunities. *BMC Infect Dis.* 2017;17:800.
19. R Core Team. R: a language and environment for statistical computing [Internet]. R Foundation for Statistical Computing; 2024. Accessed December 1, 2024. https://www.R-project.org/.
20. Stan Development Team. RStan: the R interface to Stan [Internet]; 2024. Accessed December 1, 2024. ⟨https://mc-stan.org/⟩.
21. Stan Development Team. Stan Reference Manual, version 2.23.2 [Internet]; 2024. Accessed December 1, 2024. ⟨https://mc-stan.org/⟩.
22. Wickham H. *ggplot2: Elegant Graphics for Data Analysis.* 2nd ed Springer International Publishing; 2016:1.
23. Betancourt M. MCMC Visualization Tools [Internet]; 2025. Accessed January 31 2025. https://github.com/betanalpha/mcmc_visualization_tools.
24. Brodersen KH, Gallusser F, Koehler J, et al. Inferring causal impact using Bayesian structural time-series models. *Ann Appl Stat.* 2015;9:247–274.
25. Michels HT, Keevil CW, Salgado CD, Schmidt MG. From laboratory research to a clinical trial: copper alloy surfaces kill bacteria and reduce hospital-acquired infections. *HERD.* 2015;9:64–79.
26. Salgado CD, Sepkowitz KA, John JF, et al. Copper surfaces reduce the rate of healthcare-acquired infections in the intensive care unit. *Infect Control Hosp Epidemiol.* 2013;34:479–486.
27. Sifri CD, Burke GH, Enfield KB. Reduced health care-associated infections in an acute care community hospital using a combination of self-disinfecting copper-impregnated composite hard surfaces and linens. *Am J Infect Control.* 2016;44:1565–1571.