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# Role of copper in reducing hospital environment contamination ☆

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**Summary** The environment may act as a reservoir for pathogens that cause healthcare-associated infections (HCAIs). Approaches to reducing environmental microbial contamination in addition to cleaning are thus worthy of consideration. Copper is well recognised as having antimicrobial activity but this property has not been applied to the clinical setting. We explored its use in a novel cross-over study on an acute medical ward. A toilet seat, set of tap handles and a ward entrance door push plate each containing copper were sampled for the presence of micro-organisms and compared to equivalent standard, non-copper-containing items on the same ward. Items were sampled once weekly for 10 weeks at 07:00 and 17:00. After five weeks, the copper-containing and non-copper-containing items were interchanged. The total aerobic microbial counts per $cm^2$ including the presence of 'indicator micro-organisms' were determined. Median numbers of microorganisms harboured by the copper-containing items were between 90% and 100% lower than their control equivalents at both 07:00 and 17:00. This reached statistical significance for each item with one exception. Based on the median total aerobic cfu counts from the study period, five out of ten control sample points and zero out of ten copper points failed proposed benchmark values of a total aerobic count of $<5$ cfu/$cm^2$. All indicator micro-organisms were

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only isolated from control items with the exception of one item during one week. The use of copper-containing materials for surfaces in the hospital environment may therefore be a valuable adjunct for the prevention of HCAIs and requires further evaluation.


## Introduction

Healthcare-associated infections (HCAIs) continue to cause significant morbidity and mortality. Approximately 300 000 HCAIs occur in England per annum, accounting for 5000 deaths.[1] These HCAIs are thought to cost the National Health Service (NHS) in the region of £1 billion each year.[1] It has been variously estimated that between 15% and 30% of HCAIs could be prevented by compliance with infection control practices and appropriate hygiene measures, including hand hygiene.[1,2]

Despite the lack of direct evidence to prove that environmental contaminants are responsible for HCAIs, there is increasing evidence suggesting that the environment may act as a reservoir for at least some of the pathogens causing HCAIs.[3,4] This is of concern as touching such contaminated surfaces may lead to acquisition on the hand and subsequent transfer to other inanimate objects or to patients.[5–8] A framework for setting and measuring cleanliness in the NHS has been developed although this is based primarily on the visual assessment of cleanliness.[9] This measure of cleanliness has been shown to be an unreliable indicator in assessing cleaning efficacy.[10] Indeed, it is well recognised that micro-organisms such as meticillin-resistant *Staphylococcus aureus* (MRSA) are able to persist in the clinical environment for extended durations, and that the presence of such pathogens following terminal cleaning has been demonstrated.[11,12] This may pose a challenge in the fight against HCAIs, particularly as an association between the use of certain antibiotics to treat patients and a corresponding emergence of antimicrobial-resistant staphylococci and Gram-negative bacilli isolated from the environment has been demonstrated.[13]

There are currently no standards for an acceptable environmental microbial load in the healthcare setting. However, it has been proposed that food industry approaches to the assessment of cleanliness be applied in the healthcare environment.[10] Dancer went further in a discussion paper to suggest benchmark values for the numbers of micro-organisms on hand-touch sites in the healthcare setting.[14] Indeed, based on US Department of Agriculture specifications for microbial surface counts on food-processing equipment, it was proposed that an acceptable total aerobic colony count should be $<5$ cfu/cm$^2$.[14,15] In addition, the absence of selected 'indicator organisms' such as *Staphylococcus aureus*, vancomycin-resistant enterococci (VRE), *Clostridium difficile* and Gram-negative bacilli was suggested.[14]

Other approaches to reducing microbial contamination of the environment besides cleaning deserve consideration. Such approaches include the use of hydrogen peroxide vapour decontamination and the installation of antimicrobial surfaces.[16–18] The application of antimicrobial materials for frequent hand-touch surfaces may help to reduce microbial contamination and therefore cross-contamination.[16–18]

Copper has been demonstrated to kill a range of micro-organisms in vitro including *Escherichia coli*, MRSA, *Listeria monocytogenes*, influenza A virus and *C. difficile*.[19–23] In addition, a copper-based hand rub has been developed and has achieved impressive results in vitro.[24] Recently, a study suggested the antimicrobial activity of copper in the clinical environment; further detailed studies are required.[25]

In this investigation, we evaluated for the first time, in a novel cross-over study the effect of copper-containing surfaces on microbial environmental contamination. We also compared in the clinical setting the numbers of micro-organisms detected, with the proposed benchmark values, although they have not been formally accepted.[14]

## Methods

Ethical approval was obtained from the Black Country Research Ethics Committee to conduct an evaluation of the antimicrobial properties of copper alloys in healthcare facilities.

### Clinical protocol

Three copper-containing items; a toilet seat (coated with a pure copper/resin composite, ~70% Cu); a set

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of brass tap handles (60% Cu) and a brass door push plate (70% Cu) were sampled for microbial contamination and compared against equivalent items with plastic, chrome-plated and aluminium surfaces, respectively. This was carried out on on a busy acute medical ward, which included gastroenterology patients. The items were installed at least six months prior to commencement of the study to allow both healthcare workers and domestic staff to become accustomed to the copper-containing fixtures. Each copper-containing item was compared with a standard, non-copper-containing item which was deemed to have equal opportunity for frequency of use. The toilets were located in a patient washroom; the taps were on sinks at each end of the main open ward and the door push plates at the main ward entrance. The domestic staff followed their standard ward-cleaning timetable. This defined schedule was applied between 07:00 and 17:00. It included disinfection of of the taps and door push plates four times both sides of the toilet seats approximately every 2h. Subsequent disinfection was on a request basis following any obvious visual soiling. The same disinfectant [Chlor-clean (sodium dichloroisocyanurate with 1000 ppm available chlorine and detergent), Guest Medical, Edenbridge, UK] and protocol were used for both copper and non-copper-containing items.

## Sampling protocol

Items were sampled once weekly for 10 weeks at 07:00 and 17:00 to determine the numbers of micro-organisms present following quiet and busy time periods, respectively. Each item was sampled in duplicate at each time point, selecting adjacent areas so that no area was sampled twice in any one day. For each toilet seat and door push plate sample, using a 5 cm $\times$ 5 cm sterile plastic template, a sterile nasopharyngeal swab moistened in sterile 0.9% (w/v) saline was firmly applied 15 times horizontally and a further 15 times vertically in a zig-zag pattern so that the entire area was sampled. The swab was rotated while sampling. For the tap handles, a sterile nasopharyngeal swab moistened in sterile 0.9% (w/v) saline was firmly applied six times horizontally and 15 times vertically over a 5 cm $\times$ 2 cm area in the manner outlined above. Each swab was immediately transferred to 3 mL sterile neutralising broth to neutralise any further antimicrobial activity of copper (Difco™ D/E neutralising broth, Difco, BD, Franklin Lakes, NJ, USA).[23] The neutraliser has been evaluated previously against several Gram-positive and Gram-negative bacterial species. The antimicrobial activity of copper was nullified with no toxicological effect on the micro-organisms (unpublished data). Five weeks into sampling, the copper-containing and non-copper-containing items were interchanged by the Hospital's estates department to further exclude any possibility of bias according to preferential use of any particular item based on location.

## Microbiological methods

Each volume of neutralising broth containing single swabs was vortexed for 1 min. For the toilet seat and push plate samples, 200 $\mu$L of neat solution (and, when appropriate, 200 $\mu$L of $10^{-1}$ dilution) was inoculated on to a range of microbiological culture media giving a lower detection limit of 0.6 cfu per $cm^2$ of sampled surface. For the tap handle samples, 300 $\mu$L was inoculated on to each agar plate giving a lower detection limit of 1 cfu per $cm^2$. The total aerobic microbial colony count was determined by inoculation on to blood agar plates (bioMérieux, Basingstoke, UK). In addition, the number of 'indicator' micro-organisms present on the various surfaces sampled was determined. These indicator micro-organisms included meticillin-sensitive *Staphylococcus aureus* (MSSA), MRSA, VRE, *C. difficile* and coliform bacteria.

For the detection of *S. aureus*, each solution was inoculated on to *S. aureus* chromogenic agar (chromID™ *S. aureus*, bioMérieux), for coliform bacteria, cysteine lactose electrolyte deficient agar (CLED agar, bioMérieux) and for enterococci, bile esculin agar (D-Coccosel agar, bioMérieux). Each agar plate was incubated in air at 37 °C and examined after 24 and 48 h. The identity of any presumptive *S. aureus*, coliforms and enterococci was confirmed using standard microbiological tests and the Vitek 2 (bioMérieux). In addition, the Vitek 2 was used to determine the antibiotic susceptibility of staphylococcal isolates. The antibiotic sensitivity of enterococcal isolates was determined using the BSAC disc diffusion method.[26]

For the detection of *C. difficile*, each solution was inoculated on to agar for the selective isolation agar (*Clostridium difficile* agar, bioMérieux); these were then incubated at 37 °C anaerobically and examined after 24 and 48 h. The identity of any presumptive *C. difficile* isolates was confirmed using standard microbiological tests.

The total aerobic count per $cm^2$ and presence of each indicator micro-organism was determined.

## Statistical methods

The median total aerobic count per $cm^2$ for each duplicate set was entered into non-parametric statistical analysis.

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## Results

Bed occupancy on the ward during the two five-week periods was comparable at >98% and cases included only acute medical patients. There were no outbreaks of infection during the study period. In the ten-week period, one patient had *Klebsiella pneumoniae* in sputum samples (week 6). A further patient had *Klebsiella oxytoca* cultured from urine (week 10) and another had *Enterobacter cloacae* in an abdominal drain fluid (week 10). Three patients tested positive for *C. difficile* infection (weeks 1, 5 and 7) and two patients had MSSA wound infections (both week 4).

The median total aerobic cfu counts per $cm^2$ on both the copper-containing toilet seat, set of tap handles and door push plate and their control equivalents over the ten-week period are summarised in Table I. Overall there was no significant difference in total aerobic colony counts on control items at 07:00 compared with 17:00 (median: 3.6 vs 2.1 cfu/$cm^2$ respectively; $P = 0.97$). The median total aerobic cfu count on each copper-containing item as a percentage of the median total aerobic cfu count on each control item was also calculated. Based on median total aerobic cfu counts from the 10 weeks, five out of ten control (toilets seats and tap handles) and zero out of ten copper sample points failed proposed benchmark values.[14] Median numbers of microorganisms harboured by the copper-containing items were between 90% and 100% lower than their control equivalents at both the 07:00 and 17:00 sampling time-points. This reached statistical significance in nine of the ten paired analyses (and in all ten unpaired analyses).

Over the entire study period, MRSA and *C. difficile* were not isolated. Meticillin-susceptible *S. aureus* was isolated from the control door push plate in weeks 2 and 3 of the study, and on the upper and lower surfaces of the control toilet seat during week 6. Vancomycin-resistant *Enterococcus faecium* was isolated from the upper and lower surfaces of the control toilet seat during week 1. Again, *E. coli* was isolated from the upper side of the control toilet seat during weeks 3 and 6 as well as on the lower side of the control toilet seat during week 4. No MSSA, VRE nor *E. coli* were isolated from any of the copper-containing surfaces during the study period. *Citrobacter freundii* was isolated from the control hot tap handle during week 6 and on the copper-containing hot tap handle during week 2.

**Table I** Median total aerobic colony-forming units (cfu) on copper-containing items compared with controls in the clinical setting

| Item | Time sampled | Median cfu count per $cm^2$ (range) | | Median copper cfu count as % of control cfu count (range) | Wilcoxon signed rank test *P*-value | Mann–Whitney *P*-value |
|---|---|---|---|---|---|---|
| | | Control items | Copper items | | | |
| Upper side of toilet seat | 07:00 | 87.6 (9–266.4) | 2.1 (0–38.4) | 6 (0–33) | 0.002[a] | <0.0001 |
| | 17:00 | 64.5 (28.2–254.4) | 1.2 (0–23.4) | 2 (0–15) | 0.002 | <0.0001 |
| Under side of toilet seat | 07:00 | 10.8 (0–101.4) | 0 (0–4.2) | 2 (0–129) | 0.023 | 0.007 |
| | 17:00 | 1.5 (0–121.8) | 0 (0–4.2) | 0 (0–220) | 0.027 | 0.019 |
| Push plate | 07:00 | 1.8 (0–7.8) | 0 (0–0.6) | 0 (0–100) | 0.004[a] | 0.0002 |
| | 17:00 | 0.6 (0–3.6) | 0 (0–1.2) | 0 (0–100) | 0.016 | 0.009 |
| Hot tap handle | 07:00 | 6.6 (0–504) | 0 (0–3) | 10 (0–[b]) | 0.016 | 0.023 |
| | 17:00 | 3 (0–36) | 0 (0–39) | 0 (0–2700) | 0.195 | 0.019 |
| Cold tap handle | 07:00 | 7.5 (0–87) | 0 (0–3) | 0 (0–100) | 0.016[a] | 0.005 |
| | 17:00 | 4.5 (0–51) | 0 (0–3) | 0 (0–100) | 0.016[a] | 0.005 |

[a] A positive cfu count was present on copper surfaces compared with a zero count on standard surfaces.
[b] Paired variables were negatively correlated. For this reason, the Mann–Whitney test was also performed (on all items for completeness).

## Discussion

Contamination of hand contact surfaces may act as an important reservoir for micro-organisms. These

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micro-organisms may then be transmitted via the hands to other inanimate objects or to patients. Although the extent to which environmental contamination is involved in the acquisition of HCAI is unclear, it is increasingly accepted that the environment plays an important role. In addition to standard cleaning, other strategies to reduce microbial contamination of the clinical environment have been evaluated. One such example is the use of hydrogen peroxide vapour decontamination. This method was superior to terminal cleaning for the reduction in environmental MRSA contamination; however, recontamination subsequently occurred.[16,17]

In this current novel study, the role of copper-containing surfaces for the continuous reduction of environmental microbial contamination was assessed. Repeated failures of proposed benchmark values were observed on standard toilet seats at both sampling time-frames.[14] This was despite documented disinfection schedules and trained domestic staff. It is likely that the contamination occurred following each disinfection and this again highlights the need for more continuous protection of commonly used surfaces in the hospital environment. By comparison, no proposed benchmark value failures were observed on the toilet seat coated with a copper composite. This continuous reduction in microbial contamination of toilet seats may be advantageous, particularly when used by patients with enteric pathogens or colonised with resistant micro-organisms such as VRE.

Similarly, whereas median total aerobic counts on control (aluminium) door push plates were low, surface hygiene failures were observed on such items over two weeks with the presence of MSSA. By comparison, the number of micro-organisms isolated from the copper-containing push plates was significantly lower and no indicator micro-organisms were detected. This again demonstrates the antimicrobial activity of copper. Dancer *et al*. demonstrated ~20% hygiene standard failures with door handles on acute surgical wards.[27] It may therefore be desirable to reduce microbial contamination via a continuous method such as with the application of copper.

Proposed benchmark values were exceeded on control chrome-plated ward sink tap handles at 07:00. These results concur with a previous study whereby rates of hygiene failures for tap handles were particularly high both before and after cleaning.[28] Potential contamination of the hands during the hand-washing process is of concern. During only one week there was a hygiene failure involving a copper-containing hot tap handle. It is possible that the micro-organisms detected were deposited immediately prior to sampling. Although copper is antimicrobial, like other antimicrobial substances its activity is not instantaneous. Indeed, it has been reported that in laboratory tests copper has a complete kill time of 30 min for EMRSA-16 when microbial concentrations reflect environmental contamination.[19]

Overall, significantly lower numbers of micro-organisms were recovered from the copper taps during the remaining nine weeks of the trial. This may therefore suggest that it would be advantageous to use brass tap handles.

Unlike the current study, previous studies evaluating the application of antimicrobial surfaces have not used a cross-over approach. Despite the disruption to the clinical environment that this entailed, we considered that the application of a cross-over was vital to overcome many of the potential variables related to the use of the items under investigation. In addition, the study was carried out on only one ward which further reduced potential bias by standardising the microbial challenge to both control and test surfaces.

The results of this trial clearly demonstrate that copper-containing items offer the potential to significantly reduce the numbers of micro-organisms in the clinical environment. However, the use of antimicrobial surfaces should not act as a replacement for cleaning in clinical areas, but as an adjunct in the fight against HCAI.

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**Conflict of interest statement**
None declared.

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