ORIGINAL ARTICLE

The Antimicrobial Efficacy of Copper Alloy Furnishing in the Clinical Environment: A Crossover Study

T. J. Karpanen, PhD;[1] A. L. Casey, PhD;[1] P. A. Lambert, DSc;[2] B. D. Cookson, FRCPath;[3] P. Nightingale, PhD;[4] L. Miruszenko, RGN;[5] T. S. J. Elliott, DSc[5]

OBJECTIVE.   To determine whether copper incorporated into hospital ward furnishings and equipment can reduce their surface microbial load.

DESIGN.   A crossover study.

SETTING.   Acute care medical ward with 19 beds at a large university hospital.

METHODS.   Fourteen types of frequent-touch items made of copper alloy were installed in various locations on an acute care medical ward. These included door handles and push plates, toilet seats and flush handles, grab rails, light switches and pull cord toggles, sockets, overbed tables, dressing trolleys, commodes, taps, and sink fittings. Their surfaces and those of equivalent standard items on the same ward were sampled once weekly for 24 weeks. The copper and standard items were switched over after 12 weeks of sampling to reduce bias in usage patterns. The total aerobic microbial counts and the presence of indicator microorganisms were determined.

RESULTS.   Eight of the 14 copper item types had microbial counts on their surfaces that were significantly lower than counts on standard materials. The other 6 copper item types had reduced microbial numbers on their surfaces, compared with microbial counts on standard items, but the reduction did not reach statistical significance. Indicator microorganisms were recovered from both types of surfaces; however, significantly fewer copper surfaces were contaminated with vancomycin-resistant enterococci, methicillin-susceptible *Staphylococcus aureus*, and coliforms, compared with standard surfaces.

CONCLUSIONS.   Copper alloys (greater than or equal to 58% copper), when incorporated into various hospital furnishings and fittings, reduce the surface microorganisms. The use of copper in combination with optimal infection-prevention strategies may therefore further reduce the risk that patients will acquire infection in healthcare environments.

Prevention of healthcare-associated infection (HCAI) is recognized as an essential element in the safe delivery of health care.[1] Prevention strategies have included many different approaches that range from developing and auditing evidence-based infection control policies to sustained improvements in hygiene practices. Despite these initiatives, HCAIs still result in significant morbidity and mortality, with associated increased costs to patient care.

Environmental hygiene has been regarded as one of the key areas in the prevention of HCAI in hospital and acute care settings.[2,3] The clinical environment may serve as a reservoir and a potential source of pathogens, with microorganisms being transferred to susceptible patients directly from the environment or by the hands of healthcare workers, patients, and visitors.[4-6] Hand hygiene is important in reducing the incidence of HCAI; however, compliance with appropriate practices is suboptimal.[7,8] A reduction in the microbial load in the environment may therefore aid in decreasing transmission of microorganisms within the healthcare environment when applied with other infection-prevention measures, including appropriate hand hygiene.

New technologies, such as those employing hydrogen peroxide vapor (fumigation) and steam cleaning, have been introduced to some hospital-cleaning regimes to support standard hospital-cleaning practices. However, many cleaning methods do not prevent subsequent microbial recolonization

of surfaces, and therefore new technologies that provide a sustained effect, such as antimicrobial-impregnated surface materials, are being explored.[9,10]

It has been well recognized that copper has intrinsic antimicrobial properties with activity against a broad spectrum of microorganisms.[11,12] Copper ions interfere with several microbial metabolic activities and interrupt the integrity of the cellular DNA, the cytoplasmic membrane, and the cell wall.[13,14] Microbial mechanisms to overcome copper toxicity include sequestration of extracellular copper ions, reduced cell permeability, increased efflux from the cell, and intracellular copper-binding proteins.[2] Reduced susceptibility to copper has been demonstrated in a laboratory scenario, but its clinical significance is unclear.[15,16] Because of this antimicrobial activity, the use of copper alloys in various healthcare applications has been explored.

Copper and its alloys have recently been considered for use in the healthcare environment as an antimicrobial surface material, and in 2008, the US Environmental Protection Agency approved the registration of copper and its alloys as antimicrobial materials.[17] However, published studies of copper efficacy in a busy clinical environment or a high-challenge environment have been limited.[18-20] The aim of the present study was to evaluate the efficacy of copper alloys, when incorporated into a wide range of furnishings and fittings, in reducing surface microbial loads in a busy clinical environment. Copper susceptibility of methicillin-resistant *Staphylococcus aureus* (MRSA), methicillin-susceptible *S. aureus* (MSSA), vancomycin-resistant enterococci (VRE), and coliforms recovered from the clinical environment was also evaluated.

METHODS

Clinical Environment

An evaluation of the antimicrobial efficacy of copper incorporated into various furnishings and equipment was undertaken on a busy acute care medical ward at a large university hospital. The study ward was predominantly a Nightingale-

TABLE 1.   Cleaning Frequencies of the Sampled Items and Frequent-Touch Surfaces on the Study Ward

Item	Cleaning frequency
Door push plates	6 times per day
Door pull handles	6 times per day
Door lever handles	6 times per day
Grab rails	6 times per day
Tap handles and sinks	6 times per day
Light pull cords/toggles	6 times per day
Patient overbed tables	6 times per day
Light switches	1 time per day
Electrical socket switches	1 time per day
Toilet seats	Minimum of 6 times per day (increased when visibly contaminated)
Toilet cistern levers	Minimum of 6 times per day (increased when visibly contaminated)
Commodes	After each use
Dressing trolleys	Before and after each use

style ward and had a total of 19 beds. The ward area was separated into an 11-bed area and a 5-bed area by floor-to-ceiling partitioning. These 2 areas were open plan, with no partitioning between the beds. There was also a single-bed side room and a two-bed side room (Figure 1).

Deep cleaning was undertaken on the study ward immediately before the commencement of the trial. This involved cleaning of all the furniture, equipment, and fittings with steam cleaning and chlorine-based detergent. During the study, a member of the domestic staff worked on the unit daily between 7:30 AM and 12:30 PM and between 5:00 PM and 8:00 PM. A standard ward-cleaning schedule (Table 1) was followed in which detergent and hot water were used for general cleaning and chlorine-based detergent (sodium dichloroisocyanurate with 1,000 ppm available chlorine) was used for frequent-touch surfaces, toilet areas, and isolation rooms. The routine ward cleaning was monitored during the course of the study.

Throughout the study, the bed occupancy level was determined. The number of patients infected or colonized with
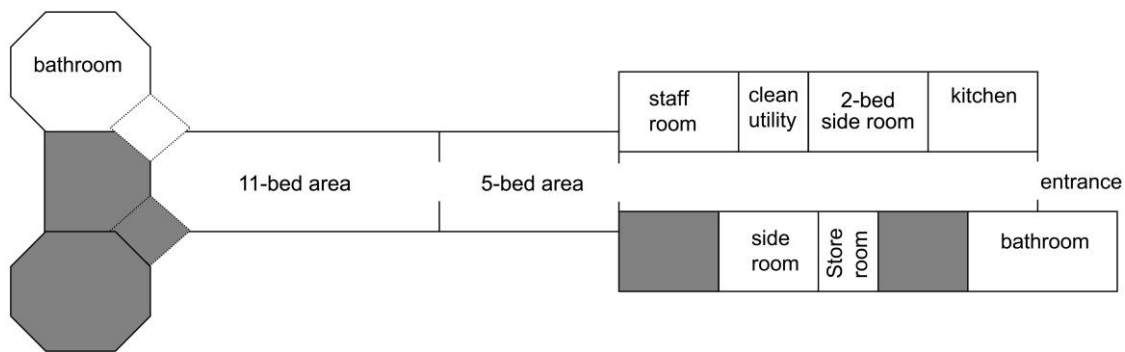

FIGURE 1.   Ward layout. The copper and standard items were located close to each other throughout the ward areas, including the 5-bed and 11-bed open-plan ward areas, 2 side rooms, 2 bathroom/toilet areas, kitchen, staff room, clean utility, and store room.

MRSA or infected with MSSA, VRE, *Clostridium difficile*, or coliform bacteria, as evidenced from routine clinical sampling and MRSA screening, was also recorded on each day of sampling. The staffing levels were also determined. Hand hygiene compliance was monitored throughout the study by the senior nurses on the ward for 20-minute periods using a Lewisham hand hygiene observational tool (a methodology adapted from the UK National Patient Safety Agency "Clean Your Hands" campaign, available at http://www.npsa.nhs.uk), and the audit data were collated for weekly reports. Full ethical committee approval for this study was obtained from the Black Country Research Ethics Committee (07/H1202/100).

Copper Fittings

The copper-containing and standard comparator items and their surface composition are given in Table 2. The copper items were installed close to the standard items throughout the ward, including in the open-plan ward area (divided into 11-bed and 5-bed areas by a partition wall), patient side rooms, patient toilet and/or bathroom areas, kitchen, staff room, clean utility, and store room. The copper items were installed a minimum of 3 months before the commencement of the study. The sampling was performed once per week in rotation, with some of the items only being sampled on alternating weeks. The copper items were compared with equivalent standard items, which were matched on the same ward in terms of location (accessibility) so that their potential for use was similar. The copper and standard items were switched after 12 weeks of sampling, and after a 4-month "wash out" period, the surfaces were sampled for an additional 12 weeks.

Microbiological Sampling

The items were sampled on the same day of each week between 2:00 PM and 5:00 PM (ie, before the afternoon cleaning), which was during visiting hours. Surfaces were sampled in duplicate with a 5 × 5-cm sterile plastic template and a sterile cotton swab moistened in sterile 0.9% (w/v) saline. The swab

was applied firmly 15 times horizontally and 15 times vertically in a zigzag pattern so that the entire area was sampled. The sampling points were selected after a pilot test that determined the areas with the highest level of microbial contamination. For surfaces to which the template could not be applied, including tap handles, light switches, socket switches, door lever handles, and toilet flush lever handles, the whole surface area was sampled with a similar horizontal and vertical swabbing motion, and the surface area was determined. All of the results were adjusted to the sample surface area and were expressed as total aerobic count (in colony-forming units [CFUs]) per centimeters squared. Sink fittings (3 cm into the sink waste) and the light pull cord toggles were sampled with swabs applied in a circular motion 5 times, and the results were presented as CFUs per sample. After sampling, each swab was immediately placed into a sterile bijou bottle containing 2 mL of neutralizing agent (BBL Dey/Engley neutralizing broth; Becton Dickinson).[18,21]

Total Aerobic Count

The swabs in the neutralizing solutions were vortexed for 30 seconds, and 200 μL of the neat solutions (and dilutions where appropriate) were inoculated onto 5% (v/v) horse blood agar plates (BA; bioMérieux). The inoculated agar plates were incubated in air at 37°C for 48 hours, and the total aerobic CFU count was determined. All of the samples were processed within 3 hours after sampling.

Indicator Microorganisms

The presence of MRSA, MSSA, VRE, *C. difficile*, and coliforms (referred to as indicator microorganisms) on the sampled surfaces was determined by inoculating 200 μL of each sample solution onto selective culture media. The selective culture media included chromogenic MRSA and MSSA agar (bioMérieux), bile esculin azide agar (LabM), MacConkey agar no. 3 (LabM), and Brazier's *C. difficile* cefoxitin cycloserine egg yolk (CCEY) agar (LabM) with 5 mg/mL lysosyme

TABLE 2.   Surface Composition of the Copper Items and Matched Control Standard-Material Items

Item	Copper item composition (cu%)	Standard item composition
Door push plate	CuZn37 (63); CuZn30 (70); CuOF (99.95)	Satin anodized aluminium
Door pull handle	CuZn39Pb3 (58); CuSn8 (92)	Satin anodized aluminium
Door lever handle	CuSn8 (92)	Satin anodized aluminium
Grab rail	CuZn30 (70)	Painted steel
Toilet seat	CuOF composite/sprayed coating (~70)	Thermoplastic composite
Toilet cistern lever	Thick copper plate over ZA3 zinc alloy (99.95)	Chromium plated zinc alloy
Commode (seat and arm pads)	CuOF composite/sprayed coating (~70)	Thermoset plastic
Tap handles	CuZn39Pb1Al (60)	Chromium plated brass
Sink waste trap	CuDHP (99.9)	Chromium plated brass
Light switch rocker	CuOF (99.95)	Thermoplastic composite
Light pull-toggle	CuDHP (99.9)	Thermoplastic composite
Socket rocker	CuOF (99.95)	Thermoplastic composite
Dressing trolley	CuZn30 (70)	Stainless steel
Patient overbed table (top surface)	CuDHP (99.9); CuOF composite/sprayed coating (~70)	Plastic laminate over wood

(Sigma-Aldrich) and 1% (v/v) horse blood (Oxoid). The inoculated agar plates were incubated in air at 37°C for 48 hours, except for Brazier's CCEY agar plates, which were incubated at 37°C in anaerobic conditions for 72 hours. The isolates that were recovered from the selective media were further identified using standard laboratory techniques. All indicator microorganisms isolated from the copper and standard surfaces were stored at −20°C for copper susceptibility testing.

Copper Susceptibility Testing

Survival of isolates of VRE, MSSA, MRSA, and coliforms on surfaces was determined by a carrier test using 1-cm^2 coupons of copper or stainless steel. These were first cleaned with acetone and sterilized by autoclaving. Suspensions of isolates were prepared in sterile distilled water from colonies grown on BA for 24 hours. Twenty microliters of suspension containing approximately 1×10^7 CFU was applied to the surface of metal coupons, spread, and allowed to dry for 1 hour in air at 37°C. The coupons were then allowed to stand for an additional 2 hours at room temperature to simulate exposure on surfaces in the hospital ward. The coupons were then placed in 1 mL of Dey/Engley broth containing glass beads and vortex mixed to release microorganisms, and counts of viable microorganisms were performed.

Statistical Analysis

The test results obtained from the surface swab samples were analyzed by nonparametric statistical methods. The total aerobic microorganism counts on the copper and standard hospital surfaces were compared by unpaired analysis (Mann-Whitney U test), and Fisher's exact test was used for the comparison of proportions. The hand hygiene compliance and the staff and bed occupancy levels were compared using the Mann-Whitney U test. Spearman rank correlation was used to compare the hand hygiene compliance rate with the surface contamination.

RESULTS

Clinical Environment

The mean number of staff on duty at the time of sampling (in both study periods) was 2.58 trained nurses (range, 2–4), 2.29 auxiliary nurses (range, 0–3), and 0.54 student nurses (range, 0–2). The staffing level between the 2 study periods did not differ significantly (median difference, 0; 95% confidence interval [CI], −1 to 1; $P = .67$). The median staff hand hygiene compliance rates were 74.1% (range, 50%–95%) and 70.3% (range, 48%–86%) during the first and second phases, respectively. The compliance rate did not differ significantly between the 2 study periods (median difference, −3%; 95% CI, −15% to 9%; $P = .57$).

The mean bed occupancy level (at the time of sampling) was 96.05% in both study periods (range, 89.5%–100% in

weeks 1–12 and 84.2%–100% in weeks 13–24; median difference, 0%; 95% CI, −5.3% to 5.2%; $P = .93$). A total of 29 patients had positive MRSA screening results. The number of patients with positive results ranged from 0 to 4 patients per week. Twenty cases occurred during the first phase of the study, and 9 cases occurred during the second phase of the study. Two of the patients had bacteremia due to MRSA (1 patient in week 6 and 1 patient in week 10), and 2 patients were infected with MSSA (1 patient with bacteremia and 1 patient with an infected wound, both in week 7). Patients with *C. difficile* infection occupied the ward during weeks 1, 3, 4, 5, 6, and 24 (1 patient each week). One patient with *Escherichia coli* infection (urinary tract infection) occupied the ward in the first week. No patients with infection due to VRE were identified during the study period.

Cohort nursing did not occur during the study period. The standard cleaning regime was followed during the study period except during and after an outbreak of diarrhea and vomiting that occurred after samples were obtained in week 18. The whole ward was closed to new admissions, visiting was restricted, and the ward underwent deep cleaning before reopening in week 19.

Total Aerobic Microbial Load on Standard and Copper Surfaces

There were no significant differences in CFU counts for the duplicate samples; therefore, the duplicate CFU counts were analyzed as a mean count per item at each time point. Eight of 14 item types demonstrated significantly lower CFU counts on the copper surfaces than on the standard materials (Figure 2). These included door push plates (median difference, −1.4 CFU/cm^2; 95% CI, −2.0 to −0.8; $P < .0001$), door pull handles (median difference, −2.3; 95% CI, −4.2 to −1.5; $P < .0001$), tap handles (median difference, −9.6; 95% CI, −19.6 to −3.8; $P < .0001$), toilet flush lever handles (median difference, −80.3; 95% CI, −147.7 to −3.9; $P = .012$), copper-sprayed overbed tables (median difference, −3.8; 95% CI, −9.4 to −0.4; $P = .019$), copper-plated overbed tables (median difference, −4.2; 95% CI, −9.0 to −1.4; $P = .001$), dressing trolleys (median difference, −0.4; 95% CI, −0.6 to −0.1; $P = .003$), socket switches (median difference, −6.4; 95% CI, −9.6 to −3.2; $P < .0001$) and light pull cord toggles (median difference, −41.0; 95% CI, −104.0 to −6.0; $P = .019$). The other 6 types of items showed reduced microbial numbers on the copper surfaces, compared with standard items, but these differences did not reach statistical significance.

Indicator Microorganisms on Standard and Copper Surfaces

All 5 types of indicator microorganisms were recovered from both the standard and the copper-containing surfaces; however, significantly fewer copper surfaces were contaminated with VRE, MSSA, and coliforms, compared with the number
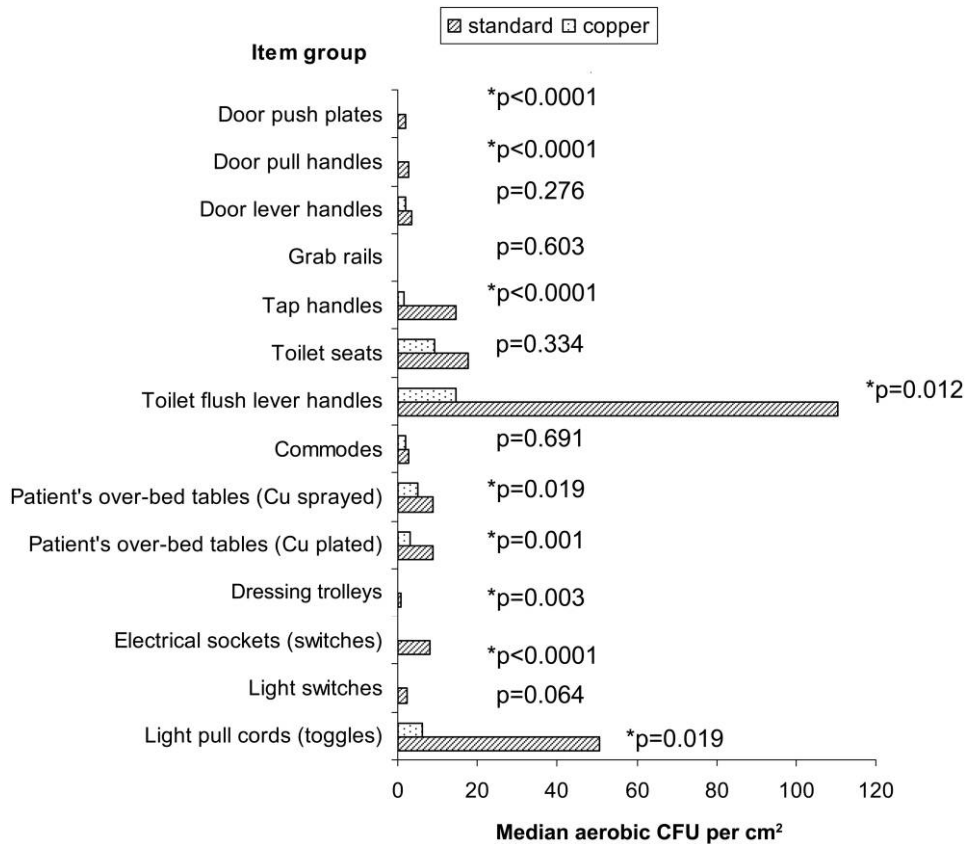
FIGURE 2.   Median aerobic colony-forming unit (CFU) counts per square centimeter on the standard and copper (Cu) items on the ward environment during the 24-week study period. Asterisks indicate statistical significance ($P < .05$).

of standard-material surfaces that were contaminated (Table 3).

Copper Susceptibility

None of the VRE ($n = 1$), MSSA ($n = 7$), MRSA ($n = 13$), or coliform ($n = 19$) isolates showed evidence of resistance to copper. On the metallic copper surface, the number of viable microorganisms was reduced by greater than 3 $\log_{10}$ CFU/mL (ie, there was a reduction in mean viable numbers of microorganisms from 1×10^7 to below 1×10^4 CFU/mL) within the 3-hour test period, compared with less than 1 $\log_{10}$ CFU/mL on the stainless steel surface.

DISCUSSION

Maintaining a clean hospital environment, which is essential for the delivery of safe patient care, is challenging in a busy clinical setting. Cleaning may not always be consistent, and some fomites and surfaces, such as door handles and light switches, may be cleaned less often or less efficiently than others, such as tables, toilet seats, and sinks, because of their design and function.[22] The level of contamination on surfaces that experience frequent hand contact will depend in part on the frequency and effectiveness of hand hygiene.[1] Other areas,

such as toilet seats and flush handles, will also be contaminated more readily via other mechanisms, such as directly through use or via the hands of the users. In addition to the touch surfaces, sink fittings may also be a source for potential infection. For example, handwash basins have been linked to outbreaks of multidrug-resistant *Pseudomonas aeruginosa* and *Acinetobacter baumannii* infections in the healthcare setting.[23,24]

In the current study, microorganisms, including hospital-associated pathogens such as MSSA and MRSA, were recovered from the ward furnishings and fittings despite rigorous application of standard hospital cleaning and a relatively high level of hand hygiene. The highest total aerobic counts were detected in the bathroom areas and included toilet seats, tap handles, and light pull cord toggles. This contamination could reflect the level and nature of use and the associated microbial challenge that these surfaces receive, rather than being indicative of inconsistent cleaning. These levels of microbial contamination, especially on the frequent-touch surfaces, may contribute to the cross-transfer of pathogens, particularly when these surfaces are touched without the application of appropriate hand hygiene. This highlights the need to consider other strategies in addition to cleaning in maintenance

TABLE 3.   Number of Surfaces Contaminated with the Indicator Microorganisms during the 24-Week Study Period (Excluding Sink Fittings)

| | No. (%) of contaminated surfaces | | | |
	Copper surfaces ($n = 559$)	Standard surfaces ($n = 542$)	P	OR (95% CI)
Indicator microorganism				
VRE	1 (0.2)	10 (1.8)	.005	0.095 (0.012–0.748)
MSSA	7 (1.3)	25 (4.6)	.001	0.262 (0.112–0.612)
MRSA	13 (2.3)	20 (3.7)	.217	0.621 (0.306–1.262)
Coliforms	19 (3.4)	44 (8.1)	.001	0.398 (0.229–0.692)
Clostridium difficile	8 (1.4)	2 (0.4)	.108	3.920 (0.828–18.551)

NOTE.   Statistical significance was determined by Fisher's exact test. CI, confidence interval; MRSA, methicillin-resistant *Staphylococcus aureus*; MSSA, methicillin-susceptible *S. aureus*; OR, odds ratio; VRE, vancomycin-resistant enterococci.

of specific standards. High levels of microorganisms, including coliforms, staphylococci, and VRE, were also isolated from sink fittings below the sink waste. These microorganisms could also have acted as a source for environmental contamination. However, this possibility was not investigated in detail in our study.

Copper-containing surfaces may be a beneficial addition to commonly applied cleaning practices, because they provide continuous and persistent antimicrobial action even with surface wear and oxidation.[25] In our study, when copper was incorporated into various fomites, it resulted in a reduction in the microbial load on associated surfaces on a busy acute care medical ward. Most importantly, the surfaces that were frequently touched by the staff, visitors, and patients, such as door push plates, pull handles, and tap handles on the ward, were less contaminated when copper fittings were used than when standard fittings were used. Some items, such as toilet seats, had high numbers of microorganisms on their surfaces when copper was used; however, this may be attributable to more recent or heavier initial contamination rather than to reduced antimicrobial activity. Indeed, the antimicrobial activity of copper is not immediate, and resistance to copper was not observed in this study.

Earlier studies have also demonstrated the so-called halo effect, in which there is reduced microbial contamination in the environment close to antimicrobial surfaces.[10,26] This may enhance the potential for copper to further reduce the opportunity for cross-transfer of microorganisms within the healthcare environment. Copper furnishings may therefore be a beneficial adjunct to standard hospital cleaning and hygiene procedures in reducing environmental contamination and the risk of cross-transfer of microorganisms within the healthcare environment.

Address correspondence to Tom Elliott, DSc, Corporate Division, Queen Elizabeth Hospital, University Hospitals Birmingham National Health Service Foundation Trust, Edgbaston, Birmingham B15 2TH, United Kingdom (tom.elliott@uhb.nhs.uk).

REFERENCES

1. Allegranzi B, Storr J, Dziekan G, Leotsakos A, Donaldson L, Pittet D. The first global patient safety challenge "clean care is safer care": from launch to current progress and achievements. *J Hosp Infect* 2007;65(suppl 2):115–123.

2. UK Department of Health. Winning ways: working together to reduce healthcare associated infection in England. http://www.dh.gov.uk/en/Publicationsandstatistics/Publications/PublicationsPolicyAndGuidance/DH_4064682. 2003. Accessed January 15, 2011.

3. Pratt RJ, Pellowe CM, Wilson JA, et al. Epic2: national evidence-based guidelines for preventing healthcare-associated infections in NHS hospitals in England. *J Hosp Infect* 2007;65(suppl 1):S1–S64.

4. Boyce JM. Environmental contamination makes an important contribution to hospital infection. *J Hosp Infect* 2007;65(suppl 2):50–54.

5. Carling PC, Bartley JM. Evaluating hygienic cleaning in health care settings: what you do not know can harm your patients. *Am J Infect Control* 2010;38:S41–S50.

6. Dancer SJ. The role of environmental cleaning in the control of hospital-acquired infection. *J Hosp Infect* 2009;73:378–385.

7. Gould DJ, Moralejo D, Drey N, Chudleigh JH. Interventions to improve hand hygiene compliance in patient care. *Cochrane Database Syst Rev* 2010:CD005186.

8. Scheithauer S, Oberrohrmann A, Haefner H, et al. Compliance with hand hygiene in patients with methicillin-resistant *Staph-*

ylococcus aureus and extended-spectrum *β*-lactamase-producing enterobacteria. *J Hosp Infect* 2010;76:320–323.

9. Hardy KJ, Gossain S, Henderson N, et al. Rapid recontamination with MRSA of the environment of an intensive care unit after decontamination with hydrogen peroxide vapour. *J Hosp Infect* 2007;66:360–368.

10. Taylor L, Phillips P, Hastings R. Reduction of bacterial contamination in a healthcare environment by silver antimicrobial technology. *J Infect Prevent* 2009;10:6–12.

11. Dollwet HH, Sorenson JRJ. Historic uses of copper compounds in medicine. *Trace Elem Med* 1985;2:80–87.

12. Grass G, Rensing C, Solioz M. Metallic copper as an antimicrobial surface. *Appl Environ Microbiol* 2011;77(5):1541–1547.

13. Santo CE, Lam EW, Elowsky CG, et al. Bacterial killing by dry metallic copper surfaces. *Appl Environ Microbiol* 2011;77: 794–802.

14. Weaver L, Noyce JO, Michels HT, Keevil CW. Potential action of copper surfaces on methicillin-resistant *Staphylococcus aureus.* *J Appl Microbiol* 2010;109:2200–2205.

15. Santo CE, Morais PV, Grass G. Isolation and characterization of bacteria resistant to metallic copper surfaces. *Appl Environ Microbiol* 2010;76:1341–1348.

16. Santo EC, Taudte N, Nies DH, Grass G. Contribution of copper ion resistance to survival of *Escherichia coli* on metallic copper surfaces. *Appl Environ Microbiol* 2008;74:977–986.

17. US Environmental Protection Agency. US Environmental Protection Agency (EPA) registers copper-containing alloy products. http://www.epa.gov/pesticides/factsheets/copper-alloy-products .htm. 2008. Accessed January 17, 2011.

18. Casey AL, Adams D, Karpanen TJ, et al. Role of copper in reducing hospital environment contamination. *J Hosp Infect* 2010;74:72–77.

19. Marais F, Mehtar S, Chalkley L. Antimicrobial efficacy of copper touch surfaces in reducing environmental bioburden in a South African community healthcare facility. *J Hosp Infect* 2010;74: 80–82.

20. Mikolay A, Huggett S, Tikana L, Grass G, Braun J, Nies DH. Survival of bacteria on metallic copper surfaces in a hospital trial. *Appl Microbiol Biotechnol* 2010;87:1875–1879.

21. Wheeldon LJ, Worthington T, Lambert PA, Hilton AC, Lowden CJ, Elliott TS. Antimicrobial efficacy of copper surfaces against spores and vegetative cells of *Clostridium difficile*: the germination theory. *J Antimicrob Chemother* 2008;62:522–525.

22. Carling PC, Von Beheren S, Kim P, Woods C. Intensive care unit environmental cleaning: an evaluation in sixteen hospitals using a novel assessment tool. *J Hosp Infect* 2008;68:39–44.

23. Hota S, Hirji Z, Stockton K, et al. Outbreak of multidrug-resistant *Pseudomonas aeruginosa* colonization and infection secondary to imperfect intensive care unit room design. *Infect Control Hosp Epidemiol* 2009;30:25–33.

24. La Forgia C, Franke J, Hacek DM, Thomson RB Jr, Robicsek A, Peterson LR. Management of a multidrug-resistant *Acinetobacter baumannii* outbreak in an intensive care unit using novel environmental disinfection: a 38-month report. *Am J Infect Control* 2010;38:259–263.

25. Michels HT, Noyce JP, Wilks SA, Keevil CW. Copper alloys for human infectious disease control. In: Program and abstracts of the Materials Science and Technology Conference. Pittsburgh, PA: 2005.

26. Hirsch BE, Attaway H, Nadan R, et al. Copper surfaces reduce microbial burden in out-patient infectious disease practice. In: Program and abstracts of the Interscience Conference on Antimicrobial Agents and Chemotherapy (ICAAC). Boston, MA: American Society for Microbiology, 2010.