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A UK district general hospital cleaning study: a comparison of the performance of ultramicrofibre technology with or without addition of a novel copper-based biocide with standard hypochlorite-based cleaning

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Abstract

We compared the performance of an ultramicrofibre (UMF)-based system with or without a novel copper-based biocide (CuWB50) with standard cleaning using Actichlor Plus in four hospital wards in a crossover study design, and analysed our results using univariate and multivariate statistics. We measured total viable counts (TVCs) and ATP levels in 10 near-patient sites three times weekly, one hour before and after cleaning. Standard cleaning reduced TVCs further than UMF cleaning with water, but UMF cleaning with CuWB50 produced equivalent TVC reduction. Furthermore we identified a 'residual effect' with UMF+CuWB50, conferring TVC suppression for up to a week after application. ATP results did not correlate with TVCs. We conclude that UMF-based cleaning with CuWB50 results in TVC reductions equivalent to hypochlorite-based standard cleaning, with the added advantages of a residual effect that keeps TVCs lower between cleaning rounds.

Introduction

Adverse media attention has heightened public concern about the standards of cleanliness in hospitals and its perceived effect on healthcare associated infection (HAI) rates. The rise in antibiotic-resistant bacterial infections has been particularly difficult to control and this generates morbidity, mortality, increased healthcare costs, and public anxiety.

The hospital environment contributes to cross-infection (Boyce, 2007; Hota, 2004). The complex nature of the healthcare environment provides numerous transmission opportunities for pathogenic micro-organisms such as meticillin resistant *Staphylococcus aureus* (MRSA) and *Clostridium difficile* (Dancer, 2008; Verity et al, 2001). Furthermore, most pathogenic micro-organisms can contaminate and persist in a viable state in the hospital environment for weeks or months (Kramer et al, 2006).

It is well established that effective hand hygiene practice reduces the spread of bacteria that cause HAIs in hospitals, and the beneficial role of cleaning is also now becoming clear (Dancer, 2009). Effective removal of bacteria from the environment using classical cloth/mop-based cleaning requires disinfectants if pathogens are to be consistently and effectively removed and/or neutralised (Rutala et al, 2007; White et al, 2007).

Microfibre (MF) materials make a significant difference to the effectiveness of surface cleaning (Moore and Griffith, 2006; Nilsen et al, 2002; Wren et al, 2008), and MF mops have been shown to be more effective at microbial removal from surfaces in hospital wards than string mops (Rutala et al, 2007). However, MF cloths and mops become contaminated during cleaning and this can lead to the spread of viable bacteria (Bergen et al, 2009).

We have shown that the novel copper-based biocide CuWB50, which is effective against a wide range of pathogenic bacteria, is, unlike hypochlorite-based disinfectants, also compatible with ultramicrofibre mops and cloths (UMF) (Gant et al. 2007, 2010). Thus, UMF impregnated with CuWB50 should assist in the control of pathogenic bacteria during the cleaning process, and equally importantly, in the subsequent safe handling of used UMF (Gant et al, 2007).

Our previous study demonstrated that cleaning with UMF+CuWB50 reduced total viable (bacterial) counts (TVCs) on hospital surfaces by

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56% compared with a 30% TVC reduction with UMF+water (Hamilton et al, 2010). Interestingly, there were two separate effects of CuWB50; a direct antibacterial effect seen one hour after cleaning and a residual effect observed 23 hours after cleaning (one hour before the next cleaning round) that reduces bacterial levels 'round-the-clock'.

In the present cleaning study we aimed to confirm and extend our previous findings in a different hospital. Thus, we investigated the ability of UMF with or without the addition of CuWB50 (300 ppm) to remove bacteria (assessed by TVCs) and also the cleaning efficacy (assessed using the 3 M Clean-Trace ATP assay) in four working wards at Mayday Healthcare NHS Trust Hospital (Croydon, London) in a crossover design 12-week trial in comparison with standard cleaning with cotton mops and cloths using a hypochlorite-releasing disinfectant product (Actichlor Plus at 1000 ppm of available chlorine).

Materials and methods

Materials

Ultramicrofibre cloths and mops (UMF) were provided by Vikan (UK) Ltd (Swindon, UK). The copper-based biocide CuWB50 was provided by ICICS Ltd (Gant et al, 2007). All microbiological materials were purchased from Oxoid Ltd (Basingstoke, UK).

Laundry processing

UMF were laundered, impregnated with 300 ppm CuWB50 (UMF+CuWB50) and packaged for use by Microncleanan Ltd (Skegness, UK). Electrolux Professional R&D provided a Clarus Controlled W4130H washer-extractor and a specially constructed base frame and re-use tank for the study. Briefly, used UMF were rinsed to open up the fibres and release trapped organisms and soil and were then washed at 71°C for three minutes in accordance with health service guideline HSG(95)18 (1995) (Hall et al, 2009a). Following further rinsing the UMF were then impregnated with CuWB50 and spun at 490 rpm for eight seconds to ensure the cloths contained the correct moisture content for effective cleaning. The UMF+CuWB50 were then packaged in plastic bags and delivered back to Mayday Hospital by a courier service. Clean, dry UMF (also supplied by Microncleanan Ltd) were moistened with water (UMF+water) at Mayday Hospital in the Healthcare Initial laundry. All UMF were transported back to Microncleanan for reprocessing after use. The same set of UMF was used throughout the study and one spare set of ready-to-use UMF were available at Mayday throughout the study. UMF+CuWB50 were used within 72 hours of production. The shelf-life of the packaged UMF+CuWB50 is at least two weeks.

Study design

This study compared the relative ability of ultramicrofibre cloths and mops (UMF) moistened with either water (UMF+water) or copper biocide (UMF+CuWB50; 300 ppm), to remove bacteria from several working ward environments in comparison to standard cleaning with cotton mops and cloths with 1,000 ppm Actichlor Plus (Ecolabs, Swindon, UK).

We assessed four working wards for bacterial contamination and cleanliness. The trial lasted for 12 weeks as shown in Figure 1. Cleaning took place every day. The crossover design aimed to eliminate time- and place-dependent confounding variables in the wards in the multivariate analysis. The Purley wards are a mix of elderly care and medical patients, and the Queens wards are for surgical patients.

Ten defined surfaces were sampled with (i) contact plates to enumerate bacterial levels, described by colony number as TVCs, and (ii) the 3M Clean-Trace system, an ATP bioluminescence assay that acts as a surrogate measure for cleaning efficacy (Cooper et al, 2007). The designated sampling sites were either in the bathroom: bin lid top, towel dispenser top, soap dispenser front, floor under sink, floor under toilet, or in the patient area: floor by bed, over-bed table, door push, locker top, patient's chair arm.

Microbiological sampling

Microbiological sampling was undertaken on Monday, Wednesday and Friday each week one hour before cleaning and one hour after cleaning, at the designated sampling sites. The microbiological sampling regimen was designed to assess TVCs (a count of all bacteria retrieved and capable of colony formation). To obtain the total viable count, irradiated 19.6 cm^2 tryptone soya agar contact plates with neutraliSers (Oxoid Ltd; PO-00262) were used. The contact plate neutralisers were not tested against Actichlor Plus or CuWB50. Each plate was pressed onto a dry sampling site surface for five seconds and the plates were then incubated at 36°C for 48 hours. Bacterial colonies were then counted. TVCs were counted up to 100, as accurate counting at higher densities (recorded as >100, but counted as 100 in statistical analyses) was inaccurate owing to colony fusion.

ATP sampling

The assay was as described by the manufacturer (3M Ltd, Bridgend, UK). Briefly, swabs were removed from their containers and drawn in a defined and consistent pattern (up and down, then side to side while rotating the swab) across a 25 cm^2 area on each sampling site. The swabs were then reinserted into their containers and allowed to react with the reagents in the cuvette for 10 seconds. The swabs were then immediately placed into a hand-held luminometer and the relative light unit (RLU) reading on the display was recorded.

Bacterial contamination of UMF

UMF cloths moistened with water ($n=12$) or CuWB50 (300 ppm; $n=12$) were used to clean adjacent areas (900 cm^2) on bathroom floors before daily standard cleaning. The cloths were folded and

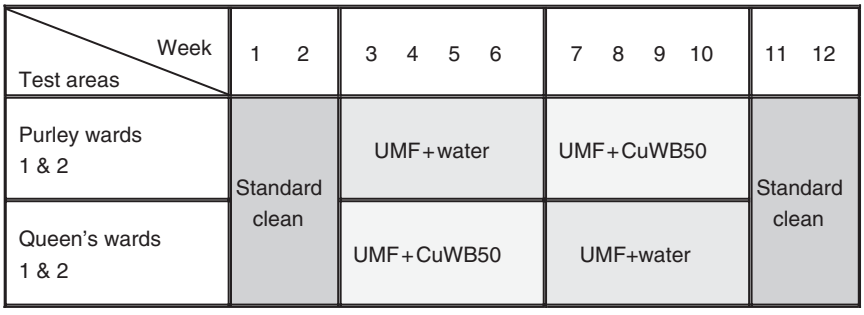

Figure 1. Mayday Hospital cleaning study protocol. The Purley wards are a mix of elderly care and medical patients, the Queens wards are for surgical patients. Standard cleaning used cotton mops and cloths with hypochlorite (as Actichlor Plus 1,000 ppm). Ultramicrofibre mops and cloths (UMF) were moistened with water or CuWB50 (300 ppm). Cleaning took place every day. Sampling with contact plates to determine bacterial levels (TVC) or the 3M Clean-Trace system to determine cleaning efficacy (ATP assay) took place on Monday, Wednesday and Friday every week.

placed individually into plastic stomacher bags and were stored at room temperature for three hours ($n=6$ UMF±CuWB50) or 24 hours ($n=6$ UMF±CuWB50) before processing. To assess bacterial numbers retained by the cloths, 60 ml of phosphate-buffered saline was added to the bags, which were then placed into a Stomacher-80 (Seward Ltd, Worthing, UK) for three minutes at 250 rpm in order to release bacteria from the cloths (Hall et al, 2009a). Three 0.1 ml samples were taken from each bag and ten-fold dilutions were made in quarter strength Ringer's solution (to neutralise CuWB50; Hall et al, 2009b) and then 0.1 ml samples were spread onto tryptone soya agar plates and cultured for 48 hours at 36°C when colony forming units (CFUs) were counted.

Statistical analyses

Univariate analysis

As previously described (Hamilton et al, 2010), we used STATA 9.2 and *p*-values <0.05 were reported as significant. Box-Cox regression was used to assess deviation from normality, median TVCs and RLUs for investigation of univariate trends. For univariate tests of significance the Mann-Whitney test was used for dichotomous variables such as cleaning application (standard cleaning versus UMF+CuWB50 versus UMF+water). We compared median TVCs and RLUs before and after cleaning in order to establish: (a) the existence of a 'residual' effect of UMF+CuWB50 evident before cleaning, (b) the existence of a direct effect of UMF+water and (c) the direct effect of UMF+CuWB50, and (d) the effect of washout evident after stopping application of CuWB50. The 'residual' effect represents the hypothesis that outcomes tend be lower in the UMF+CuWB50W arms before as well as after cleaning, as a result of a cumulative effect of copper residue on the environment.

Multivariate analyses

We used multivariate linear regression to estimate the individual hypothetical components of cleaning represented in the form of a multiplicative model. We did this by means of multivariable regression of the natural logarithms of TVCs and RLUs, enabling us to also control for the effects of several potential confounders inherent in the design of the study (ward, sampling site, day of the week, sequence, and effects of washout). The regression coefficient estimates enabled us to calculate attributable effects, E_i, for each cleaning component *i*. For example, if i=1 for standard cleaning, then E_1 x 100 is the percent drop in geometric mean TVC levels attributable to standard cleaning alone. If i=2 and i=3 for the direct and residual effects of UMF+CuWB50 respectively, then E_2 x 100 is the direct component drop in TVCs due to UMF+CuWB50 *over and above* the effect expected of standard cleaning and E3 x 100 represents the drop in pre-cleaning TVCs resulting from the residual effect of copper biocide. The *overall* effect of cleaning with UMF+CuWB50 is then given by the expression $100 \times [1 - (E_1 \times E_2 \times E_3)]$.

The cleaning effects of primary interest were: (a) standard cleaning (E_1), (b) effects on pre-cleaning TVC (or RLU) levels (the 'residual' effects) (E_3 as a result of UMF+CuWB50 and E_5 as a result of UMF+water), (c) the 'direct' effect seen as the reduction in TVC (and RLU) one hour post-cleaning (E_2 as a result of UMF+CuWB50 and E_4 as a result of UMF+water) and (d) the effect of washout (E_6), evident in the week after stopping cleaning with CuWB50.

We used four modelling approaches to address the problem of having an artificial upper ceiling of 100 colony counts for TVC readings that were actually >100. Approach 1: linear regression on the natural logs of TVC+1 and RLU+1 using the whole dataset (with TVC readings >100 counted as 100); Approach 2: same as approach 1 except that TVCs were only analysed for sites where the 'baseline' median TVC was <100 (i.e. one bathroom site: the soap dispenser front; and four patient area sites: the over-bed table, the door push, the locker top and the patient's chair arm); Approach 3: logistic regression where the outcome was 1 if TVC or RLU were greater than the overall 'baseline' median, and Approach 4: greater than 'baseline' 1st interquartile. We define 'baseline' as those pre-cleaning samples taken in the first two weeks of the study (standard cleaning). We also used multilevel analysis methods on all four approaches to test for the effect of nesting of sampling sites within wards (Twisk, 2006).

Results

Univariate analysis

Figure 2(a) suggests that standard cleaning substantially reduced median TVCs from 100 pre-cleaning to 29 post-cleaning ($p<0.001$), while UMF+water performed poorly (100 to 58; $p<0.001$) relative to standard cleaning or cleaning with UMF+CuWB50 (78 to 30; $p=0.0003$). The UMF+CuWB50 arms were associated with lower pre-cleaning TVC geometric means, suggesting a 'residual' effect due to the copper biocide lingering until after the next pre-cleaning sampling event (Figure 2(a)). In contrast, cleaning with UMF+water was much more successful in reducing median RLU readings relative to standard cleaning, while UMF+CuWB50 did not add any improvement in this respect (Figure 2(b)).

Multivariate analyses

In the multivariate analyses, the results of Approaches 2, 3 and 4 were almost identical to Approach 1 and we therefore present only the

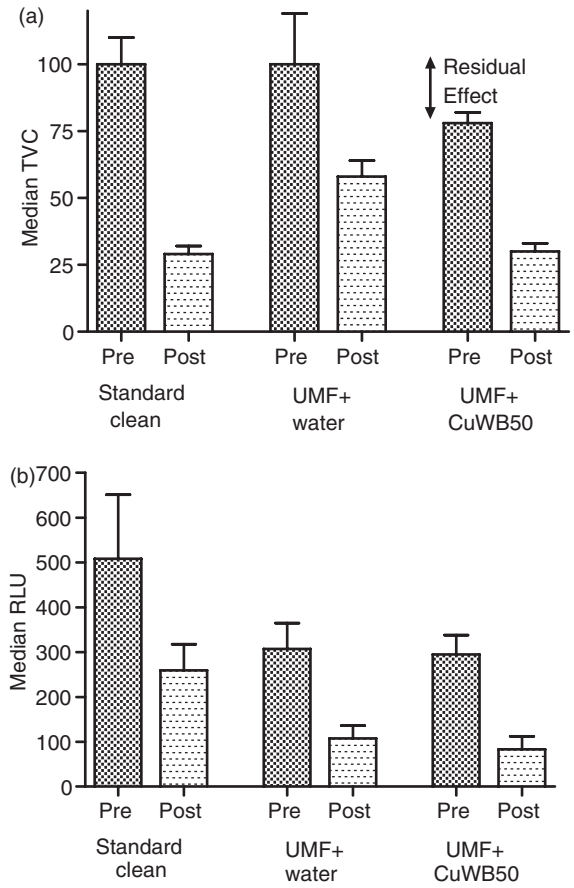

Figure 2. Effect of standard cleaning or cleaning with UMF+water or UMF+CuWB50 on (a) bacterial levels (TVCs) and (b) on cleaning efficacy (ATP assay). The results shown are median TVC (per sampling plate) with upper 95% confidence limit. Pre and Post refer to sampling one hour before and after cleaning. All pre versus all post, $p<0.001$. Pre-cleaning with UMF+CuWB50 versus standard cleaning or UMF+water, $p<0.001$. Post-cleaning with standard cleaning or UMF+CuWB50 vs. UMF+water, $p<0.001$.

Table 1. Multivariate statistical analyses

Cleaning components	TVC	RLU (ATP assay)
Direct effects	% drop (95% CI); *p*-value	% drop (95% CI); *p*-value
Standard cleaning (E_1)	47.7 (41.5, 53.3); <0.001	42.6 (32.9, 50.9); <0.001
UMF (E_4)	−48.3 (−26.2, −74.6); <0.001	33.4 (16.8, 46.7); <0.001
CuWB50 (E_2)	25.2 (11.9, 36.4); 0.001	6.77 (−16.8, 25.6); 0.543
Residual effects		
UMF (E_5)	−21.2 (−38.6, −5.90); 0.005	43.7 (34.1, 51.9); <0.001
CuWB50 (E_3)	19.9 (10.0, 28.7); <0.001	8.02 (−8.02, 21.7); 0.308
Washout (E_6)	12.4 (4.96, 19.3); 0.001	−3.31 (−23.8, 13.8); 0.725
Combined effects		
Standard cleaning	47.7 (41.5, 53.3); <0.001	42.6 (32.9, 50.9); <0.001
UMF (direct)	22.3 (12.8, 30.8); <0.001	61.8 (55.2, 67.4); <0.001
UMF (all)	5.93 (−7.64, 17.8); 0.214	78.5 (74.8, 81.6); <0.001
CuWB50 (direct)	60.9 (52.3, 67.9); <0.001	46.5 (29.6, 59.3); <0.001
CuWB50 (all)	68.7 (63.2, 73.4); <0.001	50.8 (38.4, 60.6); <0.001

CI = confidence interval; RLU = relative light units; TVC = total viable (bacterial) counts.

These data show the attributable effects of the individual cleaning components, independently and beyond the effects of other components and of confounding variables using Approach 1. Negative drops are increases in geometric means. The effects are multiplicative, and do not necessarily 'add up' to make the combined effects (see the Materials and methods and the Results sections for details).

results from Approach 1 (Table 1). There were no significant multilevel effects (nesting of site within ward). UMF+CuWB50 significantly reduced TVC geometric means by 69% ($p<0.001$), attributable to the independent effects of CuWB50 (direct: 25%, $p=0.001$; residual effect: 20%, $p<0.001$), as well as a residual 'washout' anti-bacterial effect of CuWB50 lasting for a week after stopping (12%, $p=0.001$). Cleaning with UMF+water performed worse than standard cleaning, which was consistent with its negative direct and residual effects ($E_4=-48\%$, $p<0.001$ and $E_5=-21\%$, $p=0.005$ respectively), the latter not apparent from the univariate comparisons.

Standard cleaning both significantly reduced ATP geometric means ($E_1=43\%$, $p<0.001$) and UMF+water also had additional benefits with an overall 79% drop ($p<0.001$), attributable to the independent effects of UMF (direct: 33%, $p<0.001$; residual effect: 44%, $p<0.001$). In contrast, there was a consistent lack of direct, residual and washout effects of UMF+CuWB50 on RLUs (Table 1).

Bacterial contamination of UMF

We examined the degree of bacterial contamination in UMF cloths with water or CuWB50 (300 ppm) three hours and 24 hours after they were used for cleaning during the study. The results in Figure 3 show that UMF cloths impregnated with CuWB50 contained significantly fewer viable bacteria than UMF with water at both three hours (85% fewer) and 24 hours (80% fewer) after cleaning.

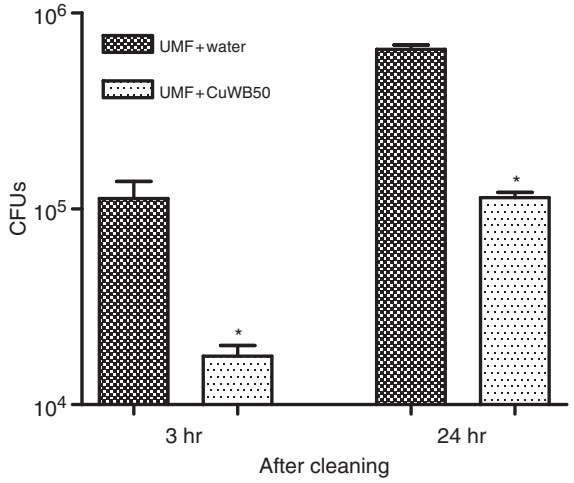

*Figure 3. Bacterial levels in UMF cloths with water or CuWB50 assessed three hours and 24 hours after cleaning. Each bar is mean±SEM colony forming units (CFUs) from six UMF cloths assessed in triplicate. *Two-tailed Mann-Whitney test UMF+CuWB50 versus UMF+water, p<0.0001.*

Discussion

The Mayday Hospital cleaning study compared the effects of ultramicrofibre cloths and mops (UMF) moistened with water or with a novel copper biocide solution (CuWB50, 300 ppm), with standard cleaning using cotton mops and cloths using 1,000 ppm Actichlor Plus, on bacterial contamination (TVCs) and cleaning efficacy (ATP assay) in four working wards over a 12 week period (Figure 1).

The results of univariate analyses shown in Figure 2 show that cleaning with UMF+CuWB50 is as effective as standard cleaning at removing bacteria from surfaces (Figure 2(a)), with the additional benefit of a residual effect observed one hour pre-cleaning (or 23 hours post-cleaning) that keeps bacterial levels lower between daily cleaning rounds. We consider the residual effect to be underestimated since many of the >100 TVC results were from plates that were confluent and most of the pre-clean standard cleaning and UMF+water TVCs were >100, while UMF+CuWB50 cleaning pre-clean had a median of 78 TVCs.

Although specific bacterial speciation was not attempted in this study, TVCs have been shown to be a useful way to assess the effects of cleaning regimes on bacterial contamination as demonstrated in recently published studies and to correlate with MRSA levels (Cooper et al, 2007; White et al, 2007).

The results in Figure 2(b) show that the cleaning efficacy of UMF+water/CuWB50 is significantly greater than standard cleaning. Taking the entire study into consideration, the pre-clean median RLUs with UMF+water/CuWB50 were equivalent to those post-clean with standard cleaning. Several groups have reported that MF and UMF products are very effective at removing dirt or soil from surfaces (Moore and Griffith, 2006; Rutala et al, 2007; Wren et al, 2008), and the present study confirms this view.

Taken together, the TVC and ATP assay results suggest that cleaning with UMF+CuWB50 offers several benefits over standard cleaning with hypochlorite or cleaning with UMF+water. Firstly, removal of bacteria is equivalent to standard cleaning with hypochlorite. Secondly, a residual effect of CuWB50 left on surfaces after cleaning maintains bacterial levels at a lower level 'round-the-clock'. (Ayliffe et al, 1967; Dancer, 2009). Thirdly, the benefit of cleaning efficacy offered by UMF combined with a safe and effective UMF-compatible biocide (unlike hypochlorite-based products; Gant et al, 2010) that rapidly kills most bacteria collected in the UMF (Figure 3). The latter point is supported by the TVC results in Figure 2(a) showing that cleaning with UMF+water is less efficient at removing bacteria than when using UMF+CuWB50.

Finally, this integrated system removes and processes laundry remotely from the hospital thereby eliminating any possibility of re-contamination in house by imperfect systems and lapses in best cleaning practice if the cloths used are not single-use.

The logistical practicability of the integrated cleaning system demonstrated in our previous study (Hamilton et al, 2010) was confirmed by the present study. However, further work will be required to demonstrate that the system is robust and reproducible enough for widespread implementation.

We asked the cleaning staff for their opinions on the use of UMF. The cleaners did not want to stop using UMF with CuWB50 for cleaning, stating that: (1) it left hospital floors and surfaces looking shinier and cleaner than when they were using standard cloths and Actichlor; (2) they liked the UMF cloths and mops with CuWB50 being supplied ready-to-use; and (3) they preferred not having to prepare 1,000 ppm Actichlor Plus for standard cleaning. It is unsurprising that surfaces appeared shinier and cleaner with UMF because they remove more dirt than standard cleaning (Figure 2(b)) which, using 1,000 ppm Actichlor Plus on all surfaces, leaves behind a dull white residue.

These results confirm and extend those of our previous study (Hamilton et al, 2010). This real life hospital implementation study demonstrates overall superior cleaning performance of UMF, which is enhanced with CuWB50, when compared with standard cleaning with hypochlorite.

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Conflict of interests

Dr Hall is a consultant to ICICS plc. Ms Jeanes and Dr Hall were consultants to Healthcare Initial Ltd for this study.

References

Ayliffe GAJ, Collins BJ, Lowbury EJL, Babb JR, Lilly HA. (1967) Ward floors and other surfaces as reservoirs of hospital infection. *Journal of Hygiene* **65**: 515–36.

Bergen LK, Meyer M, H g M, Rubenhagen B, Andersen LP. (2009) Spread of bacteria on surfaces when cleaning with microfibre cloths. *Journal of Hospital Infection* **71**: 132–7.

Boyce JM. (2007) Environmental contamination makes an important contribution to hospital infection. *Journal of Hospital Infection* **65**(**Suppl 2**): 50–4.

Cooper RA, Griffith CJ, Malik RE, Obee P, Looker N. (2007) Monitoring the effectiveness of cleaning in four British hospitals. *American Journal of Infection Control* **35**: 338–341.

Dancer SJ. (2008) Importance of the environment in meticillin-resistant Staphylococcus aureus acquisition: the case for hospital cleaning. *Lancet Infectious Diseases* **8**: 101–13.

Dancer SJ. (2009) The role of environmental cleaning in the control of hospital-acquired infection. *Journal of Hospital Infection* **73**: 378–85.

Gant VA, Jeanes A, Hall TJ. (2010) Response to: Griffith CJ, Dancer SJ. Hospital cleaning: problems with steam cleaning and microfibre. *Journal of Hospital Infection* **74**: 82–4.

Gant VA, Wren MWD, Rollins MSM, Jeanes A, Hickok SS, Hall TJ. (2007) Three novel highly charged copper–based biocides: safety and efficacy against healthcare-associated organisms. *Journal of Antimicrobial Chemotherapy* **60**: 294–9.

Hall TJ, Wren MWD, Jeanes A, Gant VA. (2009a) Decontamination of laundry at low temperature with CuWB50, a novel copper-based biocidal compound. *American Journal of Infection Control* **37**: 478–83.

Hall TJ, Wren MWD, Jeanes A, Gant VA. (2009b) Cytotoxicity of 8 commercially available hand rubs to cultured human skin cells and anti-bacterial activity of Purell and Xgel against MRSA, Acinetobacter and C difficile spores *in vitro*. *American Journal of Infection Control* **37**: 322–6.

Hamilton D, Foster A, Ballantyne L, Kingsmore P, Bedwell D, Hickok SS, Hall TJ, Jeanes A, Coen PG, Gant VA. (2010) Performance of ultramicrofibre cleaning technology with or without addition of a novel copper-based biocide. *Journal of Hospital Infection* **74**: 62–71.

Hota B. (2004) Contamination, disinfection, and cross-colonization: are hospital surfaces reservoirs for nosocomial infection? *Clinical Infectious Disease* **39**: 1182–9.

Kramer A, Schwebke I, Kampf G. (2006) How long do nosocomial pathogens persist on inanimate surfaces? A systematic review. *BMC Infectious Diseases* **6**: 130. doi:10.1186/1471–2334-6-130.

Moore G, Griffith C. (2006) A laboratory evaluation of the decontamination properties of microfibre cloths. *Journal of Hospital Infection* **64**: 379–85.

Nilsen SK, Dahl I, Jorgenson O, Schneider T. (2002) Microfibre and ultramicrofibre cloths, their physical characteristics, cleaning effect, abrasion on surfaces, friction, and wear resistance. *Building Environment* **37**: 1373–8.

Rutala WA, Gergen MF, Weber DJ. (2007) Microbiologic evaluation of microfiber mops for surface disinfection. *American Journal of Infection Control* **35**: 569–73.

Twisk JWR. (2006) *Applied multilevel analysis; Practical guides to biostatistics and epidemiology*. Cambridge University Press: Cambridge.

Verity P, Wilcox MH, Fawley W, Parnell P. (2001) Prospective evaluation of environmental contamination by Clostridium difficile in isolation side rooms. *Journal of Hospital Infection* **49**: 204–9.

White LF, Dancer SJ, Robertson C. (2007) A microbiological evaluation of hospital cleaning methods. *International Journal of Environmental and Health Research* **17**: 285–95.

Wren MWD, Rollins MSM, Jeanes A, Hall TJ, Coen PG, Gant VA. (2007) Removing bacteria from hospital surfaces: a laboratory comparison of ultramicrofibre and standard cloths. *Journal of Hospital Infection* **70**: 265–71.