LIGHTHOUSE
Environmental Infection Prevention®

Clinical Research Guide

American Journal of Infection Control ■■ (2017) ■■-■■

Contents lists available at ScienceDirect

American Journal of Infection Control

journal homepage: www.ajicjournal.org

Major Article

Prospective cluster controlled crossover trial to compare the impact of an improved hydrogen peroxide disinfectant and a quaternary ammonium-based disinfectant on surface contamination and health care outcomes

John M. Boyce MD [a,*], Kerri A. Guercia MT [b], Linda Sullivan RN, CIC [a], Nancy L. Havill MT, MHA, CIC [c], Renee Fekieta PhD [a], Janet Kozakiewicz Pharm D [d], David Goffman Pharm D [d]

[a] *Quality Improvement Support Services, Yale New-Haven Hospital, New Haven, CT*
[b] *Department of Laboratory Medicine, Yale New-Haven Hospital, New Haven, CT*
[c] *Accreditation, Safety and Regulatory Affairs, Yale New-Haven Hospital, New Haven, CT*
[d] *Pharmacy Services, Yale-New Haven Hospital, New Haven, CT*

Key Words:
Disinfectants
Disinfection/*methods
Hydrogen peroxide
Quaternary ammonium
Controlled trial
Surface disinfection
Environmental microbiology
Prospective studies

Background: Quaternary ammonium–based (Quat) disinfectants are widely used, but they have disadvantages.

Methods: This was a 12-month prospective cluster controlled crossover trial. On 4 wards, housekeepers performed daily cleaning using a disinfectant containing either 0.5% improved hydrogen peroxide (IHP) or Quat. Each month, 5-8 high-touch surfaces in several patient rooms on each ward were tagged with a fluorescent marker and cultured before and after cleaning. Hand hygiene compliance rates and antimicrobial usage on study wards were obtained from hospital records. Outcomes included aerobic colony counts (ACCs), percent of wiped surfaces yielding no growth after cleaning, and a composite outcome of incidence densities of nosocomial acquisition and infection caused by vancomycin-resistant enterococci, methicillin-resistant *Staphylococcus aureus*, and *Clostridium difficile* infection. Statistical analysis was performed using χ^2 test, Fisher exact test, Welch test, and logistic regression methods.

Results: Mean ACCs per surface after cleaning were significantly lower with IHP (14.0) than with Quat (22.2) ($P = .003$). The proportion of surfaces yielding no growth after cleaning was significantly greater with IHP (240/500; 48%) than with Quat (182/517; 35.2%) ($P < .0001$). Composite incidence density of nosocomial colonization or infection with IHP (8.0) was lower than with Quat (10.3) (incidence rate ratio, 0.77; $P = .068$; 95% confidence interval, 0.579-1.029).

Conclusions: Compared with a Quat disinfectant, the IHP disinfectant significantly reduced surface contamination and reduced a composite colonization or infection outcome.

Quaternary ammonium–based (Quat) disinfectants are widely used in health care, but they have several disadvantages.[1,2] Recently marketed hydrogen peroxide–based disinfectants with greater antimicrobial potency, so-called improved hydrogen peroxide (IHP) disinfectants,[2,3] have been shown to reduce bacterial contamination of surfaces, and offer an alternative to Quat disinfectants.[3-6] One IHP product containing 0.5% hydrogen peroxide was found to have some activity against *Clostridium difficile* spores; however, it does not have an Environmental Protection Agency (EPA)–registered sporicidal claim.[7] Use of the same product, when combined with high rates of com-

* Address correspondence to John M. Boyce, MD, J.M. Boyce Consulting, LLC, 62 Sonoma Ln, Middletown, CT 06457.
E-mail address: jmboyce69@gmail.com (J.M. Boyce).
Funding/support: Supported by Diversey Care.
Conflicts of interest: JMB is a consultant to 3M Company, Clorox Company, and GOJO Industries, and became a consultant to Diversey Care, Sodexo and PDI, Inc. following completion of the study. He has received research support from GOJO Industries. All others have none to report.

http://dx.doi.org/10.1016/j.ajic.2017.03.010

pliance with recommended cleaning protocols, was associated with reductions in health care–associated infections caused by several multidrug-resistant pathogens.[8] Based on these earlier studies,[3-8] we conducted a quality improvement project to compare the effectiveness of IHP-containing wipes and a Quat disinfectant currently in use on reducing surface contamination and health care outcomes.

METHODS

Study design

A 12-month prospective cluster controlled crossover trial was conducted on 4 patient wards located on 2 campuses of a university-affiliated hospital. On each campus, 2 wards were randomized to have housekeepers continue performing daily and discharge cleaning using the Quat disinfectant (Hyperfect 256; Genesan, Gorham, ME) used in the rest of the hospital, or to perform daily and discharge cleaning using disinfectant wipes containing 0.5% IHP (Oxivir Tb; Diversey Care, Charlotte, NC). Both the IHP ready-to-use wipes and similar dry wipes used to apply the dilutable Quat disinfectant during the trial were made of melt blown polypropylene. During months when study wards were assigned to use the Quat disinfectant, rooms of patients with *C difficile* infection (CDI) were cleaned daily and at discharge with bleach wipes. When study wards were assigned to use the IHP disinfectant, all Quat-based wipes and bleach wipes were removed from the wards, bleach wipes were not used for daily or discharge cleaning of rooms occupied by patients with CDI, and the same IHP disinfectant in solution form was used to clean floors. The study was conducted in a medical intensive care unit (MICU) and its step-down unit on one campus, and on 2 general medical wards on the other campus. After 6 months, the ward assignments were reversed.

During the study, 5-8 high-touch surfaces in a convenience sample of several patient rooms on each of the 4 study wards were marked each month by fluorescent marker and cultured before cleaning, and were checked for the presence or absence of fluorescent marker and cultured again after daily cleaning by housekeepers. Rooms selected for tagging and culturing varied from month to month. High-touch surfaces were considered to have been wiped adequately if the fluorescent marker was removed. High-touch surfaces included bedside rails, remote control module, overbed tables, toilet seats, toilet grab bars, counters, supply cart keyboards, and work stations on wheels. Not all high-touch surfaces were present in all rooms. High-touch surfaces were cultured using 1 agar contact plate per surface on each occasion. All cultures of high-touch surfaces before and after cleaning were performed by a single microbiology laboratory technologist. Housekeepers, who were aware that the study was being conducted, received continued feedback during the study to increase the likelihood that high wipe rates would be maintained.[9]

Microbiologic methods

Cultures of high-touch surfaces were obtained by using Dey-Engley agar contact plates (Remel, Lenexa, KS), which were incubated at 36°C for 48-72 hours, followed by determination of aerobic colony counts (ACCs). ACCs were reported as the number of colony forming units (CFUs) per contact plate (ie, CFUs per high-touch surface). Plates with >200 CFUs per contact plate were classified as having 200 CFUs.

Outcome measures

Microbiologic outcome variables included the mean number of ACCs per high-touch surface and the percent of wiped surfaces yielding no growth after room cleaning. Because high-touch surfaces have sometimes been defined as clean if cultures yielded <2.5 CFUs/cm^2,[4] overall results were also expressed as the proportion of surfaces that yielded <2.5 CFUs/cm^2 (equivalent to <65 CFUs per contact plate).

A health care–related outcome measure represented a composite outcome of incidence densities (expressed as new, nosocomial cases per 1,000 patient days) of patients with a surveillance or clinical culture positive for vancomycin-resistant enterococci (VRE) or methicillin-resistant *Staphylococcus aureus* (MRSA), bloodstream infection caused by VRE or MRSA, and hospital-associated, hospital onset CDI. Surveillance or clinical culture results from patients with a history of colonization or infection by VRE or MRSA were excluded because such data would be unlikely to represent new acquisition (colonization) of these pathogens. Data on the occurrence of nosocomial cases of colonization or infection by target pathogens among patients on study wards were obtained from a TheraDoc database (TheraDoc, Salt Lake City, UT) maintained by the hospital epidemiology program.

Hand hygiene compliance rates on study wards, as determined by a single secret shopper throughout the study period, were obtained from a hospital database. Antimicrobial usage data for study wards (expressed as the number of defined daily doses [DDDs] per 1,000 patient days) were provided by the hospital pharmacy.[10] Antimicrobial agents were divided into 3 main categories: (1) anti–*C difficile* agents, including oral and intravenous metronidazole, oral vancomycin, and rifaximin; (2) agents with activity against MRSA or VRE; and (3) all other antibacterial agents.

Statistical analysis

ACCs after cleaning were excluded from further analysis if fluorescent markers revealed that surfaces had not been wiped or if cultures before cleaning revealed no growth because such surfaces cannot provide information regarding disinfectant efficacy and may overestimate the effectiveness of a disinfectant.[11,12] Our study protocol stipulated that only health care–related outcome data from months when fluorescent marker monitoring revealed that ≥80% of high-touch surfaces tested on a study ward had been wiped would be included in the data analysis, an approach used by others.[8] We assumed that a study in which disinfectants are not applied to a substantial proportion of high-touch surfaces in patient rooms would be unlikely to yield accurate estimates of the potential impact of the disinfectants on health care–related outcomes. Differences in proportions were tested by χ^2 or Fisher exact tests. Mean ACCs per high-touch surface obtained after cleaning on Quat and IHP wards were compared using Welch test. A multiple logistic regression model with a dependent variable of no growth versus ≥1 CFU on surfaces after cleaning included Quat ward vs IHP ward, high-touch surface cultured, and ACC before room cleaning as independent variables. The composite outcome measure of the incidence densities for VRE colonization or infection, MRSA colonization or infection, and CDI on Quat wards and IHP wards and antimicrobial usage data were compared as rates using univariate Poisson models (MedCalc, Ostend, Belgium).

RESULTS

Microbiologic findings

The total number of high-touch surfaces cultured before daily cleaning was 561 on IHP wards and 575 on Quat wards. On the IHP wards, 35 (6.2%) of the surfaces had not been wiped, and 25 (4.5%) yielded no growth before cleaning. On the Quat wards, 30 (5.2%) had not been wiped, and 28 (4.9%) yielded no growth before cleaning. The proportion of ACCs after cleaning that were excluded from further analysis of disinfectant efficacy was similar on IHP wards

Table 1
Number of MRSA, *Clostridium difficile*, and VRE health care outcomes and overall rate of health care outcomes (number of cases per 1,000 Pt-Days) by study ward, during ward months with wipe rate of ≥80%, for improved hydrogen peroxide product versus quaternary ammonium-based product

Ward	Pt-Days	MRSA	*C difficile*	VRE	Total (rate*)
Improved hydrogen peroxide product					
MICU	1,352	12	1	17	30 (22.2)
MICU-SD	4,188	8	2	41	51 (12.2)
Med 1	1,211	0	2	0	2 (1.6)
Med 2	3,990	1	1	1	3 (0.75)
Total	10,741	21 (1.96)*	6 (0.56)*	59 (5.49)*	86 (8.0)
Quaternary ammonium–based product					
MICU	4,208	16	5	45	66 (15.7)
MICU-SD	3,570	8	4	27	39 (10.9)
Med 1	3,082	8	2	4	14 (4.5)
Med 2	630	0	1	0	1 (1.6)
Total	11,490	332 (2.79)*	12 (1.0)*	76 (6.6)*	119 (10.3)

Med 1, general medical ward 1; *Med 2*, general medical ward 2; *MICU*, medical intensive care unit; *MICU-SD*, medical intensive care unit step-down unit; *MRSA*, methicillin-resistant *S aureus*; *Pt-Days*, patient days; *VRE*, vancomycin-resistant enterococci.
*Total number of health care outcomes per 1,000 patient days.

(60/561; 10.7%) and Quat wards (58/575; 10.1%) (χ^2 test, $P = .74$). ACCs after cleaning were available for 500 surfaces on IHP wards and 517 on Quat wards. One surface on an IHP ward that had been wiped was not cultured after cleaning because of patient-related issues. The distribution of types of high-touch surfaces cultured after cleaning that was included in the analysis was similar for IHP and Quat wards (χ^2, $P = .99$). Mean ACC per high-touch surface after cleaning was significantly lower with IHP (14.0 CFUs) than with Quat (22.2 CFUs) ($P = .003$). A logistic regression model revealed that the proportion of surfaces yielding no growth after cleaning was significantly greater with IHP (240/500; 48%) than with Quat (182/517; 35%) ($P < .0001$). If one uses a cutoff of <2.5 CFUs/cm^2 as a definition of a clean surface, 462 of 500 (92.4%) surfaces were clean after use of IHP compared with 457 of 517 (88.4%) after use of the Quat disinfectant ($P = .03$).

Composite health care outcome analysis

Fluorescent marker data on wipe rates were available for 23 of 24 IHP ward months and 22 of 24 Quat ward months. On IHP and Quat wards, the number of months with wipe rates <80% was 7 of 23 (30.4%) and 5 of 22 (22.7%), respectively (Fisher exact test, $P = .74$). Eighty percent or greater of monitored surfaces were wiped during 16 ward months (10,741 patient days) on IHP wards and during 17 ward months (11,490 patient days) on Quat wards. The mean proportion of high-touch surfaces wiped during these per protocol months on IHP and Quat wards was 93.3% and 90%, respectively. The overall composite incidence density measure for per protocol ward months was 8.0 cases per 1,000 patient days on IHP wards compared with 10.3 cases per 1,000 patient days on Quat wards ($P = .068$; incidence rate ratio, 0.77; 95% confidence interval, 0.579-1.029). Incidence density rates were lower on IHP wards for each of the 3 target organisms (Table 1). Use of the IHP disinfectant was associated with lower composite incidence densities on the 2 general medical wards, but not in the MICU or step-down unit (Table 1).

Hand hygiene compliance rates were 95.8% on IHP wards and 95.5% on Quat wards. Usage of anti–*C difficile* agents was nearly twice as high on Quat wards than on IHP wards ($P < .0001$) (Table 2). Similarly, there was significantly greater usage of agents effective against MRSA or VRE ($P = .03$) and of all other antibacterial agents on Quat wards compared with IHP wards ($P = .03$) (Table 2).

Table 2
Antimicrobial usage on units using IHP or Quat disinfectants

Antimicrobial agents	IHP units (10,741 Pt-days), DDD per 1,000 Pt-days	Quat units (11,490 Pt-days), DDD per 1,000 Pt-days
Anti–*Clostridium difficile* agents	85.6	141.4
Anti-MRSA or VRE	95.9	138.0
All other agents	895.3	922.3

DDD, defined daily dose; *IHP*, improved hydrogen peroxide; *MRSA*, methicillin-resistant *Staphylococcus aureus*; *Pt-days*, patient days; *Quat*, quaternary ammonium; *VRE*, vancomycin-resistant enterococci.

DISCUSSION

To our knowledge, this study represents the first prospective, cluster controlled crossover trial comparing a Quat disinfectant with an IHP disinfectant in a real-world health care setting. We found that mean ACCs after cleaning were significantly lower with IHP than with Quat ($P = .003$) and that high-touch surfaces yielded no growth after cleaning with IHP significantly more often than with Quat ($P < .0001$). Furthermore, we found that the incidence density of a composite measure of health care outcomes caused by VRE, MRSA, and *C difficile* was 23% lower in the IHP arm than in the Quat arm when wipe rates were ≥80%; however, the difference did not reach statistical significance ($P = .068$).

Our microbiologic results are consistent with several earlier studies of IHP-based disinfectants which found that such products effectively reduce contamination of inoculated disks and environmental surfaces in health care settings.[3-6,13] The degree of difference in the mean colony counts between the Quat and IHP arms may have been reduced somewhat because of the use of bleach wipes in the rooms of CDI patients on Quat wards. A recent randomized controlled trial of enhanced disinfection measures found that the study arm that used bleach alone for terminal disinfection of rooms yielded lower bacterial counts on surfaces after disinfection than use of a Quat disinfectant.[14] Greater reduction of ACCs after cleaning in the IHP arm of our study is supported by 2 other studies that evaluated the same IHP product used in this study. One study used an in vitro stainless steel disk assay,[3] whereas the other used a new ASTM protocol (E2967-15) to evaluate the effectiveness of wipes containing IHP or Quat.[13] Both studies found that the IHP product was more effective than the Quat disinfectants tested.[3,13] The results of the present study also expand on the findings of other studies which found that Quat disinfectants reduced bacterial counts on surfaces less effectively than disinfectants based on an active oxygen compound, electrolyzed water, or a combination of peracetic acid and hydrogen peroxide.[12,15,16]

During the early months of the study, wipe rates on some study wards were as low as 52%-79%. As a result, those ward months were excluded from per protocol analysis of health care outcomes because it is unlikely that they would provide an accurate assessment of ability of a disinfectant to reduce transmission of health care–associated pathogens. The relatively high proportion of monitored high-touch surfaces that were wiped during per protocol months was most likely because of 2 factors. Housekeepers were aware that a study was being conducted and that their performance was being monitored, which likely led to a Hawthorne effect. Also, housekeepers received regular feedback, which has been shown to be necessary to maintain high wipe rates.[9] We have no reason to suspect that the Hawthorne effect accounted for the different health care outcome rates because mean wipe rates on IHP wards and Quat wards during per protocol months were similar.

The composite health care outcome measure used in our study included patients with no history of VRE or MRSA who either de-

veloped a nosocomial VRE or MRSA bloodstream infection or had a new surveillance or clinical culture positive after admission, representing either newly recognized infection or colonization. Inclusion of new-onset acquisition (colonization) and infections in outcome measures when evaluating the effectiveness of cleaning practices has been recommended in a recent Agency for Healthcare Research and Quality technical brief on environmental cleaning practices.[17] Other investigators[14,18-21] have also included acquisition of pathogens as an outcome measure in studies of environmental decontamination because the thoroughness of room cleaning is as likely, or more likely, to affect acquisition of pathogens than development of infection.

The fact that a 23% reduction in the health care–related outcomes on IHP wards was not statistically significant may have been caused in part by having to exclude a number of ward months from both the IHP and Quat arms, resulting in the per protocol analysis being underpowered to detect a statistically significant difference. However, we cannot exclude the possibility that IHP and Quat disinfectants might yield comparable health care outcome rates in a larger study.

The greater reduction in surface contamination and lower incidence density of health care–related outcomes achieved with the IHP wipes cannot be attributed to differences in the proportion of monitored surfaces that were wiped because the mean percentages of high-touch surfaces wiped on study wards were similar. Because the IHP wipes and wipes used to apply the Quat disinfectant to surfaces were both made of melt blown polypropylene, it seems unlikely that wipe composition would explain differences in effectiveness of the 2 disinfectants. Also, the nearly identical hand hygiene compliance rates on IHP and Quat wards could not explain the lower rate of health care–related outcomes on IHP wards. Although the secret shopper observational method of determining hand hygiene compliance rates is very likely to have overestimated compliance rates,[22] we have no reason to believe that the rates were biased toward IHP or Quat wards.

The higher rate of usage of *C difficile* antimicrobial agents on Quat wards may well have been because of the greater incidence of CDI on Quat wards. Similarly, greater use of agents with activity against MRSA or VRE on Quat wards may have been caused in part by the higher incidence of MRSA- and VRE-related events on those wards. Usage rates of other antimicrobials not used for treatment of CDI, MRSA, or VRE were approximately twice as high in the MICU and step-down unit as on the general medical wards (data not shown). Whether this increased antibiotic pressure, or differences in the frequency with which MRSA or VRE surveillance cultures were obtained during IHP and Quat ward months, made it more difficult to achieve a reduction in health care outcomes by use of an IHP disinfectant in the MICU and step-down unit is not clear.

Our study differs in several respects from an earlier one that compared the impact of a hydrogen peroxide cleaning agent (not a disinfectant) and the same IHP-based disinfectant used in our study on health care outcomes. In that study, Alfa et al[8] found that a high rate (>80%) of compliance with cleaning protocols, and use of the 0.5% IHP-based disinfectant, was associated with a reduction in health care–associated infections caused by MRSA, VRE, and *C difficile*. However, unlike the present trial, the earlier study used data from another hospital as a control, lacked environmental cultures, and did not include analysis of hand hygiene compliance rates or antimicrobial usage.

Of interest, the incidence density of CDI in this study was lower on IHP wards than on Quat wards, even though the 0.5% IHP product used does not have an EPA-registered sporicidal claim. Perhaps this is explained in part by the fact that the IHP disinfectant used has been shown to reduce *C difficile* spores by 2-3 $\log_{10}$.[7] In contrast with the IHP disinfectant used, Quat disinfectants have poor activity against *C difficile* spores.[23-26] It is worth mentioning that even wipes that are not considered sporicidal may result in physical removal of *C difficile* spores,[23] but may also spread *C difficile* spores from one surface to another.[26] IHP-based disinfectants also have several other advantages when compared with Quat disinfectants, including short contact times, the lowest EPA toxicity rating (category IV), lack of reduced efficacy in the presence of organic material, and no significant binding to cloths made of cotton or cellulose, which does occur with Quat-based disinfectants.[2,27,28]

Our study has several limitations, including that it was conducted on only 4 wards in a single hospital. Housekeepers and the microbiology technician were not blinded as to which disinfectant was being used on a study ward. Only 1 Quat disinfectant was compared with 1 IHP-based product. Patient-level antimicrobial agent usage was not performed. Antimicrobial usage was expressed as DDDs per 1,000 patient days according to guidelines current at the time.[10] Recently, it has been recommended that antimicrobial usage be expressed instead as days of therapy (DOTs) per 1,000 patient days.[29] Given the results of a recent study that compared DDDs with DOTs,[30] it seems unlikely that expressing usage as DOTs would change the interpretation of our results. Also, our study did not evaluate other potential confounding variables, including colonization pressure and the frequency with which surveillance cultures were obtained. Such potential confounders would not however have explained the greater reduction of surface contamination achieved in the IHP arm, and the fact that units on each campus were randomly assigned to the study arms and the crossover design of the study should have reduced the likelihood that such potential confounders would have influenced the health care–associated outcomes observed.

In conclusion, our findings and those of others suggest that IHP-based disinfectants are more effective than Quat-based disinfectants in reducing bacterial contamination on surfaces. Our study also suggests that IHP-based disinfectants may be more effective than Quat disinfectants in reducing health care–related outcomes, but the lower rate of health care–associated outcomes observed in the IHP arm of the study did not reach statistical significance. Accordingly, further prospective controlled trials comparing IHP-based disinfectants with Quat-based disinfectants are needed to clarify the relative abilities of IHP and Quat disinfectants to reduce health care–related outcomes.

References

1. Sattar SA. Promises and pitfalls of recent advances in chemical means of preventing the spread of nosocomial infections by environmental surfaces. Am J Infect Control 2010;38(Suppl):S34-40.
2. Rutala WA, Weber DJ. Selection of the ideal disinfectant. Infect Control Hosp Epidemiol 2014;35:855-65.
3. Rutala WA, Gergen MF, Weber DJ. Efficacy of improved hydrogen peroxide against important healthcare-associated pathogens. Infect Control Hosp Epidemiol 2012;33:1159-61.
4. Boyce JM, Havill NL. Evaluation of a new hydrogen peroxide wipe disinfectant. Infect Control Hosp Epidemiol 2013;34:521-3.
5. Cadnum JL, Mana TS, Jencson A, Thota P, Kundrapu S, Donskey CJ. Effectiveness of a hydrogen peroxide spray for decontamination of soft surfaces in hospitals. Am J Infect Control 2015;43:1357-9.
6. Rutala WA, Gergen MF, Sickbert-Bennett EE, Williams DA, Weber DJ. Effectiveness of improved hydrogen peroxide in decontaminating privacy curtains contaminated with multidrug-resistant pathogens. Am J Infect Control 2014;42:426-8.
7. Alfa MJ, Lo E, Wald A, Dueck C, DeGagne P, Harding GK. Improved eradication of Clostridium difficile spores from toilets of hospitalized patients using an accelerated hydrogen peroxide as the cleaning agent. BMC Infect Dis 2010;10:268.
8. Alfa MJ, Lo E, Olson N, MacRae M, Buelow-Smith L. Use of a daily disinfectant cleaner instead of a daily cleaner reduced hospital-acquired infection rates. Am J Infect Control 2015;43:141-6.
9. Rupp ME, Fitzgerald T, Sholtz L, Lyden E, Carling P. Maintain the gain: program to sustain performance improvement in environmental cleaning. Infect Control Hosp Epidemiol 2014;35:866-8.

10. Dellit TH, Owens RC, McGowan JE Jr, Gerding DN, Weinstein RA, Burke JP, et al. Infectious Diseases Society of America and the Society for Healthcare Epidemiology of America guidelines for developing an institutional program to enhance antimicrobial stewardship. Clin Infect Dis 2007;44:159-77.
11. Moore G, Smyth D, Singleton J, Wilson P. The use of adenosine triphosphate bioluminescence to assess the efficacy of a modified cleaning program implemented within an intensive care setting. Am J Infect Control 2010;38:617-22.
12. Carling PC, Perkins J, Ferguson J, Thomasser A. Evaluating a new paradigm for comparing surface disinfection in clinical practice. Infect Control Hosp Epidemiol 2014;35:1349-55.
13. Sattar SA, Bradley C, Kibbee R, Wesgate R, Wilkinson MA, Sharpe T, et al. Disinfectant wipes are appropriate to control microbial bioburden from surfaces: use of a new ASTM standard test protocol to demonstrate efficacy. J Hosp Infect 2015;91:319-25.
14. Anderson DJ, Chen LF, Weber DJ, Moehring RW, Lewis SS, Triplett PF, et al. Enhanced terminal room disinfection and acquisition and infection caused by multidrug-resistant organisms and Clostridium difficile (the Benefits of Enhanced Terminal Room Disinfection study): a cluster-randomised, multicentre, crossover study. Lancet 2017;389:805-14.
15. Dharan S, Mourouga P, Copin P, Bessmer G, Tschanz B, Pittet D. Routine disinfection of patients' environmental surfaces. Myth or reality? J Hosp Infect 1999;42:113-7.
16. Meakin NS, Bowman C, Lewis MR, Dancer SJ. Comparison of cleaning efficacy between in-use disinfectant and electrolysed water in an English residential care home. J Hosp Infect 2012;80:122-7.
17. Leas BF, Sullivan N, Han JH, Pegues DA, Kaczmarek JL, Umscheid CA. Environmental cleaning for the prevention of healthcare-associated infections. Rockville (MD): Agency for Healthcare Research and Quality; 2015. Technical brief No. 22. AHRQ Publication No. 15-EHC020-EF.
18. Hayden MK, Bonten MJ, Blom DW, Lyle EA, van de Vijver DA, Weinstein RA. Reduction in acquisition of vancomycin-resistant Enterococcus after enforcement of routine environmental cleaning measures. Clin Infect Dis 2006;42:1552-60.
19. Datta R, Platt R, Yokoe DS, Huang SS. Environmental cleaning intervention and risk of acquiring multidrug-resistant organisms from prior room occupants. Arch Intern Med 2011;171:491-4.
20. Passaretti CL, Otter JA, Reich NG, Myers J, Shepard J, Ross T, et al. An evaluation of environmental decontamination with hydrogen peroxide vapor for reducing the risk of patient acquisition of multidrug-resistant organisms. Clin Infect Dis 2013;56:27-35.
21. Salgado CD, Sepkowitz KA, John JF, Cantey JR, Attaway HH, Freeman KD, et al. Copper surfaces reduce the rate of healthcare-acquired infections in the intensive care unit. Infect Control Hosp Epidemiol 2013;34:479-86.
22. Srigley JA, Furness CD, Baker GR, Gardam M. Quantification of the Hawthorne effect in hand hygiene compliance monitoring using an electronic monitoring system: a retrospective cohort study. BMJ Qual Saf 2014;23:974-80.
23. Rutala WA, Gergen MF, Weber DJ. Efficacy of different cleaning and disinfection methods against Clostridium difficile spores: importance of physical removal versus sporicidal inactivation. Infect Control Hosp Epidemiol 2012;33:1255-8.
24. Rutala WA, Weber DJ, Healthcare Infection Control Practices Advisory Committee. Guideline for disinfection and sterilization in healthcare facilities, 2008. 2008. Available from: https://www.cdc.gov/hicpac/pdf/guidelines/Disinfection_Nov_2008.pdf. Accessed March 31, 2017.
25. Fraise A. Currently available sporicides for use in healthcare, and their limitations. J Hosp Infect 2011;77:210-2.
26. Cadnum JL, Hurless KN, Kundrapu S, Donskey CJ. Transfer of Clostridium difficile spores by nonsporicidal wipes and improperly used hypochlorite wipes: practice + product = perfection. Infect Control Hosp Epidemiol 2013;34:441-2.
27. Engelbrecht K, Ambrose D, Sifuentes L, Gerba C, Weart I, Koenig D. Decreased activity of commercially available disinfectants containing quaternary ammonium compounds when exposed to cotton towels. Am J Infect Control 2013;41:908-11.
28. Boyce JM, Sullivan L, Booker A, Baker J. Quaternary ammonium disinfectant issues encountered in an environmental services department. Infect Control Hosp Epidemiol 2016;37:340-2.
29. Barlam TF, Cosgrove SE, Abbo LM, MacDougall C, Schuetz AN, Septimus EJ, et al. Implementing an Antibiotic Stewardship Program: guidelines by the Infectious Diseases Society of America and the Society for Healthcare Epidemiology of America. Clin Infect Dis 2016;62:e51-77.
30. Wieczorkiewicz JT, Lopansri BK, Cheknis A, Osmolski JR, Hecht DW, Gerding DN, et al. Fluoroquinolone and macrolide exposure predict Clostridium difficile infection with the highly fluoroquinolone- and macrolide-resistant epidemic C. difficile strain BI/NAP1/027. Antimicrob Agents Chemother 2015;60:418-23.

Boyce *Antimicrobial Resistance and Infection Control* (2016) 5:10
DOI 10.1186/s13756-016-0111-x

Antimicrobial Resistance and Infection Control

REVIEW Open Access

Modern technologies for improving cleaning and disinfection of environmental surfaces in hospitals

John M. Boyce

Abstract

Experts agree that careful cleaning and disinfection of environmental surfaces are essential elements of effective infection prevention programs. However, traditional manual cleaning and disinfection practices in hospitals are often suboptimal. This is often due in part to a variety of personnel issues that many Environmental Services departments encounter. Failure to follow manufacturer's recommendations for disinfectant use and lack of antimicrobial activity of some disinfectants against healthcare-associated pathogens may also affect the efficacy of disinfection practices.

Improved hydrogen peroxide-based liquid surface disinfectants and a combination product containing peracetic acid and hydrogen peroxide are effective alternatives to disinfectants currently in widespread use, and electrolyzed water (hypochlorous acid) and cold atmospheric pressure plasma show potential for use in hospitals. Creating "self-disinfecting" surfaces by coating medical equipment with metals such as copper or silver, or applying liquid compounds that have persistent antimicrobial activity surfaces are additional strategies that require further investigation.

Newer "no-touch" (automated) decontamination technologies include aerosol and vaporized hydrogen peroxide, mobile devices that emit continuous ultraviolet (UV-C) light, a pulsed-xenon UV light system, and use of high-intensity narrow-spectrum (405 nm) light. These "no-touch" technologies have been shown to reduce bacterial contamination of surfaces. A micro-condensation hydrogen peroxide system has been associated in multiple studies with reductions in healthcare-associated colonization or infection, while there is more limited evidence of infection reduction by the pulsed-xenon system. A recently completed prospective, randomized controlled trial of continuous UV-C light should help determine the extent to which this technology can reduce healthcare-associated colonization and infections.

In conclusion, continued efforts to improve traditional manual disinfection of surfaces are needed. In addition, Environmental Services departments should consider the use of newer disinfectants and no-touch decontamination technologies to improve disinfection of surfaces in healthcare.

Keywords: Disinfection, Disinfectants, Cleaning, Ultraviolet light, UV-C, Hydrogen peroxide vapor

Background

In recent years, there is an increasing consensus that improved cleaning and disinfection of environmental surfaces is needed in healthcare facilities [1–4]. Experts generally agree on a number of areas, including the fact that careful cleaning and/or disinfection of environmental surfaces, daily and at time of patient discharge, are essential elements of effective infection prevention programs. Moreover, when disinfectants are used, they must be used appropriately to achieve the desired effects. However, there are a number of areas of disagreement and controversy regarding best practices for cleaning and disinfection of environmental surfaces. Some experts favor physical removal of microorganisms using only a detergent solution [3]. Other individuals believe that manual disinfection of surfaces using currently available disinfectants is adequate, and that newer approaches to disinfection are not necessary.

The purpose of this article is to summarize the many factors that affect standard cleaning and disinfection practices and to discuss modern technologies that can supplement traditional cleaning and disinfection methods.

Correspondence: jmboyce69@gmail.com
J.M. Boyce Consulting, LLC, 62 Sonoma Lane, Middletown, CT 06457, USA

Personnel-related issues

Multiple studies have shown that manual cleaning and disinfection of surfaces in hospitals is suboptimal. In many facilities, only 40 to 50 % of surfaces that should be cleaned are wiped by housekeepers [5]. In addition, observational methods combined with use of adenosine triphosphate (ATP) bioluminescence have shown that individual housekeeper performance varies considerably [6]. One study found variations among housekeepers in the amount of time spent cleaning surfaces, the number of wipes used in each room, and the level of cleanliness achieved [6]. Specialized cleaning teams that included infection control personnel have been shown to reduce *C. difficile* surface contamination more effectively than routine housekeepers [7]. Personnel turnover among Environmental Services departments is a significant problem [8, 9], which may reach 30 to 50 % in some facilities. As a result, shortages in Environmental Services personnel were reported by more than 50 % of hospitals in a recent survey conducted in the United States [10]. Among housekeepers and nursing personnel, there is often confusion about who is responsible for cleaning various surfaces and equipment [11, 12].

Issues related to disinfection protocols and practices

In addition to the above personnel-related issues, there are many other factors that can potentially have adverse effects on the efficacy of traditional cleaning and disinfection practices. The type of surface being cleaned or disinfected can affect the completeness with which bacteria are removed. For example, Ali et al. found that the type of material from which bed rails were made affected how well they could be cleaned by microfiber cloths, and that bacteria were removed more effectively by antibacterial wipes than by microfiber [13]. Disinfectants may be applied using inadequate contact times. Failure of housekeepers to use an adequate number of wipes per room can result in poor cleaning of surfaces [6]. Use of wipes without sufficient antimicrobial activity against target pathogens can result in poor disinfection of surfaces and can lead to spread of pathogens from one surface to another [14, 15]. Binding of quaternary ammonium disinfectants to cloths made of cotton or wipes containing substantial amounts of cellulose may reduce the antimicrobial efficacy of the disinfectant [16, 17]. At least one laboratory-based study has shown that detergent wipes have variable ability to remove pathogens from surfaces, and may in fact transfer pathogens between surfaces [18].

Inappropriate over-dilution of disinfectant solutions by housekeepers or by malfunctioning automated dilution systems may result in applying disinfectants using inappropriately low concentrations [9, 17]. For example, an investigation of housekeeping practices at a large teaching hospital included an audit of 33 automated disinfectant dispensing stations that mix concentrated disinfectant with water to yield a desired in-use quaternary ammonium concentration of 800 ppm [17]. Quaternary ammonium concentrations of solutions dispensed were tested using commercially-available test strips. The audit revealed that several dispensing stations yielded solutions with less than 200 ppm, approximately 50 % of stations delivered solutions with 200 to 400 ppm. An investigation revealed several flaws in the dispensing system. Inexpensive test strips and more complicated titration kits are available to monitor quaternary ammonium concentrations of disinfectants.

Contamination of disinfectant solutions can occur, particularly if recommendations for their use are not followed [19–21]. For example, Kampf et al. recently reported that 28 buckets from 9 hospitals contained surface-active disinfectants (e.g., quarternary ammomium solutions) that were contaminated with *Achromobacter* or *Serratia* strains [21]. Buckets and roles of wipes had not been handled according to manufacturer recommendations. In studies that involved culturing high-touch surfaces in patient rooms before and shortly after housekeepers had performed routine cleaning, we found that cultures obtained from several surfaces in one room after cleaning yielded large numbers of *Serratia* and smaller numbers of *Achromobacter* which were not present before cleaning [Fig. 1] [20]. The housekeeper's bucket of quaternary ammonium-based disinfectant contained 9.3×10^4 CFUs/ml of gram-negative bacilli (mostly *Serratia marcescens* and fewer numbers of *Achromobacter xylosoxidans*). Pulsed-field gel electrophoresis demonstrated that *Serratia* isolates recovered from the disinfectant were the same strains as those recovered from surfaces in the patient room. Genome sequencing of one of the *Serratia* strains by collaborating investigators revealed that it contained four different *qac* resistance genes that permitted the organism to grow and survive in the disinfectant (unpublished data). If

Fig. 1 Contact agar plate cultures showing bacterial colonies recovered from a patient's overbed table before (*left*) and after (*right*) the surface was cleaned by a housekeeper using contaminated quaternary ammonium disinfectant. Colonies on right are *Serratia marcescens* and *Achromobacter xylosoxidans*

disinfectant contamination is suspected, a sample of the product can be used to inoculate a broth medium or solid agar containing neutralizers effective against the active agent(s) in the disinfectant solution.

Numerous studies have found that standard manual cleaning or disinfection of surfaces can reduce, but often does not eliminate, important pathogens such as *C. difficile,* staphylococci including methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant enterococci (VRE), and multi-drug-resistant *Acinetobacter* [7, 22–28]. Failure to adequately disinfect patient rooms at the time of hospital discharge contributes to the increased risk of acquisition of resistant pathogens among patients admitted to a room where the prior room occupant was colonized or infected with a multidrug-resistant pathogen [29–31].

Monitoring housekeeping practices

In order to improve standard cleaning and disinfection practices, it is recommended that the practices of housekeepers be monitored and that they receive feedback regarding their performance. However, monitoring of housekeeper performance is often not performed as frequently as needed, if at all [10]. Recently, fluorescent marking systems (Fig. 2) and ATP bioluminescence assays (Fig. 3) have proven useful for evaluating cleaning practices and providing housekeepers with feedback [32, 33]. Unfortunately, such objective means of monitoring the adequacy of cleaning/disinfection practices are not routinely used in many facilities [10]. Perhaps the lack of monitoring of housekeepers is due in part to the fact that monitoring activities can be time-consuming and must be conducted on an ongoing basis in order to be effective [34].

Given the multitude of challenges to achieving and maintaining adequate cleaning and disinfection in healthcare facilities, there is a need to consider the use of modern technologies designed to improve disinfection of surfaces in hospitals. New technologies fall into several categories, including: (A) new liquid surface disinfectants, (B) improved methods for applying disinfectants, (C) self-disinfecting surfaces, (D) light-activated photosensitizers, and (E) no-touch (automated) technologies.

New liquid disinfectants

New disinfectants that are currently available or under development include improved hydrogen peroxide liquid disinfectants, peracetic acid-hydrogen peroxide combination, electrolyzed water, cold atmospheric pressure plasma, and polymeric guanidine. Several improved hydrogen peroxide disinfectants have been shown to be effective one-step cleaner/disinfectant agents that significantly reduce bacterial levels on surfaces [35–38]. In one study, use of a product containing 0.5 % (weight/volume) improved hydrogen peroxide was associated with fewer healthcare-associated infections when compared to an existing cleaning product, although all potential confounding variables were not analyzed [38]. Improved hydrogen peroxide liquid disinfectants can also be used to reduce contamination by multidrug-resistant pathogens on soft surfaces such as bedside curtains [14, 39]. Several of the improved hydrogen peroxide disinfectants also have activity against norovirus surrogate viruses, although they are not as potent as sodium hypochlorite (bleach) solutions [40]. These newer disinfectants have Environmental Protection Agency (EPA) safety rating of category IV (housekeepers do not need to wear any personal protective equipment while using these products).

A new sporicidal disinfectant that contains both peracetic acid and hydrogen peroxide has been shown to reduce bacterial levels on surfaces to a greater degree than a quaternary ammonium disinfectant in one study, and reduced contamination by *C.difficile*, MRSA, and VRE as effectively as sodium hypochlorite in another study [41, 42]. The product has a smell similar to vinegar that may be of concern when it is initially

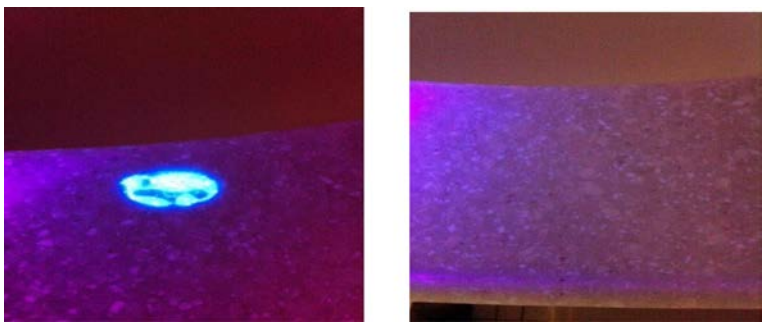

Fig. 2 Photographs of a fluorescent marker visible with a "black light" on a high touch surface before cleaning (*left*), and absence of the fluorescent marker after cleaning was performed (*right*)

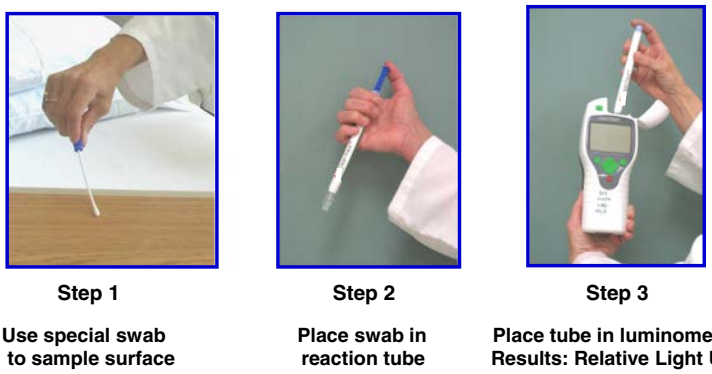

Fig. 3 Three steps of an ATP bioluminescence assay for monitoring cleanliness of surfaces. Step 1: a special swab is used to sample the surface. Step 2: the swab is placed in a reaction tube and shaken for 10–15 s. Step 3: the reaction tube is placed in a luminometer and a result is reported as relative light units (RLUs). The higher the RLU value, the greater the amount of ATP detected on the surface

introduced. The combination product gives hospitals a potential alternative to sodium hypochlorite when a sporicidal disinfectant is needed.

Electrolyzed water (hypochlorous acid) disinfectant is produced by passing current through a solution of water and salt [43–45]. This promising disinfectant was shown to reduce bacterial levels on surfaces near patients to greater degree than a quaternary ammonium disinfectant in one study [43]. In another study, an electrolyzed water disinfectant significantly reduced MRSA, VRE and *C. difficile* spores in in-vitro experiments, and significantly reduced aerobic bacteria and *C. difficile* spores when sprayed onto medical equipment [44]. Spraying equipment was simple, required only approximately 15 s per application, and could be left to dry without wiping. One group of investigators found that electrolyzed water effectively reduced the number of aerobic bacteria (including staphylococci) on near-patient surfaces, but for reasons not well understood, appeared to allow regrowth of staphylococci within 24 h of application [45]. Further studies of this phenomenon are warranted. Electrolyzed water has the advantage of not leaving any toxic residues on surfaces. Issues related to stability of such products and logistic issues related to its use require additional study.

Cold-air atmospheric pressure plasma systems are being investigated for possible use as surface disinfectants in healthcare facilities [46–48]. In laboratory studies, the reactive oxygen species generated by these systems have bactericidal activity against a variety of pathogens, with variable activity against *C. difficile* spores [48]. Much more experience with cold-air atmospheric pressure plasma systems is needed to determine the practicality, efficacy and safety of using such systems in hospital settings. A novel nebulized solution of polymeric guanidine has been shown in one study to have antimicrobial activity against several healthcare-associated pathogens, and may warrant further investigation [49].

New methods for applying disinfectants

Microfiber cloths or mops and ultramicrofiber cloths are among the relatively newer methods for applying liquid disinfectants to surfaces [50–54]. Some studies have shown increased cleaning efficacy of microfiber or ultramicrofiber cloths compared to standard cotton cloth or mops [51, 55]. However, it appears that all microfiber wipes are not equally effective [50]. Furthermore, if not used properly, there is some evidence that they may actually spread bacteria to other surfaces [53, 54]. When using microfiber cloths or mops, is important to know that the durability of these products is adversely affected by hypochlorite and high temperatures used during laundering and drying, and that their performance may decrease after multiple washings. One of the advantages of microfiber over cotton cloths is that microfiber is less likely than cotton cloths to bind quaternary ammonium disinfectants [16, 17]. However, presently, it is not clear how much the lower binding of microfiber cloths to quaternary ammonium disinfectants effects eradication of bacteria from contaminated surfaces. Additional studies are needed to better define the relative advantages and disadvantages of applying surface disinfectants with microfiber, cotton cloths and spunlace non-woven disposable wipes.

Self-disinfecting surfaces

Creating "self-disinfecting surfaces" by coating surfaces with heavy metals such as copper or silver that have innate antimicrobial properties or applying to surfaces compounds that retain their antimicrobial activity for weeks or months has received some attention as a new strategy for disinfecting or preventing the growth of

bacteria on surfaces in hospitals [56, 57]. Silver binds strongly with disulfide and sulfhydryl groups present in proteins of microbial cell walls, leading to cell death [56]. The antimicrobial activity of copper may be due primarily to its ability to form reactive oxygen radicals that damage nucleic acid and proteins [56]. Impregnating equipment surfaces with copper alloys has been shown to reduce bacterial contamination of surfaces [58–60], and in one study, coating several surfaces in hospital rooms with copper alloy was associated with reduction in incidence of HAIs [60]. Further studies of the long-term antimicrobial potency, practicality and cost-effectiveness of copper-coated surfaces are needed. Privacy curtains impregnated with silver have been shown to reduce or delay contamination of curtains with potential pathogens [61, 62].

Organosilane compounds are comprised of a surfactant plus an antimicrobial substance such as a quaternary ammonium moiety. These compounds are designed to minimize bacterial contamination of surfaces by maintaining their antimicrobial activity on surfaces for weeks or months. To date, the ability of these compounds to prevent contamination of surfaces for prolonged time periods is unclear. One study that applied compounds to surfaces using microfiber cloths failed to demonstrate continuing antimicrobial activity, where as two other studies using different application methods reported persistent antimicrobial activity of varying levels for differing time periods [63–65]. Further evaluation of organosilane-type compounds using a variety of application methods appears warranted. Polyhexamethylene biguanide disinfectant was found to reduce bacterial levels on surfaces for at least 24 h after application in one study [66].

Light-activated photosensitizers

A few studies have explored the potential of applying of light-activated photosensitizers such as nanosized titanium dioxide to surfaces and using UV light to generate reactive oxygen species that can disinfect surfaces [67–70]. Activated titanium dioxide has been shown to have varying antimicrobial activity, with the relative susceptibility of agents against pathogens. Research on the use of light-activated photosensitizers is in early stages, and much more information about the feasibility and safety of using this strategy is needed.

No-touch room decontamination methods

Examples of no-touch room decontamination technologies include: aerosolized hydrogen peroxide, hydrogen peroxide vapor systems, gaseous ozone, chlorine dioxide, saturated steam systems, peracetic acid/hydrogen peroxide fogging, mobile continuous ultraviolet devices, pulsed-xenon light devices, and high-intensity narrow-spectrum (405 nm) light [1, 3, 4, 71, 72].

Aerosolized hydrogen peroxide

Aerosolized hydrogen peroxide systems that utilize 3 to 7 % hydrogen peroxide with or without the addition of silver ions have been evaluated by several investigators [25, 73–79]. Aerosols (which are not vapor) generally have particle sizes ranging from 2 to 12 μ, are injected into a room, followed by passive aeration. These systems have been shown to significantly reduce bacteria, generally a 4 $\log_{10}$ reduction of spores, although in several studies spores were not completely eradicated. One system has a sporicidal claim from the EPA in the United States. In one study, use of the aerosolized hydrogen peroxide system was associated with a reduction in *C. difficile* infection, and possible reduction of MRSA acquisition in a second study [25]. Like many other strategies in infection control, there are currently no randomized controlled trials of the efficacy of these systems in preventing health-care-associated infections.

Hydrogen peroxide vapor

A "dry gas" vaporized hydrogen peroxide system that utilizes 30 % hydrogen peroxide has been shown to be effective against a variety of pathogens, including *Mycobacterium tuberculosis, Mycoplasma, Acinetobacter, C. difficile, Bacillus anthracis*, viruses, and prions [80–83]. In before/after studies, dry gas vaporized hydrogen peroxide system, when combined with other infection control measures, appears to have contributed to control of outbreaks of *Acinetobacter* in a long-term care facility and in two intensive care units in a hospital [84–86]. However, long cycle times have made it difficult to implement this system in healthcare facilities.

A micro-condensation hydrogen peroxide vapor system, which utilizes 35 % hydrogen peroxide, is effective in eradicating important pathogens including MRSA, VRE, *C. difficile, Klebsiella, Acinetobacter, Serratia, Mycobacterium tuberculosis*, fungi, and viruses. Laboratory-based and in-hospital studies documented significant reductions (often 10^6 $\log_{10}$) of a number of these pathogens, with 92 to 100 % reduction of pathogens on surfaces [23, 83, 87–93]. In before/after trials, when used in conjunction with other measures, the micro-condensation hydrogen peroxide vapor system appears to have contributed to control of outbreaks caused by MRSA, multi drug-resistant Gram-negative bacteria, and *C. difficile* [78, 87, 94–99]. A prospective, controlled trial performed by Passaretti et al. demonstrated significant reduction in the risk of acquiring multidrug-resistant organisms (MDROs), especially VRE [30]. It has also been used to decontaminate the packaging of unused medical supplies removed from isolation rooms, instead of discarding such items [100]. This system has

also been used to decontaminate rooms previously occupied by patients with the Lassa fever and Ebola virus infection [101, 102]. Despite the demonstrated ability of this system to eradicate nosocomial pathogens from surfaces, concerns over its cost and room turn-around-times have hampered adoption of this technology in healthcare settings. At least one study found that the micro-condensation hydrogen peroxide system can be implemented in hospitals when census levels are relatively high [103]. Recent improvements in the efficiency of the system permit more rapid turn-around-times than earlier equipment, which may lead to wider adoption. To date, there are no randomized, controlled trials establishing the impact of the micro-condensation hydrogen peroxide system on reduction of healthcare-associated infections. Other vapor- or aerosol-based no-touch disinfection technologies that have been described, but whose adoption appears to be limited include gaseous ozone, chlorine dioxide gas, and saturated steam systems [104–109].

Ultraviolet light devices

Automated mobile ultraviolet light devices that continuously emit UV-C in the range of 254 nm can be placed in patient rooms after patient discharge and terminal cleaning has been performed. A number of these devices can be set to kill vegetative bacteria or to kill spores. These systems often reduce the VRE and MRSA by four or more $\log_{10}$, and *C. difficile* by 1–3 $\log_{10}$ [110–118]. In one comparative trial, a continuous UV-C light system resulted in lower log reductions than a micro-condensation hydrogen peroxide vapor system [119]. Advantages of the mobile, continuous UV-C light devices include their ease of use, minimal need for special training of environmental services personnel, and unlike hydrogen peroxide vapor systems, the ability to utilize the devices without having to seal room vents or doors. Recently, a prospective, multicenter randomized controlled trial comparing a mobile continuous UV-C light system with standard and other enhanced surface disinfection methods has been completed [120]. Results of the trial should be published in the near future.

A pulsed-xenon device, which does not use mercury bulbs to produce UV light, emits light in the 200–320 nm range. It has been shown to significantly reduce pathogens in patient rooms [121–127]. The manufacturer recommends placing device in 3 locations in a room with 5–7 min cycles (shorter than with some continuous UV-C systems). While a few studies utilizing the device reported reductions in *C. difficile* infection [122, 127], a more recent 8-month study in a large institution found no significant reduction in *C. difficile* infection rates hospital-wide or on four units with high *C. difficile* infection rates [128]. One carefully-performed trial which compared the pulsed-xenon system with a continuous UV-C light device found that $\log_{10}$ reductions of pathogens achieved with the pulsed-xenon system were lower than with the continuous UV-C light device [129]. Additional evaluation of the pulsed-xenon UV system by independent investigators is needed.

High-intensity narrow-spectrum light

High-intensity narrow-spectrum (HINS) light, which is visible violet-blue light in the range of 405 nm has been tested as a means of disinfecting air and surfaces and hospital rooms. This technology targets intracellular porphyrins that absorb the light and produce reactive oxygen species [130–132]. Its antimicrobial efficacy is lower than UV-C light, but it can be used in areas occupied by patients. In one study, continuous HINS light showed a 27 to 75 % reduction in surface contamination by staphylococci compared to control areas [131]. Further investigation of this technology, including its level of activity against *C. difficile*, appears warranted.

Photocatalytic disinfection

An enclosed air purifying system designed for use by NASA utilizes UV-activated titanium dioxide photocatalytic reactions to oxidize volatile organic compounds and airborne microorganisms. Since aerosolization of pathogens such as *S. aureus* and *C. difficile* during patient care activities is known to occur, there may be some interest in using such systems in patient rooms to reduce airborne bacteria may settle onto environmental surfaces [133].

Given the increasing interest in the above-mentioned new technologies for cleaning and disinfection of environmental surfaces, the Agency for Healthcare Research and Quality (AHRQ) recently commissioned an expert panel to review data regarding these modern technologies. The panel concluded that there is a relative lack of comparative studies addressing the relative effectiveness of various cleaning, disinfecting and monitoring strategies, and that future studies are needed that directly compare newer disinfecting and monitoring methods to one another and with traditional methods [4].

Conclusions

In conclusion, manual cleaning and disinfection of environmental surfaces in healthcare facilities (daily and at patient discharge) are essential elements of infection prevention programs. Because many factors make it difficult to achieve high rates of effective disinfection on a routine and sustained basis, continued efforts to improve the quality and consistency of traditional cleaning and disinfection practices are needed. Given the many challenges in achieving desired levels of surface disinfection, adoption of modern technologies is indicated to supplement traditional methods. Further research into the

efficacy and cost-effectiveness of newer technologies, and when to best apply them, is needed. As additional data become available, it is likely that newer liquid disinfectants and some no-touch room decontamination systems will be more widely adopted to supplement traditional cleaning and disinfection practices.

Competing interests
J.M.B. is a consultant to 3 M Company, Bioquell, Clorox Company, and Diversey Care.

Received: 11 November 2015 Accepted: 23 March 2016
Published online: 11 April 2016

References

1. Rutala WA, Weber DJ. Disinfectants used for environmental disinfection and new room decontamination technology. Am J Infect Control. 2013;41:S36–41.
2. Donskey CJ. Does improving surface cleaning and disinfection reduce health care-associated infections? Am J Infect Control. 2013;41:S12–9.
3. Dancer SJ. Controlling hospital-acquired infection: focus on the role of the environment and new technologies for decontamination. Clin Microbiol Rev. 2014;27:665–90.
4. Han JH, Sullivan N, Leas BF, Pegues DA, Kaczmarek JL, Umscheid CA. Cleaning hospital room surfaces to prevent health care-associated infections. a technical brief. Ann Intern Med. 2015;163:598-607.
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:S41–50.
6. Boyce JM, Havill NL, Lipka A, Havill H, Rizvani R. Variations in hospital daily cleaning practices. Infect Control Hosp Epidemiol. 2010;31:99–101.
7. Sitzlar B, Deshpande A, Fertelli D, Kundrapu S, Sethi AK, Donskey CJ. An Environmental Disinfection Odyssey: Evaluation of Sequential Interventions to Improve Disinfection of Clostridium difficile Isolation Rooms. Infect Control Hosp Epidemiol. 2013;34:459–65.
8. Appelbaum E, Berg P, Frost A, Preuss G, Appelbaum E. The effects of work restructuring on low-wage, low-skilled workers in U.S. hospitals. In: Bernhadt A, Murnane R, editors. Low-wage America: How employers are reshaping opportunity in the workplace. New York: Russel Sage Foundation; 2003. p. 77–117.
9. Zuberi DM, Ptashnick MB. The deleterious consequences of privatization and outsourcing for hospital support work: the experiences of contracted-out hospital cleaners and dietary aids in Vancouver, Canada. Soc Sci Med. 2011;72:907–11.
10. Zoutman DE, Ford BD, Sopha K. Environmental cleaning resources and activities in Canadian acute care hospitals. Am J Infect Control. 2014;42:490–4.
11. Dumigan DG, Boyce JM, Havill NL, Golebiewski M, Balogun O, Rizvani R. Who is really caring for your environment of care? Developing standardized cleaning procedures and effective monitoring techniques. Am J Infect Control. 2010;38:387–92.
12. Anderson RE, Young V, Stewart M, Robertson C, Dancer SJ. Cleanliness audit of clinical surfaces and equipment: who cleans what? J Hosp Infect. 2011;78:178–81.
13. Ali S, Moore G, Wilson AP. Effect of surface coating and finish upon the cleanability of bed rails and the spread of Staphylococcus aureus. J Hosp Infect. 2012;80:192–8.
14. Cadnum JL, Hurless KN, Kundrapu S, Donskey CJ. Transfer of Clostridium difficile spores by nonsporicidal wipes and improperly used hypochlorite wipes: practice + product = perfection. Infect Control Hosp Epidemiol. 2013;34:441–2.
15. Siani H, Cooper C, Maillard JY. Efficacy of "sporicidal" wipes against Clostridium difficile. Am J Infect Control. 2011;39:212–8.
16. Engelbrecht K, Ambrose D, Sifuentes L, Gerba C, Weart I, Koenig D. Decreased activity of commercially available disinfectants containing quaternary ammonium compounds when exposed to cotton towels. Am J Infect Control. 2013;41:908–11.
17. Boyce JM, Sullivan L, Booker A, Baker J. Quaternary ammonium disinfectant issues encountered in an environmental services department. Infect Control Hosp Epidemiol. 2016;37:340–2.
18. Ramm L, Siani H, Wesgate R, Maillard JY. Pathogen transfer and high variability in pathogen removal by detergent wipes. Am J Infect Control. 2015;43:724–8.
19. Weber DJ, Rutala WA, Sickbert-Bennett E. Outbreaks associated with contaminated antiseptics and disinfectants. Antimicrob Agents Chemother. 2007;51:4217–24.
20. Boyce JM, Havill NL, Tetro J, Sattar SA. Bacterial growth in an in-use hospital-grade quaternary ammonium-based disinfectant. Presented at the 21st Annual Scientific Meeting of the Society for Healthcare Epidemiology of America, April 2, 2011, Dallas, TX, abstr 113, 2011.
21. Kampf G, Degenhardt S, Lackner S, Jesse K, von Baum H, Ostermeyer C. Poorly processed reusable surface disinfection tissue dispensers may be a source of infection. BMC Infect Dis. 2014;14:37.
22. Eckstein BC, Adams DA, Eckstein EC, Rao A, Sethi AK, Yadavalli GK, et al. Reduction of *Clostridium difficile* and vancomycin-resistant *Enterococcus* contamination of environmental surfaces after an intervention to improve cleaning methods. BMC Infect Dis. 2007;7:61.
23. French GL, Otter JA, Shannon KP, Adams NMT, Watling D, Parks MJ. Tackling contamination of the hospital environment by methicillin-resistant *Staphylococcus aureus* (MRSA): a comparison between conventional terminal cleaning and hydrogen peroxide vapour decontamination. J Hosp Infect. 2004;57:31–7.
24. Sigler V, Hensley S. Persistence of mixed staphylococci assemblages following disinfection of hospital room surfaces. J Hosp Infect. 2013;83:253–6.
25. Mitchell BG, Digney W, Locket P, Dancer SJ. Controlling methicillin-resistant Staphylococcus aureus (MRSA) in a hospital and the role of hydrogen peroxide decontamination: an interrupted time series analysis. BMJ Open. 2014;4:e004522.
26. Hayden MK, Bonten MJ, Blom DW, Lyle EA, van de Vijver DA, Weinstein RA. Reduction in acquisition of vancomycin-resistant *Enterococcus* after enforcement of routine environmental cleaning measures. Clin Infect Dis. 2006;42:1552–60.
27. Manian FA, Griesnauer S, Senkel D. Impact of terminal cleaning and disinfection on isolation of Acinetobacter baumannii complex from inanimate surfaces of hospital rooms by quantitative and qualitative methods. Am J Infect Control. 2013;41:384–5.
28. Strassle P, Thom KA, Johnson JK, Leekha S, Lissauer M, Zhu J, et al. The effect of terminal cleaning on environmental contamination rates of multidrug-resistant Acinetobacter baumannii. Am J Infect Control. 2012;40:1005–7.
29. Goodman ER, Platt R, Bass R, Onderdon AB, Yokoe DS, Huang SS. Impact of an environmental cleaning intervention on the presence of methicillin-resistant *Staphylococcus aureus* and vancomycin-resistant enterococci on surfaces in intenstive care unit rooms. Infect Control Hosp Epidemiol. 2008;29:593–9.
30. Passaretti CL, Otter JA, Reich NG, Myers J, Shepard J, Ross T, et al. An evaluation of environmental decontamination with hydrogen peroxide vapor for reducing the risk of patient acquisition of multidrug-resistant organisms. Clin Infect Dis. 2013;56:27–35.
31. Mitchell BG, Dancer SJ, Anderson M, Dehn E. Risk of organism acquisition from prior room occupants: a systematic review and meta-analysis. J Hosp Infect. 2015;91:211–7.
32. Carling PC, Briggs JL, Perkins J, Highlander D. Improved cleaning of patient rooms using a new targeting method. Clin Infect Dis. 2006;42:385–8.
33. Boyce JM, Havill NL, Dumigan DG, Golebiewski M, Balogun O, Rizvani R. Monitoring the effectiveness of hospital cleaning practices using an ATP bioluminescence assay. Infect Control Hosp Epidemiol. 2009;30:678–84.
34. Rupp ME, Fitzgerald T, Sholtz L, Lyden E, Carling P. Maintain the gain: program to sustain performance improvement in environmental cleaning. Infect Control Hosp Epidemiol. 2014;35:866–8.
35. Alfa MJ, Lo E, Wald A, Dueck C, Degagne P, Harding GK. Improved eradication of Clostridium difficile spores from toilets of hospitalized patients using an accelerated hydrogen peroxide as the cleaning agent. BMC Infect Dis. 2010;10:268.
36. Rutala WA, Gergen MF, Weber DJ. Efficacy of improved hydrogen peroxide against important healthcare-associated pathogens. Infect Control Hosp Epidemiol. 2012;33:1159–61.
37. Boyce JM, Havill NL. Evaluation of a new hydrogen peroxide wipe disinfectant. Infect Control Hosp Epidemiol. 2013;34:521–3.
38. Alfa MJ, Lo E, Olson N, MacRae M, Buelow-Smith L. Use of a daily disinfectant cleaner instead of a daily cleaner reduced hospital-acquired infection rates. Am J Infect Control. 2015;43:141–6.

39. Rutala WA, Gergen MF, Sickbert-Bennett EE, Williams DA, Weber DJ. Effectiveness of improved hydrogen peroxide in decontaminating privacy curtains contaminated with multidrug-resistant pathogens. Am J Infect Control. 2014;42:426–8.
40. Chiu S, Skura B, Petric M, McIntyre L, Gamage B, Isaac-Renton J. Efficacy of common disinfectant/cleaning agents in inactivating murine norovirus and feline calicivirus as surrogate viruses for human norovirus. Am J Infect Control. 2015;43:1208–12.
41. Carling PC, Perkins J, Ferguson J, Thomasser A. Evaluating a new paradigm for comparing surface disinfection in clinical practice. Infect Control Hosp Epidemiol. 2014;35:1349–55.
42. Deshpande A, Mana TS, Cadnum JL, Jencson AC, Sitzlar B, Fertelli D, et al. Evaluation of a sporicidal peracetic acid/hydrogen peroxide-based daily disinfectant cleaner. Infect Control Hosp Epidemiol. 2014;35:1414–6.
43. Meakin NS, Bowman C, Lewis MR, Dancer SJ. Comparison of cleaning efficacy between in-use disinfectant and electrolysed water in an English residential care home. J Hosp Infect. 2012;80:122–7.
44. Fertelli D, Cadnum JL, Nerandzic MM, Sitzlar B, Kundrapu S, Donskey CJ. Effectiveness of an electrochemically activated saline solution for disinfection of hospital equipment. Infect Control Hosp Epidemiol. 2013;34:543–4.
45. Stewart M, Bogusz A, Hunter J, Devanny I, Yip B, Reid D, et al. Evaluating use of neutral electrolyzed water for cleaning near-patient surfaces. Infect Control Hosp Epidemiol. 2014;35:1505–10.
46. Cahill OJ, Claro T, O'Connor N, Cafolla AA, Stevens NT, Daniels S, et al. Cold air plasma to decontaminate inanimate surfaces of the hospital environment. Appl Environ Microbiol. 2014;80:2004–10.
47. O'Connor N, Cahill O, Daniels S, Galvin S, Humphreys H. Cold atmospheric pressure plasma and decontamination. Can it contribute to preventing hospital-acquired infections? J Hosp Infect. 2014;88:59–65.
48. Claro T, Cahill OJ, O'Connor N, Daniels S, Humphreys H. Cold-air atmospheric pressure plasma against Clostridium difficile spores: a potential alternative for the decontamination of hospital inanimate surfaces. Infect Control Hosp Epidemiol. 2015;36:742–4.
49. Unal N, Yanik K, Karadag A, Odabasi H, Esen S, Gunaydin M. Evaluation of the efficacy of akacid plus(R) fogging in eradicating causative microorganism in nosocomial infections. Int J Clin Exp Med. 2014;7:5867–71.
50. Moore G, Griffith C. A laboratory evaluation of the decontamination properties of microfibre cloths. J Hosp Infect. 2006;64:379–85.
51. Rutala WA, Gergen MF, Weber DJ. Microbiologic evaluation of microfiber mops for surface disinfection. Am J Infect Control. 2007;35:569–73.
52. Moore G, Hall TJ, Wilson AP, Gant VA. The efficacy of the inorganic copper-based biocide CuWB50 is compromised by hard water. Lett Appl Microbiol. 2008;46:655–60.
53. Ali S, Moore G, Wilson AP. Spread and persistence of Clostridium difficile spores during and after cleaning with sporicidal disinfectants. J Hosp Infect. 2011;79:97–8.
54. Bergen LK, Meyer M, Hog M, Rubenhagen B, Andersen LP. Spread of bacteria on surfaces when cleaning with microfibre cloths. J Hosp Infect. 2009;71:132–7.
55. Trajtman AN, Manickam K, Alfa MJ. Microfiber cloths reduce the transfer of Clostridium difficile spores to environmental surfaces compared with cotton cloths. Am J Infect Control. 2015;43:686–9.
56. Weber DJ, Rutala WA. Self-disinfecting surfaces: review of current methodologies and future prospects. Am J Infect Control. 2013;41:S31–5.
57. Humphreys H. Self-disinfecting and microbiocide-impregnated surfaces and fabrics: what potential in interrupting the spread of healthcare-associated infection? Clin Infect Dis. 2014;58:848–53.
58. Schmidt MG, Attaway HH, Sharpe PA, John Jr J, Sepkowitz KA, Morgan A, et al. Sustained reduction of microbial burden on common hospital surfaces through introduction of copper. J Clin Microbiol. 2012;50:2217–23.
59. Schmidt MG, Attaway Iii HH, Fairey SE, Steed LL, Michels HT, Salgado CD. Copper continuously limits the concentration of bacteria resident on bed rails within the intensive care unit. Infect Control Hosp Epidemiol. 2013;34:530–3.
60. Salgado CD, Sepkowitz KA, John JF, Cantey JR, Attaway HH, Freeman KD, et al. Copper surfaces reduce the rate of healthcare-acquired infections in the intensive care unit. Infect Control Hosp Epidemiol. 2013;34:479–86.
61. Schweizer M, Graham M, Ohl M, Heilmann K, Boyken L, Diekema D. Novel hospital curtains with antimicrobial properties: a randomized, controlled trial. Infect Control Hosp Epidemiol. 2012;33:1081–5.
62. Kotsanas D, Wijesooriya WR, Sloane T, Stuart RL, Gillespie EE. The silver lining of disposable sporicidal privacy curtains in an intensive care unit. Am J Infect Control. 2014;42:366–70.
63. Baxa D, Shetron-Rama L, Golembieski M, Golembieski M, Jain S, Gordon M, et al. In vitro evaluation of a novel process for reducing bacterial contamination of environmental surfaces. Am J Infect Control. 2011;39:483–7.
64. Boyce JM, Havill NL, Guercia KA, Schweon SJ, Moore BA. Evaluation of two organosilane products for sustained antimicrobial activity on high-touch surfaces in patient rooms. Am J Infect Control. 2014;42:326–8.
65. Tamimi AH, Carlino S, Gerba CP. Long-term efficacy of a self-disinfecting coating in an intensive care unit. Am J Infect Control. 2014;42:1178–81.
66. Hedin G, Rynback J, Lore B. Reduction of bacterial surface contamination in the hospital environment by application of a new product with persistent effect. J Hosp Infect. 2010;75:112–5.
67. Page K, Wilson M, Parkin IP. Antimicrobial surfaces and their potential in reducing the role of the inanimate environment in the incidence of hospital-acquired infections. J Mater Chem. 2009;19:3819–31.
68. Park GW, Cho M, Cates EL, Lee D, Oh BT, Vinje J, et al. Fluorinated TiO(2) as an ambient light-activated virucidal surface coating material for the control of human norovirus. J Photochem Photobiol B. 2014;140:315–20.
69. Bogdan J, Zarzynska J, Plawinska-Czarnak J. Comparison of Infectious Agents Susceptibility to Photocatalytic Effects of Nanosized Titanium and Zinc Oxides: A Practical Approach. Nanoscale Res Lett. 2015;10:1023.
70. de Jong B, van Zanten ARH. Effect of MVX (titanium dioxide) on the microbial colonization of surfaces in an intensive care unit. Clinical Trials.gov identifier: NCT02348346, 2015.
71. Otter JA, Yezli S, Perl TM, Barbut F, French GL. The role of 'no-touch' automated room disinfection systems in infection prevention and control. J Hosp Infect. 2013;83:1–13.
72. Ottawa (ON): Canadian Agency for Drugs and Technologies in Health. Non-manual techniques for room disinfection in healthcare facilities: a review of clinical effectiveness and guidelines. 2014.
73. Andersen BM, Rasch M, Hochlin K, Jensen FH, Wismar P, Fredriksen JE. Decontamination of rooms, medical equipment and ambulances using an aerosol of hydrogen peroxide disinfectant. J Hosp Infect. 2006;62:149–55.
74. Shapey S, Machin K, Levi K, Boswell TC. Activity of a dry mist hydrogen peroxide system against environmental *Clostridium difficile* contamination in elderly care wards. J Hosp Infect. 2008;70:136–41.
75. Bartels MD, Kristoffersen K, Slotsbjerg T, Rohde SM, Lundgren B, Westh H. Environmental meticillin-resistant Staphylococcus aureus (MRSA) disinfection using dry-mist-generated hydrogen peroxide. J Hosp Infect. 2008;70:35–41.
76. Barbut F, Menuet D, Verachten M, Girou E. Comparison of the efficacy of a hydrogen peroxide dry-mist disinfection system and sodium hypochlorite solution for eradication of *Clostridium difficile* spores. Infect Control Hosp Epidemiol. 2009;30:507–14.
77. Piskin N, Celebi G, Kulah C, Mengeloglu Z, Yumusak M. Activity of a dry mist-generated hydrogen peroxide disinfection system against methicillin-resistant Staphylococcus aureus and Acinetobacter baumannii. Am J Infect Control. 2011;39:757–62.
78. Landelle C, Legrand P, Lesprit P, Cizeau F, Ducellier D, Gouot C, et al. Protracted outbreak of multidrug-resistant Acinetobacter baumannii after intercontinental transfer of colonized patients. Infect Control Hosp Epidemiol. 2013;34:119–24.
79. Best EL, Parnell P, Thirkell G, Verity P, Copland M, Else P, et al. Effectiveness of deep cleaning followed by hydrogen peroxide decontamination during high Clostridium difficile infection incidence. J Hosp Infect. 2014;87:25–33.
80. Fichet G, Antioga K, Comoy E, Deslys JP, McDonnell G. Prion inactivation using a new gaseous hydrogen peroxide sterilisation process. J Hosp Infect. 2007;67:278–86.
81. Heckert RA, Best M, Jordan LT, Dulac GC, Eddington DL, Sterritt WG. Efficacy of vaporized hydrogen peroxide against exotic animal viruses. Appl Environ Microbiol. 1997;63:3916–8.
82. Rogers JV, Sabourin CL, Choi YW, Richter WR, Rudnicki DC, Riggs KB, et al. Decontamination assessment of Bacillus anthracis, Bacillus subtilis, and Geobacillus stearothermophilus spores on indoor surfaces using a hydrogen peroxide gas generator. J Appl Microbiol. 2005;99:739–48.
83. Pottage T, Richardson C, Parks S, Walker JT, Bennett AM. Evaluation of hydrogen peroxide gaseous disinfection systems to decontaminate viruses. J Hosp Infect. 2010;74:55–61.
84. Ray A, Perez F, Beltramini AM, Jakubowycz M, Dimick P, Jacobs MR, et al. Use of vaporized hydrogen peroxide decontamination during an outbreak

of multidrug-resistant Acinetobacter baumannii infection at a long-term acute care hospital. Infect Control Hosp Epidemiol. 2010;31:1236–41.
85. Galvin S, Boyle M, Russell RJ, Coleman DC, Creamer E, O'Gara JP, et al. Evaluation of vaporized hydrogen peroxide, Citrox and pH neutral Ecasol for decontamination of an enclosed area: a pilot study. J Hosp Infect. 2012;80:67–70.
86. Chmielarczyk A, Higgins PG, Wojkowska-Mach J, Synowiec E, Zander E, Romaniszyn D, et al. Control of an outbreak of Acinetobacter baumannii infections using vaporized hydrogen peroxide. J Hosp Infect. 2012;81:239–45.
87. Bates CJ, Pearse R. Use of hydrogen peroxide vapour for environmental control during a *Serratia* outbreak in a neonatal intensive care unit. J Hosp Infect. 2005;61:364–6.
88. Hall L, Otter JA, Chewins J, Wengenack NL. Use of hydrogen peroxide vapor for deactivation of Mycobacterium tuberculosis in a biological safety cabinet and a room. J Clin Microbiol. 2007;45:810–5.
89. Hall L, Otter JA, Chewins J, Wengenack NL. Deactivation of the dimorphic fungi Histoplasma capsulatum, Blastomyces dermatitidis and Coccidioides immitis using hydrogen peroxide vapor. Med Mycol. 2008;46:189–91.
90. Boyce JM, Havill NL, Otter JA, McDonald LC, Adams NMT, Cooper T, et al. Impact of hydrogen peroxide vapor room decontamination on *Clostridium difficile* environmental contamination and transmission in a healthcare setting. Infect Control Hosp Epidemiol. 2008;29:723–9.
91. Otter JA, French GL. Survival of nosocomial bacteria and spores on surfaces and inactivation by hydrogen peroxide vapor. J Clin Microbiol. 2009;47:205–7.
92. Manian FA, Griesenauer S, Senkel D, Setzer JM, Doll SA, Perry AM, et al. Isolation of Acinetobacter baumannii complex and methicillin-resistant Staphylococcus aureus from hospital rooms following terminal cleaning and disinfection: can we do better? Infect Control Hosp Epidemiol. 2011;32:667–72.
93. Barbut F, Yezli S, Mimoun M, Pham J, Chaouat M, Otter JA. Reducing the spread of Acinetobacter baumannii and methicillin-resistant Staphylococcus aureus on a burns unit through the intervention of an infection control bundle. Burns. 2013;39:395–403.
94. Jeanes A, Rao G, Osman M, Merrick P. Eradication of persistent environmental MRSA. J Hosp Infect. 2005;61:85–6.
95. Dryden M, Parnaby R, Dailly S, Lewis T, Davis-Blues K, Otter JA, et al. Hydrogen peroxide vapour decontamination in the control of a polyclonal meticillin-resistant Staphylococcus aureus outbreak on a surgical ward. J Hosp Infect. 2008;68:190–2.
96. Otter JA, Yezli S, Schouten MA, van Zanten AR, Houmes-Zielman G, Nohlmans-Paulssen MK. Hydrogen peroxide vapor decontamination of an intensive care unit to remove environmental reservoirs of multidrug-resistant gram-negative rods during an outbreak. Am J Infect Control. 2010;38:754–6.
97. Cooper T, O'Leary M, Yezli S, Otter JA. Impact of environmental decontamination using hydrogen peroxide vapour on the incidence of Clostridium difficile infection in one hospital Trust. J Hosp Infect. 2011;78:238–40.
98. Snitkin ES, Zelazny AM, Thomas PJ, Stock F, Henderson DK, Palmore TN, et al. Tracking a hospital outbreak of carbapenem-resistant Klebsiella pneumoniae with whole-genome sequencing. Sci Transl Med. 2012;4:148ra116.
99. Gopinath R, Savard P, Carroll KC, Wilson LE, Landrum BM, Perl TM. Infection prevention considerations related to New Delhi metallo-beta-lactamase Enterobacteriaceae: a case report. Infect Control Hosp Epidemiol. 2013;34:99–100.
100. Otter JA, Nowakowski E, Salkeld JA, Duclos M, Passaretti CL, Yezli S, et al. Saving Costs through the Decontamination of the Packaging of Unused Medical Supplies Using Hydrogen Peroxide Vapor. Infect Control Hosp Epidemiol. 2013;34:472–8.
101. Otter JA, Barnicoat M, Down J, Smyth D, Yezli S, Jeanes A. Hydrogen peroxide vapour decontamination of a critical care unit room used to treat a patient with Lassa fever. J Hosp Infect. 2010;75:335–7.
102. Otter JA, Mepham S, Athan B, Mack D, Smith R, Jacobs M, et al. Terminal decontamination of the Royal Free London's high-level isolation unit after a case of Ebola virus disease using hydrogen peroxide vapor. Am J Infect Control. 2016;44:233–5.
103. Otter JA, Puchowicz M, Ryan D, Salkeld JAG, Cooper TA, Havill NL, et al. Assessing the feasibility of routine use of hydrogen peroxide vapor (HPV) to decontaminate rooms in a busy US hospital. Infect Control Hosp Epidemiol. 2009;30:574–7.
104. Berrington AW, Pedler SJ. Investigation of gaseous ozone for MRSA decontamination of hospital side-rooms. J Hosp Infect. 1998;40:61–5.
105. de Boer HEL, van Elzelingen-Dekker CM, van Rheenen-Verberg CMF, Spanjaard L. Use of gaseous ozone for eradication of methicillin-resistant *Staphylococcus aureus* from the home environment of a colonized hospital employee. Infect Control Hosp Epidemiol. 2006;27:1120–2.
106. Sharma M, Hudson JB. Ozone gas is an effective and practical antibacterial agent. Am J Infect Control. 2008;36:559–63.
107. Davies A, Pottage T, Bennett A, Walker J. Gaseous and air decontamination technologies for Clostridium difficile in the healthcare environment. J Hosp Infect. 2011;77:199–203.
108. Gibbs SG, Lowe JJ, Smith PW, Hewlett AL. Gaseous chlorine dioxide as an alternative for bedbug control. Infect Control Hosp Epidemiol. 2012;33:495–9.
109. Sexton JD, Tanner BD, Maxwell SL, Gerba CP. Reduction in the microbial load on high-touch surfaces in hospital rooms by treatment with a portable saturated steam vapor disinfection system. Am J Infect Control. 2011;39:655–62.
110. Nernandzic MM, Cadnum JL, Pultz MJ, Donskey CJ. Evaluation of an automated ultraviolet radiation device for decontamination of *Clostridium difficile* and other healthcare-associated pathogens in hospital rooms. BMC Infect Dis. 2010;10:197.
111. Rutala WA, Gergen MF, Weber DJ. Room decontamination with UV radiation. Infect Control Hosp Epidemiol. 2010;31:1025–9.
112. Boyce JM, Havill NL, Moore BA. Terminal decontamination of patient rooms using an automated mobile UV light unit. Infect Control Hosp Epidemiol. 2011;32:737–42.
113. Rutala WA, Gergen MF, Tande BM, Weber DJ. Rapid hospital room decontamination using ultraviolet (UV) light with a nanostructured UV-reflective wall coating. Infect Control Hosp Epidemiol. 2013;34:527–9.
114. Anderson DJ, Gergen MF, Smathers E, Sexton DJ, Chen LF, Weber DJ, et al. Decontamination of targeted pathogens from patient rooms using an automated ultraviolet-C-emitting device. Infect Control Hosp Epidemiol. 2013;34:466–71.
115. Mahida N, Vaughan N, Boswell T. First UK evaluation of an automated ultraviolet-C room decontamination device (Tru-D). J Hosp Infect. 2013;84:332–5.
116. Nerandzic MM, Fisher CW, Donskey CJ. Sorting through the wealth of options: comparative evaluation of two ultraviolet disinfection systems. PLoS One. 2014;9:e107444.
117. Rutala WA, Gergen MF, Tande BM, Weber DJ. Room decontamination using an ultraviolet-C device with short ultraviolet exposure time. Infect Control Hosp Epidemiol. 2014;35:1070–2.
118. Rutala WA, Weber DJ, Gergen MF, Tande BM, Sickbert-Bennett EE. Does coating all room surfaces with an ultraviolet C light-nanoreflective coating improve decontamination compared with coating only the walls? Infect Control Hosp Epidemiol. 2014;35:323–5.
119. Havill NL, Moore BA, Boyce JM. Comparison of the microbiological efficacy of hydrogen peroxide vapor and ultraviolet light processes for room decontamination. Infect Control Hosp Epidemiol. 2012;33:507–12.
120. Anderson DJ, Sexton DJ. Effectiveness of enhanced terminal room disinfection to prevent healthcare-associated infections (HAIs). Clinical Trials. gov identifier: NCT01579370, 2015.
121. Stibich M, Stachowiak J, Tanner B, Berkheiser M, Moore L, Raad I, et al. Evaluation of a pulsed-xenon ultraviolet room disinfection device for impact on hospital operations and microbial reduction. Infect Control Hosp Epidemiol. 2011;32:286–8.
122. Levin J, Riley LS, Parrish C, English D, Ahn S. The effect of portable pulsed xenon ultraviolet light after terminal cleaning on hospital-associated Clostridium difficile infection in a community hospital. Am J Infect Control. 2013;41:746–8.
123. Jinadatha C, Quezada R, Huber TW, Williams JB, Zeber JE, Copeland LA. 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.
124. Ghantoji SS, Stibich M, Stachowiak J, Cantu S, Adachi JA, Raad II, et al. Non-inferiority of pulsed xenon UV light versus bleach for reducing environmental Clostridium difficile contamination on high-touch surfaces in Clostridium difficile infection isolation rooms. J Med Microbiol. 2015;64:191–4.
125. Sander J, Ladenstein M. Reliability of disinfectant dispensers in hospitals (author's transl). Dtsch Med Wochenschr. 1974;99:1560–4.

126. Nagaraja A, Visintainer P, Haas JP, Menz J, Wormser GP, Montecalvo MA. Clostridium difficile infections before and during use of ultraviolet disinfection. Am J Infect Control. 2015;43:940–5.
127. Miller R, Simmons S, Dale C, Stibich M, Stachowiak J. Utilization and impact of a pulsed-xenon ultraviolet room disinfection system and multidisciplinary care team on *Clostridium difficile* in a long-term acute care facility. Am J Infect Control. 2015;43:1350–3.
128. McMullen K, Wood H, Buol W, Johnson D, Bradley A, Woeltje K, et al. Impact of a pulsed xenon ultraviolet light (PX-UV) light room disinfection system on *Clostridium difficile* rates. Presented at IDWeek 2015, abstract 1714, October 10, 2015, San Diego, CA. 2015.
129. Nerandzic MM, Thota P, Sankar CT, Jencson A, Cadnum JL, Ray AJ, et al. Evaluation of a pulsed xenon ultraviolet disinfection system for reduction of healthcare-associated pathogens in hospital rooms. Infect Control Hosp Epidemiol. 2015;36:192–7.
130. Maclean M, MacGregor SJ, Anderson JG, Woolsey GA, Coia JE, Hamilton K, et al. Environmental decontamination of a hospital isolation room using high-intensity narrow-spectrum light. J Hosp Infect. 2010;76:247–51.
131. Bache SE, Maclean M, MacGregor SJ, Anderson JG, Gettinby G, Coia JE, et al. Clinical studies of the High-Intensity Narrow-Spectrum light Environmental Decontamination System (HINS-light EDS), for continuous disinfection in the burn unit inpatient and outpatient settings. Burns. 2012;38:69–76.
132. Maclean M, McKenzie K, Anderson JG, Gettinby G, MacGregor SJ. 405 nm light technology for the inactivation of pathogens and its potential role for environmental disinfection and infection control. J Hosp Infect. 2014;88:1–11.
133. Cram N, Shipman N, Quarles JM. Reducing airborne microbes in the surgical operating theater & other clinical settings: A study utilizing the AiroCide System. J Clin Engineering. 2004;79–88.

CONCISE COMMUNICATION

Quaternary Ammonium Disinfectant Issues Encountered in an Environmental Services Department

John M. Boyce, MD;[1,2] Linda Sullivan, RN;[1] Arica Booker;[3] James Baker[3]

We identified several factors affecting the use of quaternary ammonium-based (Quat) disinfectant in our facility. Microfiber wipers, cotton towels, and 1 of 2 types of disposable wipes soaked in a Quat disinfectant revealed significant binding of the disinfectant. Concentrations of Quat delivered by automated disinfectant dispensers varied widely.

Infect. Control Hosp. Epidemiol. 2016;37(3):340–342

Quaternary ammonium-based (Quat) products are among the most widely used disinfectants, and they are commonly used in healthcare facilities in the United States for disinfection of inanimate surfaces.[1–3] Recently, a few studies have raised concerns regarding the ability of various types of wipers, towels, and wipes to bind Quat disinfectants, resulting in decreased disinfectant efficacy.[2,4,5] In our facility, microfiber wipers are normally used for applying disinfectants to surfaces, but cotton towels are used when insufficient microfiber wipers are available. As part of a review of practices utilized by our environmental services department, we conducted a study to evaluate the impact on Quat concentrations of different types of wiping materials used for environmental disinfection, and we identified variations in Quat concentrations delivered by dispensing stations.

METHODS

The study was conducted in a tertiary university-affiliated hospital. Environmental Services personnel filled 3 buckets with a Quat-based disinfectant currently used by the hospital. The disinfectant, a concentrated solution of alkyl dimethyl ammonium chloride and dodecyl dimethyl ammonium chloride with a pH of 8.0, is dispensed from wall-mounted distribution stations that mix the product with water to achieve an appropriate in-use concentration. Initially, 3 types of wiping materials were included in the study: (1) commercially available microfiber wipers composed of 80% polyester and 20% polyamide (CPI-Creative Products, Pittsburgh, PA), (2) cotton towels, and (3) disposable wipes occasionally used for product application (type A; KimTech Wettask, Kimberly-Clark, TX). First, 30 microfiber wipers were placed in 1 bucket, 30 cotton towels were placed in another, and a roll of disposable wipes was placed in another. Every 5 minutes for the first 30 minutes, 3 wipers, towels, or wipes were removed from each respective bucket. This procedure was then repeated every 30 minutes for a total time of 4 hours. At each time point, excess solution was wrung from each respective set of wipers, towels, and wipes, and the respective solutions expressed were tested using quaternary ammonium compound test strips (Hydrion, Micro Essential Lab, Brooklyn, NY). The average concentration of each solution was recorded. Based on the initial results obtained, a second type of disposable wipe designed specifically for use with disinfectants (type B; KimTech, Wettask model 6211) was evaluated using the same method.

Statistical analysis was performed using the repeated-measures ANOVA method using MedCalc software. Quat concentrations in fluid expressed from wiping materials at different points in time were entered as the repeated-measurements variable (ie, within-subject factor), and wiping material type was entered as the grouping variable (ie, between-subject factor).

When obtaining the Quat product from a dispensing station, we noted that the Quat concentration was substantially below the level claimed by the vendor. Dispensing stations are designed to dispense 0.5 ounce of concentrated disinfectant per gallon of water, yielding an in-use concentration of 800 ppm. As a result, an audit of 33 disinfectant dispensing stations was conducted to measure Quat concentrations delivered.

RESULTS

After the first 3 wiping materials had been submerged in the disinfectant solution for 5 minutes and then wrung out, the Quat concentrations in the respective solutions expressed were reduced by 21% in microfiber wipers and by 50% in both cotton towels and type A disposable wipes (Figure 1). Within 30 minutes, the average Quat concentration of solution expressed from the 3 wiping materials remained stable, respectively, for the following 3 hours: microfiber wipers at 400 ppm, cotton towels at 200 ppm, and disposable wipes near zero. On several occasions, microfiber wipers and disposable wipes soaked in disinfectant for >30 minutes were tested. Test strips were pressed between layers of the microfiber wipers and disposable wipes, respectively, and the Quat concentrations were recorded. Immediately following this process, the microfiber wipers, and disposable wipes were used to apply the disinfectant product to the surface of a table, and additional test strips were then immediately pressed against the respective surfaces while they were still wet. Test strips pressed between layers of the wiping materials and those pressed against their respective wet surfaces revealed equal concentrations. For microfiber wipers, the Quat concentration was 400 ppm in both locations; with type A disposable wipes, the Quat concentration was <100 ppm in both locations. Following the aforementioned studies, we evaluated a second type of disposable wipe (type B) designed specifically for use with

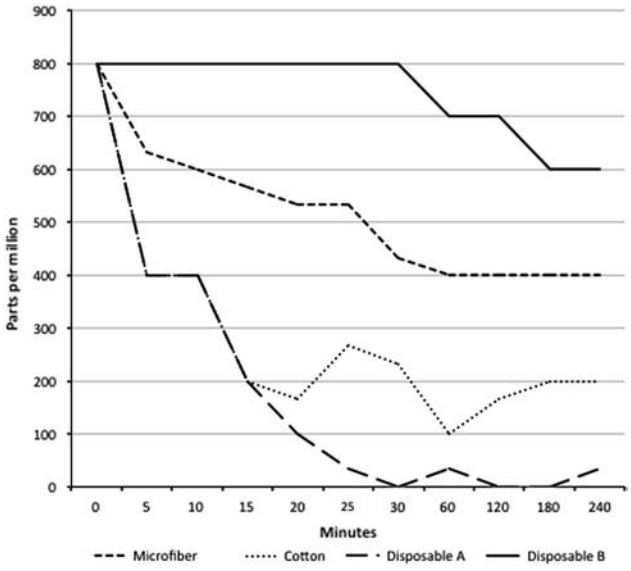

FIGURE 1. Quaternary ammonium concentrations in fluid expressed from microfiber wipers, cotton towels, and 2 types of disposable wipes (types A and B) soaked for varying lengths of time in an in-use concentration of a commercial quaternary ammonium disinfectant.

disinfectants. Our test revealed that Quat concentrations remained in the 600–700 ppm range in the type B wipes after submersion in disinfectant for up to 4 hours (Figure 1).

Statistical analysis of Quat concentrations obtained from the 4 types of wipes revealed statistically significant differences between the wiping material types ($P < .001$) and within-subject effects ($P < .001$). A statistically significant interaction between material type × Quat concentration was detected ($P < .001$), confirming the common assumption that differences in measured concentrations depend in part on the wiping material.

Disinfectant solutions obtained from the 33 dispensing stations audited had Quat concentrations of <200 ppm from 7 stations, 200–400 ppm from 17 stations, and 400–600 ppm from 6 stations. In addition, 2 stations contained no concentrated disinfectant and 1 station was inoperative. Investigation by the disinfectant vendor revealed that variations in water pressure at dispensing stations and certain design issues in the dispensing system were responsible for the variations in the concentration of Quat dispensed. Installation of water-pressure regulators on each dispensing station and modifications of the flow-control devices in jugs of concentrated disinfectant by the vendor resulted in Quat concentrations of ≥800 ppm in dispensed solutions.

DISCUSSION

Our investigation identified several unique issues related to the use of Quat-based disinfectants in our facility, including significant binding of the disinfectant by several types of wiping material. Unlike previous studies, the Quat disinfectant used in the current study differed from that used by Engelbrecht et al,[5] and it was likely different than that used by MacDougall et al.[2] Furthermore, the microfiber wipers we used were from a different manufacturer than those tested by Engelbrecht et al.[5] Despite these differences, our results confirm and extend the findings reported in a few previous studies demonstrating binding of Quat disinfectants to various wiping materials.[2,5]

Differences between our results and the findings of others may be explained by the disinfectant chemical composition, pH, and the degree of positive charge of the disinfectant product being evaluated. Furthermore, the composition of microfiber wipers may affect the degree of binding of Quat-based disinfectants.

We were surprised that the type A wipes that we initially tested bound the disinfectant to a greater degree than cotton towels under our test conditions. Subsequent investigation revealed that the type A disposable wipe, which is occasionally used by environmental services, was designed for use with solvents rather than disinfectants and had a composition that promoted binding of Quat-based solutions. Testing of the type B disposable wipe (designed for use with disinfectant solutions) revealed minimal binding. Our findings are consistent with previous studies showing relatively little Quat-binding by some wipes while others have a strong binding effect.[2] We believe that this important phenomenon is not widely recognized by environmental services and infection prevention personnel.

Another unique aspect of our study was the discovery that differences in water pressure in various parts of the hospital and issues related to the design of the disinfectant dispenser system resulted in wide variations of the Quat concentrations obtained from disinfectant dispensers. We are aware of only 1 previous study in which "fixed-volume" dispensers used to dispense disinfectant solutions yielded concentrations that differed greatly from predicted levels.[6]

Our study has several limitations, including the fact that the study was performed in a single facility. Also, we documented that the Quat concentrations of disinfectant solution expressed from microfiber wipers, cotton towels, and 1 type of disposable wipe were considerably below the concentration (660 ppm) that the manufacturer used to establish efficacy of its product against healthcare-associated pathogens. However, we did not conduct microbiological tests to determine whether the low concentrations of Quat in the disinfectant product released from the 3 wiping materials resulted in less effective reduction of bacterial counts on surfaces. Notably, Engelbrecht et al[5] found that Quat concentrations in the range of 100–200 ppm (similar to those noted in our study) failed to meet efficacy standards when tested using the Association of Analytical Communities (AOAC) 961.02 Germicidal Spray test. Because studies of the frequency with which cotton towels are used to apply disinfectants in other hospitals have been limited in scope, the extent to which our findings regarding cotton towels are generalizable is unclear.[7]

Finally, our Environmental Services personnel submerge microfiber wipers in disinfectant for minutes to hours until

they are removed for use, which may result in greater binding of the Quat disinfectant to these wipers than the "dip and wipe" method, wherein microfiber wipers are submerged in disinfectant solution for only 5–10 seconds before being removed and used to wipe surfaces.[8]

In conclusion, healthcare facilities utilizing Quat-based disinfectants should be aware that some wipers, towels, and wipes may reduce the Quat concentration applied to surfaces to well below the concentration promoted as effective by the manufacturer. Also, it may be reasonable for hospitals utilizing dispensing stations to periodically test concentrated solutions of disinfectant mixed with water to verify that appropriate in-use concentrations of product are being dispensed.

ACKNOWLEDGMENTS

Financial support. None reported. There was no financial support provided for this study.

Potential conflicts of interest. J.M.B. has received a research grant from Diversy Care, and serves as a consultant to 3M Company and Clorox Company. All other authors report no conflicts of interest relevant to this article. A.B. is now with Charlotte Hungerford Hospital, Torrington, Connecticut.

Affiliations: 1. Hospital Epidemiology and Infection Control Program, Yale New-Haven Hospital, New Haven, Connecticut; 2. Yale University School of Medicine, New Haven, Connecticut; 3. Environmental Services Department, Yale-New Haven Hospital, New Haven, Connecticut

Address correspondence to John M. Boyce, MD, Hospital Epidemiology and Infection Control, Yale-New Haven Hospital, 20 York Street, New Haven, CT 06510 (jmboyce69@gmail.com).

Received April 23, 2015; accepted: August 22, 2015; electronically published November 27, 2015

 0899-823X/2016/3703-0015. DOI: 10.1017/ice.2015.299

REFERENCES

1. Rutala WA, Weber DJ, and the Healthcare Infection Control Practices Advisory Committee. Guideline for disinfection and sterilization in healthcare facilities, 2008. Centers for Disease Control and Prevention website. www.cdc.gov/ncidod/dhqp/pdf/guidelines/Disinfection_Nov_2008.pdf. Published 2008. Accessed November 5, 2015.
2. MacDougall KD, Morris C. Optimizing disinfectant application in healthcare facilities. *Infect Control Today* 2006;10:62–67.
3. Gerba CP. Quaternary ammonium biocides: efficacy in application. *Appl Environ Microbiol* 2015;81:464–469.
4. Bloss R, Meyer S, Kampf G. Adsorption of active ingredients of surface disinfectants depends on the type of fabric used for surface treatment. *J Hosp Infect* 2010;75:56–61.
5. Engelbrecht K, Ambrose D, Sifuentes L, et al. Decreased activity of commercially available disinfectants containing quaternary ammonium compounds when exposed to cotton towels. *Am J Infect Control* 2013;41:908–911.
6. Sander J, Ladenstein M. [Reliability of disinfectant dispensers in hospitals (author's transl.)]. *Dtsch Med Wochenschr* 1974;99:1560–1564.
7. Sifuentes LY, Gerba CP, Weart I, Engelbrecht K, Koenig DW. Microbial contamination of hospital reusable cleaning towels. *Am J Infect Control* 2013;41:912–915.
8. Quat Absorption onto Textiles. Ecolab website. http://www.ecolab.com/innovation/resources/healthcare-clinical-literature-resources/ ~ /media/A1800AE5B40643F78DD217772AD2DDF5.ashx. Published 2009. Accessed March 21, 2015.

ORIGINAL ARTICLE

Monitoring the Effectiveness of Hospital Cleaning Practices by Use of an Adenosine Triphosphate Bioluminescence Assay

John M. Boyce, MD; Nancy L. Havill, MT; Diane G. Dumigan, RN; Michael Golebiewski; Ola Balogun, BS, MBA; Ramo Rizvani, BS

OBJECTIVE. To evaluate the usefulness of an adenosine triphosphate (ATP) bioluminescence assay for assessing the efficacy of daily hospital cleaning practices.

DESIGN. A 2-phase prospective intervention study.

SETTING. A university-affiliated community teaching hospital.

METHODS. During phase I of our study, 5 high-touch surfaces in 20 patient rooms were sampled before and after daily cleaning. Moistened swabs were used to sample these surfaces and were then plated onto routine and selective media, and aerobic colony counts were determined after 48 hours of incubation. Specialized ATP swabs were used to sample the same high-touch surfaces in the 20 patient rooms and were then placed in luminometers, and the amount of ATP present was expressed as relative light units. During phase II of our study, after in-service housekeeper educational sessions were given, the housekeepers were told in advance when ATP readings would be taken before and after cleaning.

RESULTS. During phase I, the colony counts revealed that the 5 high-touch surfaces were often not cleaned adequately. After cleaning, 24 (24%) of the 100 surface samples were still contaminated with methicillin-resistant *Staphylococcus aureus,* and 16 (16%) of the 100 surface samples still yielded vancomycin-resistant enterococci. ATP readings (expressed as relative light units) revealed that only bathroom grab bars and toilet seats were significantly cleaner after daily cleaning than before. During phase II, a total of 1,013 ATP readings were obtained before and after daily cleaning in 105 rooms. The median relative light unit was significantly lower (ie, surfaces were cleaner) after cleaning than before cleaning for all 5 high-touch surfaces.

CONCLUSIONS. Suboptimal cleaning practices were documented by determining aerobic colony counts and by use of an ATP bioluminescence assay. ATP readings provided quantitative evidence of improved cleanliness of high-touch surfaces after the implementation of an intervention program.

Infect Control Hosp Epidemiol 2009; 30:678-684

Transmission of healthcare-associated pathogens most frequently occurs via the transiently contaminated hands of healthcare workers.[1] However, environmental contamination also contributes to the spread of healthcare-associated pathogens.[2-9] As a result, hospitals need to ensure that environmental cleaning and disinfection are integral parts of their infection control programs.[10-12]

However, routine housekeeping practices are often suboptimal,[3,13-17] and increased attention should be paid to the effectiveness of cleaning protocols. Accordingly, the Hospital of Saint Raphael formed a multidisciplinary committee to revise and update the hospital's policies. After formal acceptance of the revised and updated policies by the infection control program and environmental services, a decision was made to monitor the effectiveness of cleaning procedures.

Methods for monitoring the effectiveness of cleaning procedures include visual assessment of surfaces, application of fluorescent dye to surfaces with subsequent assessment of residual dye after cleaning, determination of aerobic colony counts, and detection of adenosine triphosphate (ATP) on surfaces.[13,15,18,19] Detection of ATP—which is present in all types of organic material (including bacteria, food, and human secretions and excretions)—on environmental surfaces has been used for years in the food and beverage industries to assess the adequacy of cleaning procedures.[19,20] Few investigators have evaluated ATP bioluminescence methods for

From the Infectious Diseases Section (J.M.B., N.L.H., D.G.D.) and the Environmental Services Department (M.G., O.B., R.R.), Hospital of Saint Raphael, and Yale School of Medicine (J.M.B.), New Haven, Connecticut.

Received August 24, 2008; accepted February 10, 2009; electronically published June 2, 2009.

 0899-823X/2009/3007-0010$15.00. DOI: 10.1086/598243

monitoring cleanliness in hospitals.[13,19,21] Therefore, we conducted a 2-phase prospective intervention study of the usefulness of an ATP bioluminescence assay to assess the adequacy of routine hospital cleaning procedures.

METHODS

Phase I

Phase I was designed to assess the thoroughness of daily cleaning procedures by determining aerobic colony counts and by use of an ATP bioluminescence assay and to compare the results of the 2 methods. We felt that expressing surface contamination as an aerobic colony count as well as an ATP reading would make it easier for hospital personnel to comprehend the results. During the first phase of the study, the following 5 high-touch surfaces in patient rooms were selected for sampling before and after daily cleaning by housekeepers: bedside rails, overbed tables, television remote controls, toilet seats, and bathroom grab bars in patient bathrooms. Surfaces were sampled for culture shortly before daily cleaning. Samples were obtained after the housekeeper had exited the room and after disinfectant had been allowed to dry for at least 10 minutes. Because of the nonuniform surfaces sampled, we were unable to sample a standardized area on each surface. Sampling included approximately one-eighth to one-fourth of the surface of an overbed table, the entire television remote control, 12 inches of the grab bars and top surface of the upper bedside rails, and one-half of the toilet seat. Surfaces were sampled by use of moistened swabs, which were used to inoculate blood agar plates, chromogenic methicillin-resistant *Staphylococcus aureus* (MRSA) selective agar plates (CHROMagar MRSA; BD Diagnostics), and *Campylobacter* agar plates and then placed in broth enrichment. No neutralizers were incorporated into the agar or broth used for culture. Broth cultures were inoculated onto the same agar plates after 24 hours of incubation. Total aerobic colony counts were determined after 48 hours of incubation. Mauve colonies growing on chromogenic MRSA selective agar were classified as MRSA after use of a confirmatory coagulase test. Colonies growing on *Campylobacter* agar that were morphologically consistent with enterococci, that tested positive for pyrrolidonyl arylamidase, and that grew on brain-heart infusion agar plates containing 6 μg/mL vancomycin were considered to be vancomycin-resistant *Enterococcus* (VRE).

An ATP bioluminescence assay (3M Clean-Trace ATP System; 3M) was used to assess the level of cleanliness of surfaces.[20] This assay includes specialized swabs for sampling surfaces, ATP bioluminescence reaction tubes, hand-held programmable luminometers for detecting and recording the amount of ATP present on swabs, and a customized database that is used to store and analyze results. At the same time that moistened swabs were used to sample the 5 high-touch surfaces for culture, ATP swabs were used to sample the surfaces immediately adjacent to the areas sampled for culture. These specialized swabs were placed into ATP bioluminescence reaction tubes and agitated for at least 5 seconds. During this time, the following reaction occurred:

$$\text{luciferase} + \text{D-luciferin} + O_2 + \text{ATP} \Rightarrow \text{luciferase} + \text{oxyluciferin} + CO_2 + \text{AMP} + PP_i + \text{light},$$

where AMP is adenosine monophosphate and PP_i is inorganic pyrophosphate.

The amount of light (ie, bioluminescence) generated is proportional to the amount of organic material present on the swabs; organic material contains ATP, which emits light when combined with the compounds in the ATP bioluminescence assay. After the reaction tubes containing the swabs were agitated, the reaction tubes were inserted into a luminometer, which provides a digital readout of the amount of light generated by the luciferase reaction, expressed as relative light units (RLUs). Well-cleaned surfaces with very little organic material present yielded less than 250–300 RLUs, whereas poorly cleaned surfaces with a lot of organic material present yielded more than 1,000 RLUs. The ATP readings obtained from the 5 high-touch surfaces before and after daily room cleaning were uploaded from the luminometer into the customized database for further analysis. The samples were obtained by a member of the infection control program from a convenience sample of 20 patient rooms to determine aerobic colony counts and ATP readings. Housekeepers were not notified that monitoring of cleaning practices was being performed.

Phase II

The major goal of phase II of our study was to establish with greater certainty the range of ATP readings to be expected on high-touch surfaces in patient rooms before and after daily cleaning. A secondary goal was to determine whether alerting housekeepers that cleaning procedures were being monitored would result in improved cleaning practices, as reflected in the ATP readings. At the beginning of phase II, in-service educational sessions regarding the role contaminated environmental surfaces play in the transmission of pathogens, the importance of daily cleaning, and the results of phase I were presented to housekeepers by an infection control practitioner. During the second phase of our study, 2 environmental services managers were instructed on how to use the ATP swabs and luminometers. Before obtaining samples of the 5 high-touch surfaces in a patient room, the managers notified housekeepers that they would be obtaining ATP readings of the 5 high-touch surfaces before and after cleaning. Housekeepers were aware of which surfaces were being monitored. ATP readings were obtained in patient rooms located on all medical and surgical wards. The wards where the sampling was performed were randomized by use of SPSS software, version 10.1.0 (SPSS). This was done to ensure that the sam-

ples were obtained in rooms occupied by different types of patients and that the rooms were cleaned by a variety of housekeepers. The individual patient rooms to be sampled were not randomized.

Hospital Cleaning Methods

Daily cleaning of the patient rooms included in our study was performed with the use of a detergent disinfectant containing 660 ppm of active quaternary ammonium (Virex II 256; JohnsonDiversey). Wipes submerged in buckets containing the disinfectant were used to clean surfaces. Rooms disinfected with 10% household bleach were not included, because high concentrations of bleach can quench the ATP bioluminescence reaction.

Statistical Analysis

The data collected from all of the samples were transferred to SPSS software, version 10.1.0 (SPSS), for statistical analysis. The median aerobic colony count and the median RLU were determined for each of the 5 high-touch surfaces before and after daily cleaning. Paired data were analyzed by use of the Wilcoxon signed ranks test. When comparing ATP readings after daily cleaning during phases I and II, the data were analyzed by use of the Mann-Whitney *U* test.

RESULTS

Phase I

Colony counts obtained before and after cleaning in the 20 patient rooms varied considerably for all 5 high-touch surfaces (Table 1). The proportions of surfaces with a colony count after cleaning that was lower than before cleaning were as follows: 12 (60%) of 20 bedside rails, 6 (30%) of 20 overbed tables, 5 (25%) of 20 television remote controls, 11 (55%) of 20 bathroom grab bars, and 14 (70%) of 20 toilet seats. The median colony counts obtained after cleaning were significantly lower than those obtained before cleaning for bathroom grab bars ($P = .02$) and toilet seats ($P = .03$) only (Table 1).

The proportions of samples for culture that were positive for MRSA before cleaning were as follows: 12 (60%) of 20 bedside rails, 9 (45%) of 20 overbed tables, 9 (45%) of 20 television remote controls, 4 (20%) of 20 bathroom grab bars, and 6 (30%) of 20 toilet seats. The proportions of samples for culture that were positive for MRSA after cleaning were as follows: 9 (45%) of 20 bedside rails, 8 (40%) of 20 overbed tables, 4 (20%) of 20 television remote controls, 3 (15%) of 20 bathroom grab bars, and none (0%) of 20 toilet seats. Of the 100 surface samples tested by culture, 40 (40%) were positive for MRSA before cleaning, and 24 (24%) were positive for MRSA after cleaning. For surface samples that were positive for MRSA by direct plating, the median colony count on culture was less than 5 for all surfaces, except overbed tables after cleaning (median colony count on culture, 24) and television remote controls after cleaning (median colony count on culture, 15).

The proportions of samples for culture that were positive for VRE before cleaning were as follows: 6 (30%) of 20 bedside rails, 8 (40%) of 20 overbed tables, 2 (10%) of 20 television remote controls, 3 (15%) of 20 bathroom grab bars, and 5 (25%) of 20 toilet seats. The proportions of samples for culture that were positive for VRE after cleaning were as follows: 3 (15%) of 20 bedside rails, 3 (15%) of 20 overbed tables, 4 (20%) of 20 television remote controls, 2 (10%) of 20 bathroom grab bars, and 4 (20%) of 20 toilet seats. Of the 100 surface samples tested by culture, 24 (24%) were positive for VRE before cleaning, and 16 (16%) were positive for VRE after cleaning. For surface samples that were positive for VRE by direct plating, the median colony count on culture was less than 10 for all surfaces, except bathroom grab bars after cleaning (median colony count on culture, 100) and toilet seats before cleaning (median colony count on culture, 65).

ATP readings (expressed as RLUs) that were obtained before and after cleaning in 20 patient rooms also varied considerably for the 5 high-touch surfaces (Table 1). The proportions of surface samples with a median RLU value that was lower after cleaning than before cleaning were as follows: 7 (35%) of 20 bedside rails, 10 (50%) of 20 overbed tables, 12 (60%) of 20 television remotes controls, 16 (80%) of 20 bathroom grab bars, and 16 (80%) of 20 toilet seats. The median RLU values obtained after cleaning were statistically significantly lower than those obtained before cleaning only for bathroom grab bars ($P = .03$) and toilet seats ($P = .01$) (Table 1).

The aerobic colony counts obtained before and after clean-

TABLE 1. Phase I Data on Samples Obtained From 5 High-Touch Surfaces in 20 Patient Rooms, Before and After Daily Cleaning, at the Hospital of Saint Raphael

Unit of measure, time of sampling	Bedside rails	*P*	Overbed tables	*P*	Television remote controls	*P*	Bathroom grab bars	*P*	Toilet seats	*P*
Median ACC on culture (range)		.07		.20		.55		.02		.03
Before cleaning	43 (1 to >100)		21 (2 to >100)		20 (0 to >100)		9 (0 to >100)		14.5 (2 to >100)	
After cleaning	19 (4 to >100)		57.5 (1 to >100)		15 (0 to >100)		2 (0 to >100)		1 (0 to >100)	
Median RLU values (range)		.17		.60		.23		.03		.01
Before cleaning	275 (73–3,070)		212 (15–13,413)		324 (54–7,993)		431 (40–1,987)		293 (64–4,744)	
After cleaning	614 (32–3,254)		201 (9–2,658)		187 (50–2,296)		182 (33–2,338)		82 (12–6,488)	

NOTE. ACC, aerobic colony count; RLU, relative light unit.

ing were combined and compared with the RLU values obtained both before and after cleaning. There was a low, albeit statistically significant, correlation between colony counts and RLU values for each of the 5 high-touch surfaces, with correlation coefficients ranging from 0.356 to 0.649 (Table 2).

Phase II

A total of 1,013 ATP readings were obtained from the 5 high-touch surfaces before and after daily cleaning of 105 patient rooms on 16 wards. The RLU values obtained from the samples of the high-touch surfaces before and after cleaning are shown in Table 3. The proportions of surface samples with a median RLU value that was lower after cleaning than it was before cleaning were as follows: 76 (74%) of 103 bed rails, 85 (83%) of 102 overbed tables, 72 (71%) of 101 television remotes controls, 72 (73%) of 99 bathroom grab bars, and 69 (70%) of 98 toilet seats. The median RLU values obtained after cleaning were statistically significantly lower than those obtained before cleaning for all 5 high-touch surfaces (Table 3).

A comparison of the RLU values obtained after cleaning during phase I (when housekeepers were unaware that ATP readings were being taken) with those obtained after cleaning during phase II (when housekeepers had already gone to in-service educational sessions and were told in advance that ATP readings would be taken) revealed that the median RLU values were significantly lower during phase II than during phase I, except for toilet seats, which revealed low RLU values during phase I (Figure).

TABLE 2. Correlation Between Aerobic Colony Counts and Relative Light Unit Values for Samples Obtained From 5 High-Touch Surfaces in 20 Patient Rooms at the Hospital of Saint Raphael

High-touch surface sample	Spearman rank correlation coefficient	*P*
Bedside rail	0.356	.024
Overbed table	0.428	.006
Television remote control	0.401	.011
Bathroom grab bar	0.385	.018
Toilet seat	0.649	<.001

NOTE. The aerobic colony counts obtained both before and after cleaning were compared with the relative light unit values obtained both before and after cleaning.

DISCUSSION

We used both aerobic colony counts and the detection of ATP to monitor the effectiveness of daily cleaning of 5 high-touch surfaces in patient rooms, and we established that housekeepers were not adhering to a set of newly implemented cleaning policies. On the basis of these findings, new educational programs were developed and presented to housekeepers, and discussions were held with environmental services managers regarding the deficiencies identified. Subsequently, housekeepers were notified in advance when the patient rooms to be cleaned would be checked after cleaning. This combination of measures resulted in significant improvement in the cleanliness of all 5 high-touch surfaces, as reflected in the reduced levels of ATP observed on the surface samples after daily cleaning.

In many hospitals, it is likely that there has been little assessment of the adequacy of routine housekeeping practices. Recent studies have documented that cleaning of patient care areas is often suboptimal and that surfaces may remain contaminated with pathogens after routine cleaning.[3,13-17] In some hospitals, visual inspection of cleaned surfaces has been assumed to be adequate. However, surfaces that meet visual criteria for cleanliness often remain contaminated with microorganisms or other organic material.[19,21-23] As a result, more quantitative methods are warranted to adequately assess the effectiveness of cleaning practices.[19]

Our phase I finding that, after the cleaning of some surfaces, the colony counts and ATP readings were not significantly lower than those obtained before cleaning is consistent with other studies demonstrating that 45%–50% of surfaces that should be cleaned are suboptimally cleaned.[3,15] The occurrence of colony counts and ATP readings that were higher after cleaning than before cleaning has also been reported elsewhere.[19] When colony counts and ATP readings in the present study documented that surfaces were not always cleaned appropriately, discussions with housekeepers and environmental services managers identified several obstacles to appropriate cleaning of surfaces that were successfully overcome.

Comparing the aerobic colony counts observed in our study with those reported in earlier studies is problematic because the sampling methods that we used were different from those used by some other investigators.[13,19,22,24,25] We expressed results as the number of colony-forming units recovered from each surface sample, rather than as the number of colonies per centimeters squared, because the nonuniform size and shape of the items sampled made it difficult to use a template or Rodac-type contact plates. Nevertheless, we documented that high-touch surfaces were frequently contaminated with a variety of bacteria, including MRSA and VRE.

Although we used the same ATP bioluminescence assay that was utilized in several studies in the United Kingdom, the median RLU values observed in the present study were considerably lower than the mean RLU values reported previously.[19,22] This finding may be related to differences in the types of surfaces sampled and cleaning solutions used in the various studies. The median RLU values observed in phase II of our study were similar to those obtained by Lewis et al.[21] following a modified cleaning protocol. The low degree of correlation between colony counts and ATP readings noted in our study has been reported by others[24,26] and is due to the fact that colony counts detect only viable aerobic bacteria on surfaces, whereas an ATP bioluminescence assay detects all types of organic material present on surfaces.

Phase II was conducted for 2 reasons. We wanted to obtain

a larger sample of observations that reflected the range of ATP readings after daily cleaning on multiple wards by a variety of housekeepers. Also, because the ATP readings obtained during phase I obviously reflected suboptimal cleaning practices, we wanted to establish the level of ATP readings that could be expected when more thorough cleaning was performed. It was for this reason that housekeeper educational sessions were conducted and cleaning personnel were informed in advance that selected rooms would be tested after cleaning. We found that high-touch surfaces were significantly cleaner after daily cleaning during phase II than they were after cleaning during phase I (Figure). Overall, 388 (77%) of 503 surface samples tested after cleaning during phase II had ATP readings of less than 250 RLUs, a recently proposed standard for defining hospital surfaces as clean.[21] Smooth, flat surfaces were more likely than irregular surfaces to yield RLU values of less than 250.

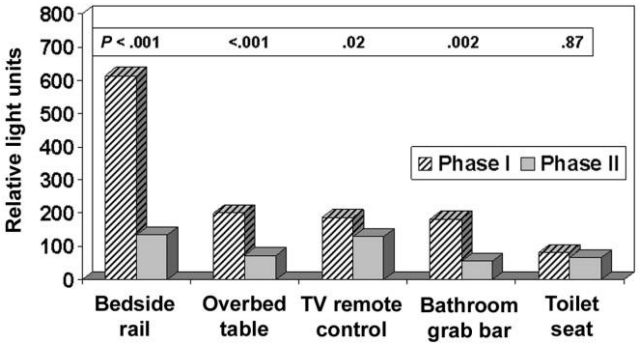

FIGURE. Bar graph of adenosine triphosphate readings, expressed as relative light units, from 5 high-touch surface samples after daily cleaning, during phase I *(striped bars)* and phase II *(solid bars)*. TV, television.

Our study has several limitations. Colony counts were obtained from a small number of rooms and may not reflect the level of bacterial contamination of such surfaces throughout our facility or in other hospitals. Failure to incorporate a neutralizer into culture media may have resulted in an underestimation of the number of bacteria on surfaces. During phase II, financial constraints and limited resources prevented us from performing colony counts. Notifying housekeepers in advance that the room they were about to clean would be monitored could well have resulted in the Hawthorne effect, whereby housekeepers' performance improved only when they knew they were being observed. However, it is of interest to note that an improvement in cleaning practices was sustained throughout phase II and was greater during the latter half of phase II than during the initial half (data not shown). To determine whether the Hawthorne effect accounted for much of the improvement observed during phase II, we are conducting a third phase of the study in which random, unannounced ATP readings will be obtained after rooms have been cleaned, and housekeepers will be given the results of the ATP readings shortly after they have completed cleaning the rooms. In addition, housekeepers deemed by environmental services managers to be the most thorough are being observed, and ATP readings after cleaning are being analyzed in an effort to determine whether the recently proposed breakpoint ATP reading of less than 250 RLUs is a practical criterion for classifying surfaces as clean in acute care settings.[21] Additional studies from multiple healthcare facilities are needed before a standardized ATP bioluminescence breakpoint can be established for defining surfaces as adequately cleaned.

The role of monitoring cleaning procedures in healthcare facilities is just beginning to be understood. A recent study

TABLE 3. Phase II Adenosine Triphosphate (ATP) Readings (Expressed as Relative Light Units [RLUs]) of Samples Obtained From 5 High-Touch Surfaces in 105 Patient Rooms, Before and After Daily Cleaning, at the Hospital of Saint Raphael

ATP reading	Bedside rails[a]	Overbed tables[b]	Television remote controls[c]	Bathroom grab bars[d]	Toilet seats[e]
Before cleaning					
<250 RLUs	40/104 (38)	49/104 (47)	44/103 (43)	49/99 (50)	55/100 (55)
250–499 RLUs	21/104 (20)	29/104 (28)	34/103 (33)	23/99 (23)	15/100 (15)
500–999 RLUs	28/104 (27)	16/104 (15)	12/103 (12)	13/99 (13)	9/100 (9)
>1,000 RLUs	15/104 (14)	10/104 (10)	13/103 (13)	14/99 (14)	21/100 (21)
After cleaning					
<250 RLUs	66/103 (64)	90/102 (88)	72/101 (71)	80/99 (81)	80/98 (82)
250–499 RLUs	22/103 (21)	7/102 (7)	20/101 (20)	8/99 (8)	9/98 (9)
500–999 RLUs	8/103 (8)	3/102 (3)	4/101 (4)	3/99 (3)	4/98 (4)
>1,000 RLUs	7/103 (7)	2/102 (2)	5/101 (5)	8/99 (8)	5/98 (5)

NOTE. Data are proportion (%) of surface samples tested.

[a] Median value (range) of 393 (10–17,587) before and 134 (9–3,001) after cleaning ($P < .001$).

[b] Median value (range) of 255.5 (9–4,387) before and 72.5 (12–3,311) after cleaning ($P < .001$).

[c] Median value (range) of 289 (10–130,960) before and 129 (14–9,103) after cleaning ($P < .001$).

[d] Median value (range) of 246 (8–3,480) before and 56 (9–3,259) after cleaning ($P < .001$).

[e] Median value (range) of 195.5 (8–16,313) before and 65.5 (10–5,590) after cleaning ($P < .001$).

demonstrated that, for housekeepers, the combination of education, observation, and feedback resulted in reduced VRE environmental contamination and reduced acquisition of the organism by patients.[3] Marking environmental surfaces with a fluorescent dye, using a black light to detect a residual marker, and providing housekeepers with feedback with regard to the findings has resulted in a greater number of surfaces being cleaned.[7,15,16,27] Of note, a majority of the latter studies did not document that surfaces were in fact cleaner or had less bacterial contamination.[15,16,27] Another study found that the use of a fluorescent marker and feedback based on this monitoring system resulted in surfaces being less contaminated with MRSA and VRE.[7] Of interest, there was no association between the removal of the marker from a specific surface and the likelihood that the surface sample would yield MRSA or VRE on culture. In another study, 33% of toilet samples with no visible residual fluorescent marker were still contaminated with *Clostridium difficile* spores in rooms of patients with *C. difficile*–associated diarrhea.[28] In contrast to fluorescent markers, the ATP bioluminescence assay provides a quantitative measure of the amount of organic material remaining on surfaces after cleaning.

In conclusion, the ATP bioluminescence assay was used in our study to document the level of cleanliness of high-touch surfaces after routine daily cleaning in patient rooms and to study the impact of educational sessions and training on the adequacy of cleaning practices. This assay could also be used to evaluate the efficacy of terminal cleaning procedures. ATP readings can provide real-time feedback to housekeepers regarding their performance, an advantage over the 24–48 hours required to obtain results using microbiological methods. The digital readings obtained using the ATP bioluminescence assay and accompanying data analysis software provide a system for tracking the adequacy of cleaning over time.

ACKNOWLEDGMENTS

Financial support. The work was supported in part by a research grant from 3M.

Potential conflicts of interest. J.M.B. has served as a consultant to 3M. All other authors report no conflicts of interest relevant to this article.

Address reprint requests to John M. Boyce, MD, Infectious Diseases Section, Hospital of Saint Raphael, 1450 Chapel Street, New Haven, CT 06511 (JBoyce@srhs.org).

Presented in part: 18th Annual Scientific Meeting of the Society for Healthcare Epidemiology of America; Orlando, Florida; April 5–8, 2008.

REFERENCES

1. Siegel JD, Rhinehart E, Jackson M, Chiarello L; Health Care Infection Control Practices Advisory Committee. 2007 Guideline for isolation precautions: preventing transmission of infectious agents in health care settings. *Am J Infect Control* 2007; 35 (Suppl 2):S65–S164.
2. Samore MH, Venkataraman L, Degirolami PC, Levin E, Karchmer AW. Clinical and molecular epidemiology of sporadic and clustered cases of nosocomial *Clostridium difficile* diarrhea. *Am J Med* 1996; 100:32–40.
3. Hayden MK, Bonten MJ, Blom DW, Lyle EA, van de Vijver DA, Weinstein RA. Reduction in acquisition of vancomycin-resistant *Enterococcus* after enforcement of routine environmental cleaning measures. *Clin Infect Dis* 2006; 42:1552–1560.
4. Hayden MK, Blom DW, Lyle EA, Moore CG, Weinstein RA. Risk of hand or glove contamination after contact with patients colonized with vancomycin-resistant *Enterococcus* or the colonized patient's environment. *Infect Control Hosp Epidemiol* 2008; 29:149–154.
5. Martínez JA, Ruthazer R, Hansjosten K, Barefoot L, Snydman DR. Role of environmental contamination as a risk factor for acquisition of vancomycin-resistant enterococci by in patients treated in a medical intensive care unit. *Arch Intern Med* 2003; 163:1905–1912.
6. Huang SS, Datta R, Platt R. Risk of acquiring antibiotic-resistant bacteria from prior room occupants. *Arch Intern Med* 2006; 166:1945–1951.
7. Goodman ER, Platt R, Bass R, Onderdon AB, Yokoe DS, Huang SS. Impact of an environmental cleaning intervention on the presence of methicillin-resistant *Staphylococcus aureus* and vancomycin-resistant enterococci on surfaces in intenstive care unit rooms. *Infect Control Hosp Epidemiol* 2008; 29:593–599.
8. Wu HM, Fornek M, Schwab KJ, et al. A norovirus outbreak at a long-term–care facility: the role of environmental surface contamination. *Infect Control Hosp Epidemiol* 2005; 26:802–810.
9. Dancer SJ. Mopping up hospital infection. *J Hosp Infect* 1999; 43:85–100.
10. Siegel JD, Rhinehart E, Jackson M, Chiarello L; Healthcare Infection Control Practices Advisory Committee. Management of multidrug-resistant organisms in health care settings. *Am J Infect Control* 2006; 35 (10 Suppl 2):S165–S193.
11. Sehulster L, Chinn RY; Centers for Disease Control and Prevention; Healthcare Infection Control Practices Advisory Committee. Guidelines for environmental infection control in health-care facilities. Recommendations of CDC and the Healthcare Infection Control Practices Advisory Committee (HICPAC). *MMWR Recomm Rep* 2003; 52(RR-10):1–42.
12. Muto CA, Jernigan JA, Ostrowsky BE, et al. SHEA guideline for preventing nosocomial transmission of multidrug-resistant strains of *Staphylococcus aureus* and *Enterococcus. Infect Control Hosp Epidemiol* 2003; 24: 362–386.
13. Malik RE, Cooper RA, Griffith CJ. Use of audit tools to evaluate the efficacy of cleaning systems in hospitals. *Am J Infect Control* 2003; 31: 181–187.
14. French GL, Otter JA, Shannon KP, Adams NMT, Watling D, Parks MJ. Tackling contamination of the hospital environment by methicillin-resistant *Staphylococcus aureus* (MRSA): a comparison between conventional terminal cleaning and hydrogen peroxide vapour decontamination. *J Hosp Infect* 2004; 57:31–37.
15. Carling PC, Briggs JL, Perkins J, Highlander D. Improved cleaning of patient rooms using a new targeting method. *Clin Infect Dis* 2006; 42: 385–388.
16. Carling PC, Parry MF, Von Beheren SM; Healthcare Environmental Hygiene Study Group. Identifying opportunities to enhance environmental cleaning in 23 acute care hospitals. *Infect Control Hosp Epidemiol* 2008; 29:1–7.
17. Eckstein BC, Adams DA, Eckstein EC, et al. Reduction of *Clostridium difficile* and vancomycin-resistant *Enterococcus* contamination of environmental surfaces after an intervention to improve cleaning methods. *BMC Infect Dis* 2007; 7:61.
18. Dancer SJ. How do we assess hospital cleaning? A proposal for microbiological standards for surface hygiene in hospitals. *J Hosp Infect* 2004; 56: 10–15.
19. Griffith CJ, Cooper RA, Gilmore J, Davies C, Lewis M. An evaluation of hospital cleaning regimes and standards. *J Hosp Infect* 2000; 45:19–28.
20. Davidson CA, Griffith CJ, Peters AC, Fielding LM. Evaluation of two methods for monitoring surface cleanliness—ATP bioluminescence and traditional hygiene swabbing. *Luminescence* 1999; 14:33–38.
21. Lewis T, Griffith C, Gallo M, Weinbren M. A modified ATP benchmark for evaluating the cleaning of some hospital environmental surfaces. *J Hosp Infect* 2008; 69:156–163.

22. Cooper RA, Griffith CJ, Malik RE, Obee P, Looker N. Monitoring the effectiveness of cleaning in four British hospitals. *Am J Infect Control* 2007; 35:338–341.
23. Griffith CJ, Obee P, Cooper RA, Burton NF, Lewis M. The effectiveness of existing and modified cleaning regimens in a Welsh hospital. *J Hosp Infect* 2007; 66:352–359.
24. Aycicek H, Oguz U, Karci K. Comparison of results of ATP bioluminescence and traditional hygiene swabbing methods for the determination of surface cleanliness at a hospital kitchen. *Int J Hyg Environ Health* 2006; 209:203–206.
25. White LF, Dancer SJ, Robertson C, McDonald J. Are hygiene standards useful in assessing infection risk? *Am J Infect Control* 2008; 36:381–384.
26. Poulis JA, de Pijper M, Mossel DAA, Dekkers PPhA. Assessment of cleaning and disinfection in the food industry with the rapid ATP-bioluminescence technique combined with the tissue fluid contamination test and a conventional microbiological method. *Int J Food Microbiol* 1993; 20:109–116.
27. Carling PC, Von Beheren S, Kim P, Woods C; Healthcare Environmental Hygiene Study Group. Intensive care unit environment cleaning: an evaluation in sixteen hospitals using a novel assessment tool. *J Hosp Infect* 2008; 68:39–44.
28. Alfa MJ, Dueck C, Olson N, et al. UV-visible marker confirms that environmental persistence of *Clostridium difficile* spores in toilets of patients with *C. difficile*-associated diarrhea is associated with lack of compliance with cleaning protocol. *BMC Infect Dis* 2008; 8:64–70.

Evaluating hygienic cleaning in health care settings: What you do not know can harm your patients

Philip C. Carling, MD, and Judene M. Bartley, MS, MPH, CIC
Boston, Massachusetts, and Detroit, Michigan

Recent studies using direct covert observation or a fluorescent targeting method have consistently confirmed that most near patient surfaces are not being cleaned in accordance with existing hospital policies while other studies have confirmed that patients admitted to rooms previously occupied by patients with hospital pathogens have a substantially greater risk of acquiring the same pathogen than patients not occupying such rooms. These findings, in the context recent studies that have shown disinfection cleaning can be improved on average more than 100% over baseline, and that such improvement has been associated with a decrease in environmental contamination of high touch surfaces, support the benefit of decreasing environmental contamination of such surfaces. This review clarifies the differences between measuring cleanliness versus cleaning practices; describes and analyzes conventional and enhanced monitoring programs; addresses the critical aspects of evaluating disinfection hygiene in light of guidelines and standards; analyzes current hygienic practice monitoring tools; and recommends elements that should be included in an enhanced monitoring program.

Key Words: Enhanced environmental hygiene monitoring; surface disinfection cleaning; health care process improvement; patient safety; health care-associated pathogen transmission; quality assurance.

 (Am J Infect Control 2010;38:S41-50.)

The medical and economic toll of infections with increasingly antibiotic resistant pathogens has continued to escalate. Whereas efforts to improve hand hygiene and isolation practices have been implemented to help mitigate this problem, recent studies have documented the limitation of such interventions.[1-4] Although active surveillance protocols and rigorous adherence to precautions may decrease methicillin-resistant *Staphylococcus aureus* (MRSA) transmission, in certain settings[5] such interventions have not decreased overall nosocomial infection rates in several northern European countries, which remain similar to rates in southern European countries and the United States,[6] and have not been shown to be consistently effective or necessary in this country.[7] It has now been well documented that a wide range of particularly environmentally resilient hospital-acquired infection (HAI) pathogens can be readily cultured from near patient surfaces.[8-10] Eight recent studies have now confirmed that patients occupying rooms previously occupied by patients with vancomycin-resistant *Enterococcus* (VRE),[11-15] MRSA,[13-16] *Clostridium difficile*,[17] and *Acinetobacter baumannii*[18] infection or colonization have on average a 73% increased risk of acquiring the same pathogen than patients not occupying such rooms (Fig 1). Over the past 4 years, 8 studies using direct covert observation or a fluorescent targeting method have confirmed that only 40% of near patient surfaces are being cleaned in accordance with existing hospital policies.[11,19-25] These findings, in the context of the fact that 11 studies have now shown that the thoroughness of disinfection cleaning can be improved to 82% (on average more than 100% over baseline)[11,21,22,26-33] and the fact that such improvement has been associated with an on average 68% decrease in environmental contamination of ''high-risk objects,''[11,21,22,24,28,34] together support the likely benefit of decreasing environmental contamination of such surfaces. In addition, 5 studies have recently shown that improved routine disinfection cleaning practice is associated with an average 40% decrease in transmission of VRE,[11-15,28] MRSA,[15,34] and *A baumannii*.[18]

From the Infectious Diseases Section, Department of Medicine, Boston University School of Medicine, Boston, MA; and VP Epidemiology Consulting Services, Inc (ECSI), Detroit, MI.

Address correspondence to Philip C. Carling, MD, director of Hospital Epidemiology, Carney Hospital, 2100 Dorchester Ave, Boston, MA 02124. E-mail: Pcarling@cchcs.org.

STATEMENT OF CONFLICT OF INTEREST: Dr. Carling has been compensated as a consultant of Ecolab and Steris. He owns a patent for the florescent targeting evaluation system described in the manuscript. Ms. Bartley reports no conflicts of interest.

Publication of this article was made possible by unrestricted educational grants from The Clorox Company, the American Society for Healthcare Engineering, and the Facility Guidelines Institute.

0196-6553/$36.00

doi:10.1016/j.ajic.2010.03.004

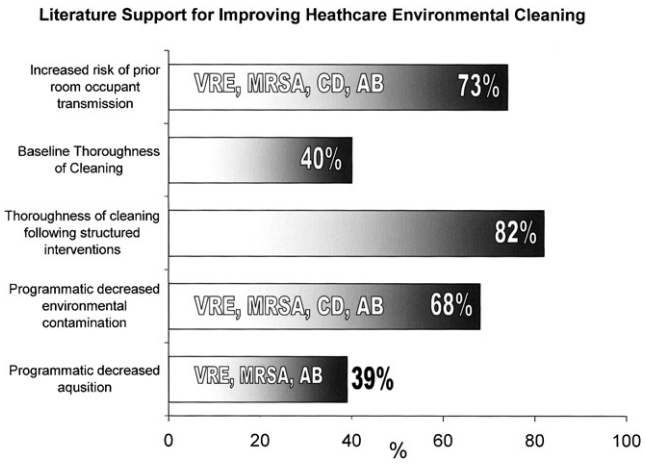

Fig 1. Summary of studies that provide support for improving heath care environmental cleaning practice.

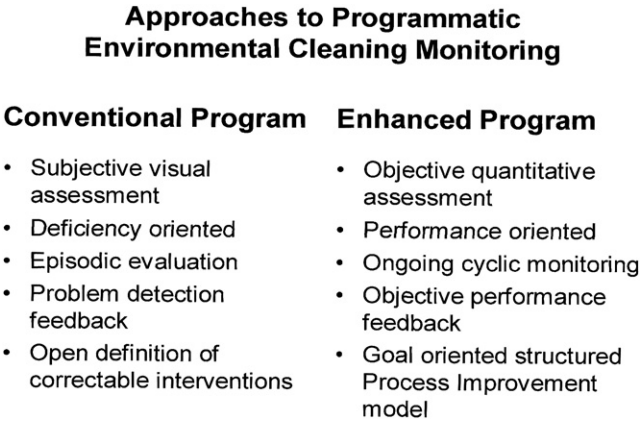

Fig 2. A comparison of the elements of conventional hygienic monitoring with enhanced programs.

GUIDELINES AND STANDARDS

During the past 6 years, there has been a dramatic evolution of recommendations and standards as well as state laws related to improving environmental hygiene in health care settings. In 2003, the Centers for Disease Control and Prevention (CDC) Guidelines for Environmental Infection Control in Healthcare Facilities—Environmental Surfaces recommended that hospitals clean and disinfect ''high-touch surfaces.''[35] A subsequent CDC guideline strongly recommended (category 1B) that hospitals ''monitor (ie, supervise and inspect) cleaning performance to ensure consistent cleaning and disinfection of surfaces in close proximity to the patient and likely to be touched by the patient and health care professionals.''[36] As a consequence of these recommendations, the 2007 revised Center for Medicare and Medicaid Services Interpretative Guideline for its infection control standard now requires that the infection prevention and control program of hospitals ''must include appropriate monitoring of housekeeping activities to ensure that the hospital maintains a sanitary environment.''[37] These documents, as well as similar ones in Great Britain and Canada, reflect an evolving mandate that patient area environmental hygiene in health care settings be objectively analyzed and optimized.[38,39]

EVALUATING ENVIRONMENTAL CLEANING PRACTICE

Problem-oriented environmental monitoring

As a result of studies that linked environmental contamination with the transmission of *Staphylococcus aureus* in the late 1950s, attempts were made to use swab-based environmental culturing for *S aureus* as a means for evaluating low-level disinfection cleaning practice in many hospitals. Although the practice diminished in value as the prevalence of *S aureus* in HAIs decreased and the unreliability of sporadic poorly standardized environmental culturing became evident, environmental surface culturing continues to have a role in infection prevention practice. The CDC pointed to the lack of environmental standards for routine sampling but also identified its value if used properly for research or education.[35] The use of environmental cultures has greatly enhanced our understanding of the epidemiology of *C difficile* transmission[40,41] as well as MRSA[42] and VRE.[43,44] Such cultures have also been useful in evaluating the role of environmental contamination in outbreak settings involving *C difficile*,[45,46] *Acinetobacter*,[47] VRE,[11] MRSA,[48] and glycopeptide insensitive *S aureus*.[49] Although potentially useful, logistical challenges involved in the collection of a large enough number of cultures to permit proper epidemiologic analysis, the cost of data collection and specimen analysis (typically including pulse-field gel electroforesis or other strain identification process) as well as the intrinsic challenge of drawing epidemiologically sound conclusions from possibly erratic fluctuations in environmental contamination as a result of unknown confounding variables represent important challenges related to problem-oriented environmental monitoring. Given these issues, the possible short- and long-term benefits of such information make it prudent to weigh carefully the overall value of collecting such data.

Conventional environmental cleaning monitoring

The ongoing evaluation and monitoring of cleaning interventions to reduce the risk of transmission of environmental pathogens through defined procedures have been elements of infection prevention and control practice in

Approaches to Programmatic Hygienic Monitoring

Conventional Program

Advantages

An established model
Easily incorporated into general patient safety monitoring rounds
Rapid remedial action feasible

Limitations

Inability to evaluate actual HP
Based only on negative outcome analysis
Limited generalizability of findings
Poor specificity and low sensitivity
Intrinsically subjective with a high potential for observer bias
Poor programatic specificity
Potential for observer bias
Only evaluates daily HP
Limited ability to support TJC standard EC.04.01.03.EP2
Limited ability to demonstrate compliance with CMS CoP 482.42
Benchmarking not feasible

Enhanced Program

Advantages

Direct evaluation of Environmental cleaning
Uses a standardized, consistent,objective and uniform system of monitoring
Provides regular and ongoing performance results to ES staff
Facilitates the monitoring of many data points to optimize performance analysis
Provides positive practice based feedback to ES staff
Allows for objective remedial interventions
Easily adaptable to existing PI modalities
Facilitates compliance with TJC standards
Facilitates compliance with CMS CoP
Intrinsic internal benchmarking
External benchmarking, reporting and recognition feasible

Limitations

Requires new program implementation
Ongoing administrative support critical to success
Potential resistance to objective monitoring and reporting
While useful, the covert baseline evaluation may be difficult to implement effectively

Potential monitoring tool issues

Fig 3. A comparison of the advantages and limitations of conventional versus enhanced programmatic monitoring of EC process.

acute care hospitals for many years. Until recently, such evaluation has exclusively relied on visual assessment of the cleanliness of surfaces. Currently, 89% of a large sample of US acute care hospitals confirmed that they perform visual assessments of cleanliness during regular environment of care rounds as the primary means for evaluating cleaning practice in their hospitals.[50] The elements of what can be considered ''conventional'' monitoring of low-level disinfection or environmental cleaning (EC) are outlined in Fig 2. Traditionally, such rounds are performed on a regular basis and involve the infection preventionist (IP) and director of emergency services (ES) as well as an administrative representative from patient care services. Together, these individuals visit several patient care areas to monitor compliance with a range of safety practices and to assess visual cleanliness. The identified deficiencies, as they pertain to potential pathogen transmission issues, are reviewed and remedial activities approved by the infection control committee. Such assessment of EC, known as a ''visual audit'' in Great Britain, relies on the observation of visible soilage of surfaces by potentially infectious material or dust and dirt.[9] Such findings are assumed to represent practice failures by the individual or individuals directly responsible for ''ensuring''[36] the microbial safety of the surface in question. Whereas conventional monitoring may identify sporadic gross lapses in cleaning practice as summarized in Fig 3, this practice has a number of limitations including the following:

- An inability to objectively assess actual EC practice;
- the reliance on episodic negative findings as a basis for remedial individual and programmatic interventions;
- placement of undue emphasis on the cleanliness of floors and walls, which have limited roles in pathogen transmission,[51,52] because of the ease with which gross contamination or dirt can be visually documented on these surfaces;
- with the exception of gross contamination by potentially infected material, a low sensitivity for defining what represents a microbiologically ''dirty'' surface;
- poor correlation with microbial contamination, namely, what appears to be clean may harbor substantial levels of microbial contamination[53,54];
- poor programmatic specificity, ie, what may appear to represent a lapse in EC may not be;
- intrinsically subjective with a high potential for observer bias;
- the direct involvement of ES management and patient care leadership in a monitoring system with low sensitivity and specificity, which may lead to inconsistent and potentially misdirected responses to what appear to be lapses in EC;
- an inability to evaluate other than daily EC practice;
- limited ability to support The Joint Commission (TJC) standard EC.04.01.03.EP2, which states that the institution must be able to demonstrate that it ''uses the results of data analysis to identify opportunities to resolve environmental safety issues''[55];
- limited ability to demonstrate compliance with the Center for Medicare Services (CMS)[37] Conditions for Participation (CoP), section 482.42.;
- the need to utilize substantial leadership level personnel resources;
- a limited ability to evaluate more than a small sample of patient care areas on a frequent basis; and
- an inability to define and respond to institutional or interinstitutional standards of EC through benchmarking.

As an adjunct to such conventional monitoring activities, 78% of hospitals also analyze patient satisfaction surveys to evaluate EC.[50] Whereas such surveys may episodically identify gross lapses in EC, the very poor specificity and sensitivity of such surveys make it challenging to use them to evaluate overall practice within an institution.

Enhanced EC monitoring

In response to an evolving understanding of the importance of the near-patient environment (also referred to as the ''patient zone'')[56] in the transmission of health care-associated pathogens (HAP) as well as studies that identified opportunities for improving EC,[57-59] an objective and substantially more structured approach to monitoring such activities has recently evolved. As currently practiced and summarized in Fig 2, the basic components of ''Enhanced'' EC monitoring encompasses the following elements:

- Uses an objective monitoring tool to evaluate the process of EC;
- is performance rather than deficiency oriented;
- is based on the development of an independently functioning structured monitoring program incorporating specific EC policy-based expectations and goals;
- relies on the repetitive monitoring of actual EC by trained, unbiased individuals on an ongoing basis; and
- is incorporated independently into the institution's ongoing quality improvement process through the infection control committee.

As summarized in Fig 3, the advantages of such an enhanced program include the following elements:

- Allows for the direct evaluation of the process of hygienic cleaning;
- incorporates a built-in standardization and uniformity of evaluation;

Evaluating Patient Zone Environmental Hygiene

Method	Ease of Use	Identifies Pathogens	Useful for Individual Teaching	Directly Evaluates Cleaning	Published Use in Programatic Improvement
Covert Practice Observation	Low	No	Yes	Yes	1 Hospital [11]
Swab cultures	High	Yes	Not Studied	Potentially	1 Hospital [60]
Agar slide cultures	Good	Limited	Not Studied	Potentially	1 Hospital [58]
Fluorescent gel	High	No	Yes	Yes	49 Hospitals [22,26,32,33]
ATP system	High	No	Yes	Potentially	2 Hospitals [20,74]

Fig 4. Summary of the 5 methods used in evaluating environmental hygiene.

- incorporates ES staff education based on specific objectively evaluable expectations;
- facilitates the development of a program that has a high potential for identifying specific as well as systemic institutional programmatic issues that limit or adversely impact EC;
- allows for short cycle monitoring of ES staff performance with direct feedback to improve EC and documents the sustainability of improvements, once they have been achieved;
- has the potential for using positive performance achievement to reinforce good performance and the value of such performance in the context of the institution's objectively defined patient safety goals;
- has the ability to objectively identify and document individual EC oversights and the need for remedial action;
- represents a system easily adaptable to established process improvement (PI) modalities such as the Plan-Do-Act (PDA) cycle, Positive Deviance, Six sigma, and others;
- facilitates compliance with TJC standards;
- facilitates compliance with CMS CoP mandates;
- provides objective performance information for internal and interinstitutional benchmarking;
- allows for use of the same monitoring systems for one-on-one and small group, hands-on, education; and
- facilitates the use of the same process improvement system over a range of practices and venues within the hospital and potentially other health care settings.

It is beyond the scope of the current discussion to provide a complete cost/benefit analysis of these programs, but, in light of current financial constraints, one additional advantage worth noting is that, overall in a large study of 36 hospitals, the program appears to be resource neutral, with less than a 1% increase in ES resources.[26]

Although enhanced EC monitoring has a range of advantages, several limitations to its use have so far been identified (Fig 3), including the following:

- The need to develop and implement a new program often in a setting of limited IPs' resources;
- the critical need for administrative support for successful implementation and maintenance of the ongoing program;
- the need to maintain a positive, blameless, close working relationship between IP and ES leadership;
- complexities associated with the need (or at least value) of covertly collecting a preintervention assessment of EC to optimize subsequent data analysis and education; and
- potential monitoring tool issues.

Whereas objective monitoring of practice has evolved as the cornerstone of enhanced programs, the incorporation of patient survey results and problem-based interventions constitute important components of the overall program.

ANALYSIS OF HYGIENIC PRACTICE MONITORING TOOLS

Whereas the advantages of enhanced EC monitoring in contrast to the limitations of conventional monitoring provide support for hospitals implementing programs to objectively monitor EC, the advantages and limitations of various monitoring approaches and tools must also be considered. As summarized in Fig 4 and noted below, there are currently 5 systems that may be potentially useful for enhanced programmatic monitoring.

Covert practice observation

Covertly monitoring EC can provide an objective assessment of individual ES staff performance and

compliance with cleaning protocols. This approach has been used to evaluate and improve environmental hygiene related to VRE transmission in one hospital. Hayden et al utilized a trained research observer to covertly monitor daily disinfection cleaning of 8 high-risk objects in an intensive care unit during the 2-month baseline portion of the study.[11] Thoroughness of disinfection cleaning was then monitored following educational interventions along with immediate feedback during cleaning by the research staff. As a result, the thoroughness of environmental cleaning improved from 48% to 87%, and VRE transmission decreased significantly. Although clearly effective, logistical issues related to maintaining such a program outside a research setting could limit adaptation of this form of EC monitoring as a process improvement intervention.

Swab cultures

As noted previously, swab cultures of surfaces have been utilized in a range of clinical settings to study the environmental epidemiology of many HAPs as well as in the evaluation of outbreaks related to specific organisms. Whereas several outbreak intervention studies have attributed favorable outcomes to improved EC in association with decreased environmental contamination by target organisms, none of the reports specifically note whether serial environmental culture results were actually used to provide EC practice feedback to the ES staff. In a single study evaluating the impact of various programmatic and educational interventions to improve disinfection cleaning of intensive care unit keyboards, the confirmation of VRE contamination was used effectively to improve cleaning performance.[27] Broth-enriched swab cultures to quantify bacterial contamination of patient area surfaces have been used in a single study, along with Adeneinetriphosphate (ATP) results, to provide direct feedback to ES staff.[60] In this study, overall ATP scores improved following feedback, but the impact on actual bacterial contamination was not reported. Although swab cultures are easy to use, the cost of processing, including isolate identification (if needed), the delay in analyzing results, the need to develop baseline values for comparisons, and the limited feasibility of monitoring multiple surfaces in multiple patient rooms as part of an ongoing EC monitoring program in other than a research setting may be issues that could limit the broad application of such a system for evaluating EC practice.

Agar slide cultures

Agar-coated glass slides with finger holds were developed to simplify quantitative cultures of liquids. The slides have been adopted for use in environmental surface monitoring to assess the limitations of visual audits of EC.[58] Subsequently, several studies have used agar-coated slide systems to evaluate cleaning practice as well as to compare cleaning regimens[61,62] by quantifying aerobic colony counts (ACCs) per square centimeter[61,63] as well as to compare cleaning regimens.[61,63] Although 2 studies[61,64] measured ACCs before and after cleaning, no studies to date have evaluated the actual thoroughness of cleaning of the same objects to determine whether objects with relatively high ACCs surfaces were either poorly cleaned or actually overlooked by the ES staff. Although some difficulties have been encountered in utilizing the agar contact culturing on other than large, flat surfaces, they potentially provide an easy method for quantifying viable microbial surface contamination. There is a need, similar to that noted above for swab cultures, to develop baseline values for accurate interpretation of study findings. Agar-coated slides and dedicated incubation systems are commercially available.

Fluorescent gel

A monitoring system using an essentially invisible transparent gel that dries on surfaces following application and resists abrasion was developed specifically to evaluate the thoroughness of environmental cleaning in health care settings. Following the identification of opportunities to improve cleaning in 23 hospitals,[59] use of the system within a structured process improvement program led to the thoroughness of disinfection cleaning improving from 48% to 77% in 36 study hospitals.[26] The same system was subsequently used by Goodman et al to evaluate EC in 10 intensive care units in a single hospital. Following performance feedback, the thoroughness of cleaning improved from 44% to 71%.[22] Further analysis of this study has confirmed that improved EC was associated with decreased MRSA and VRE transmission.[15] Most recently, the same monitoring tool and PI system were used in coordination with group performance benchmarking and facilitated program analysis in 12 hospitals within a single health care system.[33] Average thoroughness of terminal room disinfection cleaning improved significantly with 11 of the 12 study hospitals achieving sustained rates of improved cleaning to 85% or above. However, as noted in Fig 4, the fluorescent gel system cannot be used to measure actual cleanliness of surfaces but only thoroughness of cleaning practice. For this reason, the system must be used in conjunction with environmental cultures for problem-oriented hygienic monitoring as discussed previously. The system is commercially available for use in acute care hospitals on a subscription basis.

ATP bioluminescence

The measurement of organic ATP on surfaces using a luciferase assay and luminometer has been used to evaluate cleanliness of food preparation surfaces for more than 30 years.[65] A specialized swab is used to sample a standardized surface area, which is then analyzed using a portable handheld luminometer. The amount of ATP, both microbial and nonmicrobial, is quantified and expressed as relative light units (RLU). Although readout scales vary more than 10-fold[66] and sensitivity varies between commercially available systems,[67] very low readings are typically associated with low ACCs on food preparation surfaces.[68] Very high RLU readings may represent either the viable bioburden, organic debris including dead bacteria, or a combination of both. Indeed, a recent study has found that debris accounts for approximately 66% of ATP on surfaces.[58] The clinical relevance of this issue was clarified by Griffith et al[69] as well as in a study of ambient contamination of surfaces potentially touched following handwashing based on proposed cleanliness standards.[70] A mean ATP RLU reading of 3707 was found on the 618 surfaces tested, with 89% failing to meet the <500 RLU level in a proposed standard. In contrast, only 27% (168/618) of the same surfaces had ACCs above the proposed ACC cleanliness standard of <2.5 (colony-forming units)/cm^2. In 2007, a study was undertaken by the National Health Service to evaluate the potential role the ATP tool in evaluating EC in hospitals.[54] While noting limitations in the ATP system, the authors concluded that the tool could potentially be used effectively for education of ES staff, although an evaluation of such use was not part of the study design. Although it is likely that part of the lack of correlation between ATP readings and ACCs noted in the preceding studies relates to the fact that ATP systems measure organic debris as well as viable bacterial counts, several studies have noted additional environmental factors that may increase or decrease ATP readings, including residual detergent and disinfectants that may either increase of decrease RLU readings,[71] plasticisers found in microfiber cloths,[72] ammonium compounds found in laundry chemistries,[72] and surfaces in poor condition.[58] Additional logistical limitations of the ATP tool include the need to develop baseline values, to evaluate a surface within a few minutes of cleaning,[70] and the inability to use the system when a bleach-based disinfectant is being used for cleaning.[60] Boyce et al[60] used preintervention ACCs along with ATP results in education of the ES. Subsequently, individual housekeepers were asked to clean a room that they were told would be monitored by the ATP system following cleaning. As a result of these interventions, the authors documented significant improvement in the daily cleaning of 4 near-patient surfaces as measured by the ATP system.[60] Luminometers and specimen collection swabs are available from several commercial sources.

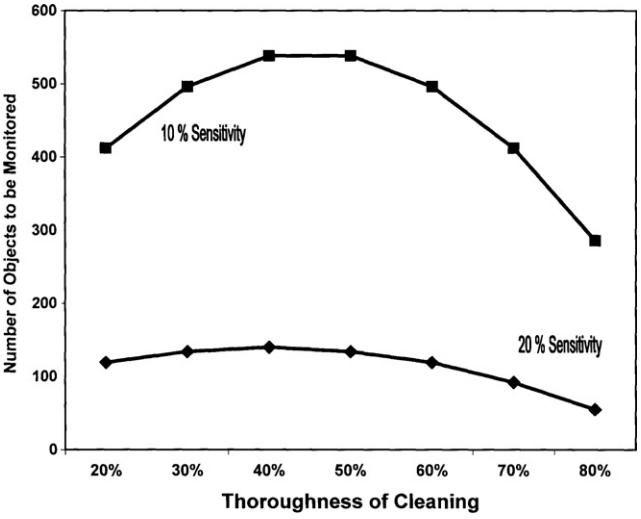

Fig 5. The relationship between the number of high-risk objects evaluated and the ability to detect significant change in the thoroughness of cleaning.

Cleanliness versus cleaning practice

When choosing an evaluation method for use in an enhanced program of EC monitoring, it is important to consider whether the cleaning process or the actual cleanliness of surfaces is to be monitored. Observation and fluorescent gel systems directly evaluate the *cleaning process*, but the swab or slide culture as well as ATP bioluminescence systems measure *cleanliness*. Although the latter 3 systems could be used to monitor hygienic cleaning practice, to do so necessitates monitoring the surface to be evaluated both before and after cleaning because a proportion of surfaces may actually be clean prior to monitoring as a result of their being cleaned previously and not yet contaminated at the time of monitoring.[60,73] Furthermore, the intrinsically low concentration of most major HAPs on surfaces limits the use of pathogen-specific monitoring as a means for assessing actual practice.[62,73,74] Although it is conceptually possible to effectively monitor hygienic cleaning with the latter systems, defining the level of microbial contamination that actually correlates with good or poor EC in a clinical setting has yet to be defined objectively.

GENERAL ELEMENTS OF ENHANCED MONITORING PROGRAMS

The most critical aspect of implementing an enhanced hygienic monitoring program relates to the need for the program to be developed from its inception

as a joint ''blame-free'' undertaking between the infection prevention team and the ES leadership. The program must be based on the mutual understanding of the need to optimize patient and health care personnel environmental pathogen/contaminant transmission safety through mutually developed policies and procedures as well as structured, objective performance monitoring. Whereas the CMS standard states that ''monitoring housekeeping activities'' represents a defined component of the responsibilities of ''infection control,''[37] the development of a mutually supportive approach to maximizing patient and health care personnel safety through optimized EC has been critical to programmatic success.[26,33] CMS sees infection prevention and control more programmatically, ie, it is everyone's responsibility. The program in this case needs ownership by major stakeholders, eg, environmental services and infection prevention specialists to be a continuous performance improvement process, with measures that can be appreciated by all participants.

Logistical issues must also be considered as part of planning for the implementation of an enhanced program. Before a decision has been made to use one of the approaches to objectively monitor cleaning practice, it is important to determine the number of data points that must be monitored on a regular basis to accurately assess practice. Although it would be ideal to be able to identify small fluctuations in practice accurately, such an approach would be highly labor intensive. As noted in Fig 5, the sample size needed to accurately detect a 10% variation in cleaning practice within the range of baseline cleaning thoroughness found by the Healthcare Environmental Hygiene Study Group hospitals (20%-80%) is quite substantial.[75] In contrast, monitoring of only 50 to 120 surfaces would be needed to accurately detect a 20% change in practice. Given the range of patient zone objects monitored in the published reports of hygienic practice, which vary from 8[11] to 15,[22] a reasonably accurate determination of thoroughness of cleaning practice could be determined by monitoring 10 to 15 representative patient rooms per evaluation cycle depending on the estimated overall thoroughness of cleaning anticipated.

In addition, it is important, while considering the benefits of enhanced programmatic monitoring of EC, not to overlook the intrinsic importance of standardizing and optimizing cleaning processes, equipment, and disinfectant/cleaning system use to realize the full benefits of more thorough cleaning of high-risk surfaces in the patient zone.

SUMMARY

Although basic monitoring of EC using visual assessment can identify gross lapses in practice, it has recently become evident that opportunities to improve the thoroughness of patient zone surface cleaning exist within a range of health care settings with only 34% of surfaces in 8 different health care settings being cleaned according to policy.[68] In the context of careful epidemiologic studies that have confirmed a substantially increased risk of acquiring HAPs from prior room occupants and the clear documentation that thoroughness of environmental hygiene can be objectively evaluated and improved through structured interventions and that improved cleaning of high-risk surfaces both decreases environmental contamination and patient acquisition of HAPs, it would appear that there is clear support for hospitals and other health care facilities to consider the importance of optimizing EC in the patient zone. Although the implementation of the type of enhanced hygienic monitoring program outlined above will facilitate compliance with TJC and CMS standards, it is also important to note that such programs meet the specifications of the Department of Health and Human Services Action Plan to Prevent Healthcare Associated Infections (June 2009), which states the following: ''Standardized methods (ie, performance methods) that are feasible, valid, and reliable'' should be used ''for measuring and reporting compliance with broad-based HAI prevention practices that must be practiced consistently by a large number of health care personnel.''[76] Carrying out such a systematic program with measurable achievements and goals can receive deserved visibility by being included in the chief executive officer and Board of Trustee's dashboard on a quarterly basis. Given the increased attention by Department of Health and Human Services to patient satisfaction surveys, now that reimbursement depends on such reporting, it is likely that future CMS reimbursement will depend on actual performance. Furthermore, in this context, patient perception of cleanliness takes on another dimension and level of importance to organizations' leadership. In view of the above considerations, it is highly likely that enhanced environmental monitoring programs will enable the organization to provide measurable, objective data to support their claims of providing a clean and safe environment for patients, their families, and health care personnel.

References

1. Silvestri L, Petros AJ, Sarginson RE, de la Ca MA, Murray AE, van Saene HKF. Handwashing in the intensive care unit: a big measure with modest effects. J Hosp Infect 2005;59:172-9.
2. Rupp ME, Fitzgerald T, Puumala S, Anderson JR. Prospective, controlled, cross-over trial of alcohol-based hand gel in critical care units. Infect Control Hosp Epidemiol 2008;29:8-15.
3. Kirkland KB. Taking off the gloves: toward a less dogmatic approach to the use of contact isolation. Clin Infect Dis 2009;48:766-71.

4. Morgan DJ, Diekema DJ, Spkowitz K, Perencevich EN. Adverse outcomes associated with contact precautions: a review of the literature. Am J Infect Control 2009;37:85-93.
5. Huang SS, Yokoe DS, Hinrichsen VL, Spurchise LS, Datta R, Miroshink I, et al. Impact of routine intensive care unit surveillance cultures and resultant barrier precautions on hospital-wide methicillin-resistant *Staphylococcus aureus* bacteremia. Clin Infect Dis 2006;43:971-8.
6. Department of Health. Winning ways. Working together to reduce health care associated infection in England. Report from the Chief Medical Officer. London: Crown Copyright; 2003. Available from: http://www.dh.gov.uk/assetRoot/04/06/46/89/04064689.pdf. Accessed January 30, 2010.
7. Diekema DJ, Edmond MB. Look before you leap: active surveillance for multidrug-resistant organisms. Clin Infect Dis 2007;44:1101-7.
8. Kramer A, Schwebke I, Kampf G. How long do nosocomial pathogens persist on inanimate surfaces? A systematic review. BMC Infect Dis 2006;6:130.
9. Dancer SJ. The role of environmental cleaning in the control of hospital-acquired infection. J Hosp Infect 2009;4:378-85.
10. Speck K, Naegeli A, Shangraw A, Ross LT, Speser S, Margarakis LL, et al. Environmental contamination with antimicrobial resistant organisms (MDROs). Abstract 157. Annual Meeting of the Society for Healthcare Epidemiology of America. Baltimore, MD. April 2007.
11. Hayden MK, Bonten MJ, Blom DW, Lyle EA. Reduction in acquisition of vancomycin-resistant enterococcus after enforcement of routine environmental cleaning measures. Clin Infect Dis 2006;42:1552-60.
12. Martinez JA, Ruthazer R, Hansjosten K, Barefoot L, Snydman DR. Role of environmental contamination as a risk factor for acquisition of vancomycin-resistant enterococci in patients treated in a medical intensive care unit. Arch Intern Med 2003;163:1905-12.
13. Huang SS, Datta R, Platt R. Risk of acquiring antibiotic-resistant bacteria from prior room occupants. Arch Intern Med 2006;166:1945-51.
14. Drees M, Snydman DR, Schmid CH, Barefoot L, Hansjosten K. Antibiotic exposure and room contamination among patients colonized with vancomycin-resistant enterococci. Infect Control Hosp Epidemiol 2008;29:709-15.
15. Datta R, Platt R, Kleinman K, Huang SS. Impact of an environmental cleaning intervention on the risk of acquiring MRSA and VRE from prior room occupants. Abstract 273. Annual Meeting of the Society for Healthcare Epidemiology of America. San Diego, CA. March 2009.
16. Hardy KJ, Oppenheim BA, Gossain S, Gao F, Hawkey PM. A study of the relationship between environmental contamination with methicillin-resistant *Staphylococcus aureus* (MRSA) and patients' acquisition of MRSA. Infect Control Hosp Epidemiol 2006;27:127-32 Epub February 8, 2006.
17. Shaugnessy M, Micielli R, Depestel D, Arndt J, Strachan C, Welcch K, et al. Evaluation of hospital room assignment and acquisition of *Clostridium difficile* associated diarrhea. Abstract K-4194. Presented at the 48th Annual ICAAC/IDSA 46th Annual Meeting. Washington, DC. October 2008.
18. Wilks M, Wilson A, Warwick S, Price E, Kennedy D, Ely A, et al. Control of an outbreak of multidrug-resistant *Acinetobacter baumannii calcoaceticus* colonization and infection in an intensive care unit (ICU) without closing the ICU or placing patients in isolation. Infect Control Hosp Epidemiol 2006;27:654-8.
19. Carling PC, Briggs J, Hylander D, Perkins J. An evaluation of patient area cleaning in 3 hospitals using a novel targeting methodology. Am J Infect Control 2006;34:513-9.
20. Boyce JM, Havill NL, Dumigan DG, Golebiewski M, Balogun O, Rizvani R. Monitoring the effectiveness of hospital cleaning practices by use of an adenosine triphosphate bioluminescence assay. Infect Control Hosp Epidemiol 2009;30:678-84.
21. Eckstein BC, Adams DA, Eckstein EC, Rao A. Reduction of *Clostridium difficile* and vancomycin-resistant enterococcus contamination of environmental surfaces after an intervention to improve cleaning methods. BMC Infect Dis 2007;7:61.
22. Goodman ER, Platt R, Bass R, Onderdonk AB, Yokoe DS, Huang SS. Impact of an environmental cleaning intervention on the presence of methicillin-resistant *Staphylococcus aureus* and vancomycin-resistant enterococci on surfaces in intensive care unit rooms. Infect Control Hosp Epidemiol 2008;29:593-9.
23. Jefferson J, Whelan R, Dick B, Carling PC. A novel technique to identify opportunities for improving environmental hygiene in the operating room. AORN J 2010. In press.
24. Guerrero D, Carling PC, Jury L, Ponnada S, Nerandzic M, Eckstein EC, et al. Beyond the "Hawthorne effect": reduction of *Clostridium difficile* environmental contamination through active intervention to improve cleaning practices. Abstract 60. SHEA Fifth Decennial Meeting. Atlanta, GA. March 18-22, 2010.
25. Carling PC, Po JL, Bartley J, Herwaldt L. Identifying opportunities to improve environmental hygiene in multiple health care settings. SHEA Fifth Decennial Meeting. Atlanta, GA. March 18-22, 2010.
26. Carling PC, Parry MM, Rupp ME, Po JL, Dick BL, Von Beheren S, for the Healthcare Environmental Hygiene Study Group. Improving cleaning of the environment surrounding patients in 36 acute care hospitals. Infect Control Hosp Epidemiol 2008; 29:1035-41.
27. Po JL, Burke R, Sulis C, Carling PC. Dangerous cows: an analysis of disinfection cleaning of computer keyboards on wheels. Am J Infect Control 2009;37:778-80.
28. Hota B, Blom DW, Lyle EA, Weinstein RA, Hayden MK. Interventional evaluation of environmental contamination by vancomycin-resistant enterococci: failure of personnel, product, or procedure? J Hosp Infect 2009;71:123-31 Epub December 23, 2008.
29. Bruno-Murtha LA, Harkness D, Stiles T, Han L, Carling PC. Molecular epidemiology of MRSA during an active surveillance program. Abstract 53. Society for Healthcare Epidemiology of America 19th Annual Meeting. San Diego, CA. March 19-22, 2009.
30. Wiline J, Blum N, Fisher V, Douglas G, Flanagan G, Ostrosky L. The "A team": an environmental services intervention to control multidrug-resistant Acinetobacter. Abstract 589. SHEA Fifth Decennial Meeting. Atlanta, GA. March 18-22, 2010.
31. Sulis C, Estanislano R, Wedel S, Carling PC. Completeness of cleaning critical care transport vehicles. Abstract 648. SHEA Fifth Decennial Meeting. Atlanta, GA. March 18-22, 2010.
32. Clark P, Young L, Silvestri S, Muto CA. Goo begone—evaluation of compliance with cleaning of multiple high touch (HT) surfaces using fluorescent "Goo." Abstract 210. SHEA Fifth Decennial Meeting. Atlanta, GA. March 18-22, 2010.
33. Carling PC, Eck EK. Achieving sustained improvement in environmental hygiene using coordinated benchmarking in 12 hospitals. SHEA Fifth Decennial Meeting. Atlanta, GA. March 18-22, 2010.
34. Dancer SJ, White LF, Girvan EK, Robertson C. Measuring the effect of enhanced cleaning in a UK hospital: a prospective cross-over study. BMC Med 2009;7:28.
35. Centers for Disease Control and Prevention/Healthcare Infection Control Advisory Committee (HICPAC) Guidelines for environmental infection control in health care facilities. Atlanta, GA: Centers for Disease Control and Prevention. 2003. Available from: www.cdc.gov. Accessed January 20, 2010.
36. Siegel JD, Rhinehart E, Jackson M, Chiarello L. Healthcare Infection Control Practices Advisory Committee. Management of multidrug-resistant organisms in healthcare settings. 2006 Available from: http://www.cdc.gov/ncidod/dhqp/pdf/ar/mdroGuideline2006.pdf. Accessed January 15, 2009.
37. Centers for Medicare and Medicaid. State operations manual. Appendix A. Interpretive guidelines for hospitals. Available from: http://cms.hhs.gov/manuals/Downloads/som107ap_a_hospitals.pdf. Accessed January 31, 2010.
38. Pratt RJ, Pellowe CM, Wilson JA, Loveday HP, Harper PJ, Jones SR, et al. Epic 2: national evidence-based guidelines for preventing

healthcare-associated infections in NHS hospitals in England. J Hosp Infect 2007;65(Suppl 1):S1-64.
39. Health Canada Laboratory Centre for Disease Control Bureau of Infectious Diseases Nosocomial and Occupational Infections: infection control guidelines: handwashing, cleaning, disinfection and sterilization in healthcare. Canada Communicable Disease Report 1998;24:1-66.
40. Dumford DM III, Nerandzic MM, Eckstein BC, Donskey CJ. What is on that keyboard? Detecting hidden environmental reservoirs of *Clostridium difficile* during an outbreak associated with North American pulsed-field gel electrophoresis type 1 strains. Am J Infect Control 2009;37:15-29.
41. Sethi AK, Al-Nassir WN, Nerandzic MM, Bobulsky GS, Donskey CJ. Persistence of skin contamination and environmental shedding of *Clostridium difficile* during and after treatment of *C. difficile* infection. Infect Control Hosp Epidemiol 2010;31:21-7.
42. Chang S, Sethi AK, Eckstein BC, Stiefel U, Cadnum JL, Donskey CJ. Skin and environmental contamination with methicillin-resistant *Staphylococcus aureus* among carriers identified clinically versus through active surveillance. Clin Infect Dis 2009;48:1423-8.
43. Hayden MK, Blom DW, Lyle EA, Moore CG, Weinstein RA. Risk of hand or glove contamination after contact with patients colonized with vancomycin-resistant enterococcus or the colonized patients' environment. Infect Control Hosp Epidemiol 2008;29:149-54.
44. Sethi AK, Al-Nassir WN, Nerandzic MM, Donskey CJ. Skin and environmental contamination with vancomycin-resistant enterocci in patients receiving oral metronidazole or oral vancomycin treatment for *Clostridium difficile*-associated disease. Infect Control Hosp Epidemiol 2009;30:13-7.
45. Riggs MM, Sethi AK, Zabarsky TF, Eckstein EC, Jump RL, Donskey CJ. Asymptomatic carriers area potential source for transmission of epidemic and nonepidemic *Clostridium difficile* strains among long-term care facility residents. Clin Infect Dis 2007;45:992-8.
46. Kaatz G, Gitlin S, Schaberg D, Wilson K. Acquisition of *Clostridium difficile* from the hospital environment. Am J Epidemiol 1988;127: 1289-93.
47. Denton M, Wilcox M. Role of environmental cleaning in controlling an outbreak of *Acinetobacter baumannii* on a neurosurgical intensive care unit. Intensive Crit Care Nurs 2005;21:94-8.
48. Boyce JM, Potter-Bynoe G, Chenevert C, King T. Environmental contamination due to methicillin-resistant *Staphylococcus aureus*: possible infection control implications. Infect Control Hosp Epidemiol 1997; 9:622-7.
49. de Lassence A, Hidri N, Timsit JF, Joly-Guillou ML. Control and outcome of a large outbreak of colonization and infection with glycopeptide-intermediate *Staphylococcus aureus* in an intensive care unit. Clin Infect Disease 2006;42:170-8.
50. Rollins G. How clean is clean? New technologies, monitoring practice gains traction. Mater Manag in Healthcare 2009;5:18-24.
51. Maki DG, Alvarado CJ, Hassemer CA, Zilz MA. Relation of an inanimate hospital environment to endemic nosocomial infection. N Engl J Med 1982;307:1562-6.
52. Ayliffe GAJ, Collins DM, Lowbury EJL. Cleaning and disinfecting hospital floors. Br Med J 1966;2:442-5.
53. Malik RE, Cooper RA, Griffith CJ. Use of audit tools to evaluate the efficacy of cleaning systems in hospitals. Am J Infect Control 2003; 31:181-7.
54. Department of Health. Evaluation of ATP bioluminescence swabbing as a monitoring and training tool for effective hospital cleaning. London: DoH; 2007. Available from: http://195.92.246.148/knowledge_network/documents/Bioluminescence_20070620104921.pdf. Accessed January 31, 2010.
55. The Joint Commission Standards 2010. Available from: http://www.jointcommission.org/Standards/. Accessed January 30, 2010.
56. Sax H, Allegranzi B, Uckay I, Larson E, Boyce J, Pittet D. "My five moments of hand hygiene": a user-centered design approach to understand, train, monitor and report hand hygiene. J Hosp Infect 2007;67: 9-21.
57. Dancer SJ. Mopping up hospital infection. J Hosp Infect 1999;43: 85-100.
58. Griffith CJ, Cooper RA, Gilmore J, Davies C, Lewis M. An evaluation of hospital cleaning regimes and standards. J Hosp Infect 2000;45: 19-28.
59. Carling PC, Parry MF, Von Beheren SM. Identifying opportunities to enhance environmental cleaning in 23 acute care hospitals. Infect Control Hosp Epidemiol 2008;29:1-7.
60. Boyce JM, Havill NL, Lipka A, Havill H, Rizvani R. Variations in hospital daily cleaning practices. Infect Control Hosp Epidemiol 2010;31: 99-101.
61. Griffith CJ, Obee P, Cooper RA, Burton NF, Lewis M. The effectiveness of existing and modified cleaning regimens in a Welsh hospital. J Hosp Infect 2007;66(4):352-9.
62. Dancer SJ, White L, Robertson C. Monitoring environmental cleanliness on two surgical wards. Int J Environ Health Res 2008;18:357-64.
63. Dancer SJ, White LF, Lamb J, Girvan EK, Robertson C. Measuring the effect of enhanced cleaning in a UK hospital: a prospective cross-over study. BMC Med 2009;8:7-28.
64. Cooper RA, Griffith CJ, Malik RE, Obee P. Monitoring the effectiveness of cleaning in four British hospitals. Am J Infect Control 2007; 35:338-41.
65. Thorn A, Lundin A, Ansehn S. Firefly luciferase ATP assay as a screening method for bacteriuria. J Clin Microbiol 1983;218-24.
66. Anderson BM, Rasch M, Kvist J, Tollefsen T, Lukkassen R, Sandvik L, et al. Floor cleaning: effect on bacteria and organic materials in hospital rooms. J Hosp Infect 2009;71:57-65.
67. Simpson WJ, Gilells CJ, Flockhart HA. Repeatability of hygiene test systems in measurement of low levels of ATP. Care Technology Limited, Report 2006;30:606.
68. Aycicek H, Oguz U, Karci K. Comparison of results of ATP bioluminescence and traditional hygiene swabbing methods for the determination of surface cleanliness at a hospital kitchen. Int J Hyg Environ Health 2006;209:203-6.
69. Griffith CJ, Malik R, Cooper RA, Looker N, Michaels B. Environmental surface cleanliness and the potential for contamination during handwashing. Am J Infect Control 2003;31:93-6.
70. Lewis T, Griffith C, Gallo M, Weinbren M. A modified ATP benchmark for evaluating the cleaning of some hospital environmental surfaces. J Hosp Infect 2008;69:156-63.
71. Green TA, Russell SM, Fletcher DL. Effect of chemical cleaning agents and commercial sanitizers on ATP bioluminescence measurements. J Food Protect 1999;62:86-90.
72. Brown E, Eder AR, Thompson KM. Do surface and cleaning chemistries interfere with ATP measurement systems for monitoring patient room hygiene? J Hosp Infect 2010;74:193-5.
73. Sherlock O, O'Connell N, Creamer E, Humphreys H. Is it really clean? An evaluation of the efficacy of four methods for determining hospital cleanliness. J Hosp Infect 2009;72:140-6.
74. Hamilton D, Foster A, Ballantyne L, Kingsmore P, Bedwell D, Hall TJ, et al. Performance of ultramicrofibre cleaning technology with or without addition of a novel copper-based biocide. J Hosp Infect 2010;74:62-71.
75. Chow S, Shao J, Wang H. Sample size calculations in clinical research. 2nd ed. Boca Raton, FL: Chapman & Hall; 2007.
76. US Department of Health and Human Services. Final action plan to prevent healthcare-associated infections. June 2009. Available from: http://www.hhs.gov/ophs/initiatives/hai/infection.html. Accessed September 28, 2009.

CONCISE COMMUNICATION

Evaluation of Hospital Floors as a Potential Source of Pathogen Dissemination Using a Nonpathogenic Virus as a Surrogate Marker

Sreelatha Koganti, MD;[1] Heba Alhmidi, MD;[1] Myreen E. Tomas, MD;[2] Jennifer L. Cadnum, BS;[2] Annette Jencson, BSMT, CIC;[1] Curtis J. Donskey, MD[2,3]

Hospital floors are frequently contaminated with pathogens, but it is not known whether floors are a potential source of transmission. We demonstrated that a nonpathogenic virus inoculated onto floors in hospital rooms disseminated rapidly to the hands of patients and to high-touch surfaces inside and outside the room.

Infect Control Hosp Epidemiol 2016;1–4

Effective disinfection of contaminated surfaces is essential to prevent nosocomial transmission of pathogens such as *Clostridium difficile*, methicillin-resistant *Staphylococcus aureus*, and norovirus.[1] Efforts to improve disinfection usually focus primarily on surfaces that are frequently touched by the hands of healthcare workers or patients (eg, bed rails and call buttons). Notably, hospital floors are often heavily contaminated[2–4] but are not considered an important source for pathogen dissemination because they are rarely touched. However, floors are frequently contacted by objects that are subsequently touched by hands (eg, shoes, socks, slippers). In addition, it is not uncommon for high-touch objects such as call buttons and blood pressure cuffs to be in contact with the floor (authors' unpublished observations). Therefore, we hypothesized that floors might be an underappreciated reservoir for pathogen transmission.

Benign surrogate markers, such as viral DNA and nonpathogenic viruses, provide a powerful tool to study routes of pathogen transmission. In healthcare and community settings, inoculation of these markers onto high-touch surfaces (eg, door knobs, telephone handles) has been followed by widespread dissemination to environmental surfaces and hands.[5-6] In the current study, we used bacteriophage MS2, a nonpathogenic, nonenveloped RNA virus, to examine the potential for dissemination of microorganisms from floors of isolation rooms to the hands of patients and to high-touch surfaces inside and outside of rooms.

METHODS

The study protocol was approved by the Cleveland Veterans Affairs Medical Center's Institutional Review Board. Bacteriophage MS2 15597-B1 (American Type Culture Collection) was prepared as previously described.[7] Ten ambulatory patients in contact precautions for *C. difficile* infection or carriage of methicillin-resistant *S. aureus* were enrolled. For each patient, a 30×30 cm area of the wood laminate floor adjacent to the bed was inoculated with 2 mL of sterile water containing 1×10^8 plaque-forming units of MS2/mL and allowed to air dry. Patients were not aware of the precise area of inoculation. Hospital personnel were not aware of the study. The protocol for cleaning of contact precautions rooms included daily disinfection of high-touch surfaces with bleach wipes each morning but floors were cleaned only if visibly soiled; compliance with daily disinfection was monitored with fluorescent markers with more than 85% of sites demonstrating marker removal during the study. Preliminary experiments demonstrated that the MS2 inoculum persisted on wood laminate floors for at least 3 days, with a 1 to 2 log decrease in recovery attributed to desiccation.

On days 1, 2, and 3 after inoculation of MS2, sterile premoistened swabs (BBL CultureSwabs; Becton Dickinson) were used to sample environmental sites, patients' hands, and the soles of patients' footwear in the late afternoon. Environmental sites inside the inoculated room were categorized as being surfaces less than or equal to 3 feet (bed rails, bedside table, call button, telephone, bed linen) or more than 3 feet (night stand, sink, door knob, chair, light switch, pulse oximeter, and intravenous infusion pole) from the patient bed; or portable equipment; or personal items (wheelchairs, cell phones, books, clothing) (Figure 1). Environmental sites outside the inoculated room included adjacent rooms (bed rail, bedside table, call button, telephone, and floor) and the nursing station

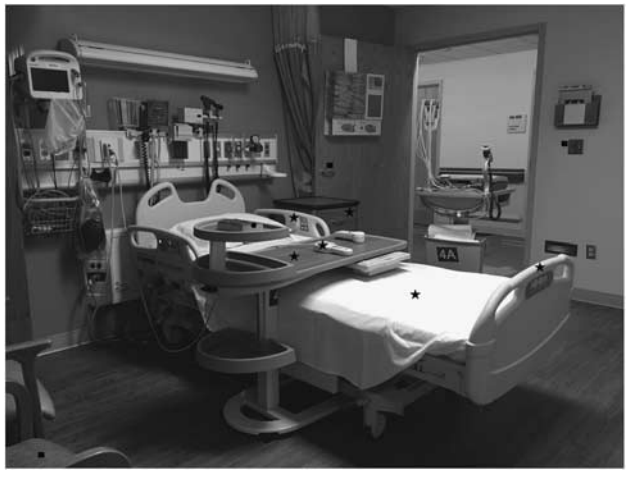

FIGURE 1. Illustration of high-touch surfaces sampled. Star, surfaces less than or equal to 3 feet from the center of the bed; square, surfaces more than 3 feet from the center of the bed; circle, personal items.

TABLE 1. Recovery of Bacteriophage MS2 From Surfaces and Patients on Days 1, 2, and 3 After Inoculation of the Floor Adjacent to the Patient's Bed

	No. positive/ no. sampled (%), mean ± SEM $\log_{10}$ PFU recovered		
Variable	Day 1	Day 2	Day 3
Patients			
Hands	4/10 (40.0), 1.0 ± 0.4	5/8 (62.5), 1.5 ± 0.7	3/7 (42.9), 1.2 ± 0.3
Footwear	10/10 (100), 4.0 ± 0.6	8/8 (100), 3.9 ± 0.5	6/7 (85.7), 3.4 ± 0.9
High-touch surfaces			
≤3 feet from the bed			
Total surfaces	32/55 (58.2), 2.3 ± 0.2	28/45 (62.2), 1.8 ± 0.2	30/39 (76.9), 1.4 ± 0.2
Side bedrail	5/10 (50.0), 2.0 ± 0.3	5/8 (62.5), 1.9 ± 0.3	6/7 (85.7) 1.1 ± 0.2
Call button	5/10 (50.0), 1.2 ± 0.5	5/8 (62.5), 1.6 ± 0.7	5/7 (71.4), 1.6 ± 0.6
Phone	3/10 (30.0), 1.7 ± 0.3	4/8 (50.0), 1.1 ± 0.5	3/7 (42.9) 1.1 ± 0.1
Bed linens	9/10 (90.0) 3.0 ± 0.4	6/8 (75.0) 3.0 ± 0.6	7/7 (100), 1.9 ± 0.3
Foot board	4/5 (80.0), 3.3 ± 0.9	3/5 (60.0), 1.4 ± 0.6	4/4 (100), 1.6 ± 0.8
Tray table	6/10 (60.0), 2.2 ± 0.5	5/8 (62.5), 1.7 ± 0.3	5/7 (71.4), 0.7 ± 0.2
>3 feet from the bed			
Total surfaces	23/58 (39.7), 1.2 ± 0.2	34/50 (68.0), 1.4 ± 0.2	15/44 (34.1), 0.8 ± 0.2
Side table	4/8 (50.0), 1.0 ± 0.2	6/6 (100), 2.0 ± 0.5	5/5 (100), 0.7 ± 0.3
Pulse oximeter	3/7 (42.9), 0.7 ± 0.3	4/6 (66.7), 1.3 ± 0.3	1/7 (14.3), 0.7
IV pole	0/7 (0), 0	2/5 (40.0), 1.1 ± 0.02	1/6 (16.7), 0.3
Chair	5/8 (62.5), 1.3 ± 0.2	7/7 (100), 1.8 ± 0.4	3/5 (60.0), 0.4 ± 0.2
Door knob	4/10 (40.0), 2.0 ± 0.3	5/8 (62.5), 0.9 ± 0.2	2/7 (28.6), 1.2 ± 0.4
Light switch	1/10 (10.0), 0.78	3/8 (37.5), 0.1 ± 0.1	0/7 (0), 0
Sink	6/8 (75.0), 1.2 ± 0.4	7/8 (87.5), 1.4 ± 0.3	3/7 (42.9), 1.3 ± 0.4
Personal items[a]	6/12 (50.0), 1.5 ± 0.5	4/9 (44.4), 1.7 ± 0.3	4/8 (50.0), 1.2 ± 0.4
Portable equipment[b]	1/3 (33.3), 0.8	3/13 (23.1), 1.2 ± 0.5	3/3 (100), 0.7 ± 0.5
Adjacent rooms			
Floor	N/A	5/5 (100), 1.9 ± 0.1	8/10 (80.0), 1.4 ± 0.4
Environment[c]	N/A	2/5 (40.0), 0.9 ± 0.1	1/9 (11.1), 0.7
Nursing stations[d]	9/17 (52.9), 0.5 ± 0.1	15/32 (46.9), 0.2 ± 0.1	17/27 (63.0), 1.0 ± 0.2

NOTE. IV, intravenous; PFU, plaque-forming units; SEM, standard error of the mean.
[a]Personal items included wheelchairs, cell phones, books, and clothing.
[b]Portable equipment included medication cart, glucometer, and phlebotomy cart.
[c]Surfaces included bed rails, bedside table, call button, and telephone.
[d]Surfaces included computer keyboards, computer mouse, and telephones.

(computer keyboards, computer mouse, telephones) on the same ward. For large surfaces, a 30×30 cm area was sampled; for smaller surfaces, such as telephones, the entire surface area was sampled. Swabs were vortexed for 1 minute in sterile water to elute the bacteriophage and serially diluted aliquots were cultured to quantify virus particles.[7] For each set of cultures, a negative control swab opened in the patient room but not placed in contact with surfaces was processed identically.

The Fisher exact test was used to compare the percentages of positive cultures on surfaces less than or equal to 3 feet vs more than 3 feet from the bed and on days 1, 2, and 3. Paired *t* tests were used to compare mean number of plaque-forming units recovered. Data were analyzed with SPSS statistical software, version 10.0 (IBM).

RESULTS

Of the 10 patients on 4 wards, 7 had samples collected for 3 days; 2 patients were discharged after 1 day and 1 was discharged after 2 days. Table 1 provides a summary of the culture results. MS2 was detected on multiple surfaces of all patient rooms by 1 day after inoculation. On days 1 and 3, the concentration of MS2 was higher for surfaces less than or equal to 3 feet vs more than 3 feet from the bed ($P < .02$ for both comparisons) and more sites were contaminated at less than or equal to 3 feet (day 1, $P < .06$; day 3, $P < .0001$). MS2 contamination was not significantly different at less than or equal to 3 feet vs more than 3 feet on day 2.

Contamination was common on high-touch surfaces in adjacent rooms, in the nursing station, and on portable equipment. Portable equipment included wheelchairs, medication carts, vital signs equipment, and pulse oximeters. All negative control swabs were negative for MS2.

DISCUSSION

We found that a nonpathogenic virus inoculated onto floors in hospital rooms disseminated rapidly to the footwear and hands of patients and to high-touch surfaces in the room. The virus was also frequently found on high-touch surfaces in adjacent rooms and at nursing stations. These results suggest that floors in hospital rooms could be an underappreciated source for dissemination of pathogens.

It is likely that both patients and healthcare personnel contributed to dissemination of the virus. MS2 virus present on patients' footwear was probably acquired during direct contact with the contaminated floor site adjacent to the bed. During removal of footwear, patients could easily acquire the virus on their hands, with subsequent transfer to touched surfaces and to other skin sites. The finding of contamination in adjacent rooms and in the nursing station clearly suggests that healthcare personnel contributed to dissemination after acquiring the virus during contact with contaminated surfaces or patients.

Our findings have important implications. Studies are needed to assess the potential for modes of dissemination from floors other than footwear. For example, wheelchairs and other wheeled equipment could disseminate pathogens.[8] If additional evidence demonstrates dissemination from floors, studies will be needed to assess the efficacy of current floor cleaning strategies and to evaluate other methods to interrupt dissemination. Because nonsporicidal disinfectants are often used on floors in rooms of patients with *C. difficile* infection, there is a particular need for data on how effectively the burden of spores is reduced on floors. Finally, studies in nonhospital settings are needed. For example, floors in community households have been shown to be frequently contaminated with *C. difficile* spores.[9]

Our study has some limitations. We studied dissemination of a virus. However, previous studies have demonstrated that transfer efficiency of MS2 and bacteria from fomites to fingers is comparable.[10] The concentration of virus applied to the floors was high, so our results are likely to reflect a worst-case scenario. We cannot exclude the possibility that results might vary with different types of floors. However, we demonstrated similar recovery of MS2 from different types of inoculated dry surfaces (authors' unpublished data).

In summary, we demonstrated that a nonpathogenic virus inoculated onto floors in hospital rooms disseminated rapidly to the hands of patients and to high-touch surfaces inside and outside the room. These findings provide further evidence that benign surrogate markers, such as nonpathogenic viruses, can provide a powerful tool to study routes of pathogen dissemination. Studies are needed to investigate the potential for contaminated hospital floors to contribute to pathogen transmission.

ACKNOWLEDGMENTS

Financial support. Department of Veterans Affairs (Merit Review grant BX002944 to C.J.D.).

Potential conflicts of interest. C.J.D reports that he has received research grants from Merck, Gojo, Steris, and EcoLab and serves on an advisory board for 3M. All other authors report no conflicts of interest relevant to this article.

Affiliations: 1. Research Service, Louis Stokes Cleveland Veterans Affairs Medical Center, Cleveland, Ohio; 2. Geriatric Research, Education, and Clinical Center, Cleveland Veterans Affairs Medical Center, Cleveland, Ohio; 3. Case Western Reserve University School of Medicine, Cleveland, Ohio.

Address correspondence to Curtis J. Donskey, MD, Geriatric Research, Education, and Clinical Center, Louis Stokes Veterans Affairs Medical Center, 10701 East Blvd, Cleveland, OH 44106 (curtisd123@yahoo.com).

Received April 8, 2016; accepted: July 7, 2016.

 DOI: 10.1017/ice.2016.181

REFERENCES

1. Donskey CJ. Does improving surface cleaning and disinfection reduce health care-associated infections? *Am J Infect Control* 2013;41:S12–S19.

2. Fekety R, Kim KH, Brown D, Batts DH, Cudmore M, Silva J Jr. Epidemiology of antibiotic-associated colitis: isolation of *Clostridium difficile* from the hospital environment. *Am J Med* 1981;70:906–908.
3. Shanom A, Muzslay M, Wilson P. A novel quantitative sampling technique for detection and monitoring of *Clostridium difficile* contamination in the clinical environment. *J Clin Microbiol* 2015;53:2570–2574.
4. Wong T, Woznow T, Petrie M, et al. Postdischarge decontamination of MRSA, VRE, and *Clostridium difficile* isolation rooms using 2 commercially available automated ultraviolet-C emitting devices. *Am J Infect Control* 2016;44:416–420.
5. Gelberg DG, Joyner SE, Jiang X, Laborde D, Islan MP, Pickering LK. Detection of pathogen transmission in neonatal nurseries using DNA markers as surrogate indicators. *Pediatrics* 2000; 105:311–315.
6. Sifuentes LY, Koenig DW, Phillips RL, Reynolds KA, Gerba CP. Use of hygiene protocols to control the spread of viruses in a hotel. *Food Environ Virol* 2014;6:175–181.
7. Tomas ME, Kundrapu S, Thota P, et al. Contamination of the skin and clothing of healthcare personnel during removal of personal protective equipment. *JAMA Intern Med* 2015;175:1904–1910.
8. Peretz A, Koiefman A, Dinisman E, Brodsky D, Labay K. Do wheelchairs spread pathogenic bacteria within hospital walls? *World J Microbiol Biotechnol* 2014;30:385–387.
9. Jahangir Alam M, Anu A, Walk ST, Garey KW. Investigation of potentially pathogenic *Clostridium difficile* in household environs. *Anaerobe* 2014;27:31–33.
10. Lopez GU, Gerba CP, Tamimi AH, Kitajima M, Maxwell SL, Rose JB. Transfer efficiency of bacteria and viruses from porous and nonporous fomites to fingers under different relative humidity conditions. *Appl Environ Microbiol* 2013;79:5728–5734.

American Journal of Infection Control xxx (2013) 1-4

Contents lists available at ScienceDirect

American Journal of Infection Control

journal homepage: www.ajicjournal.org

Major article

Microbial contamination of hospital reusable cleaning towels

Laura Y. Sifuentes PhD [a], Charles P. Gerba PhD [a], Ilona Weart BS [b], Kathleen Engelbrecht MS [c], David W. Koenig PhD [c,*]

[a] Department of Soil, Water, and Environmental Science, University of Arizona, Tucson, AZ
[b] Kimberly Clark Professional, Kimberly-Clark Corporation, Roswell, GA
[c] Corporate Research & Engineering, Kimberly-Clark Corporation, Neenah, WI

Key Words:
Disinfectant
Infection control
Nosocomial infection
Reusable towels

Background: Hospital cleaning practices are critical to the prevention of nosocomial infection transmission. To this end, cloth towels soaked in disinfectants are commonly used to clean and disinfect hospital surfaces. Cloth cleaning towels have been linked to an outbreak of *Bacillus cereus* and have been shown to reduce the effectiveness of commonly used quaternary ammonium disinfectants. Thus, it is important to determine whether the reuse of cloth towels increases the risk of pathogen transmission in hospitals.

Methods: The goal of this project was to determine the effects of laundry and cleaning practices commonly used in hospitals for washing, storage, and disinfection of cloth cleaning towels on their microbial loads.

Results: Our results indicate that cloth towels used for cleaning hospital rooms contained high numbers of microbial contaminants.

Conclusions: In this case, hospital laundering practices appear insufficient to remove microbial contaminants and may even add contaminants to the towels. Furthermore, it has been previously reported that towels can interfere with the action of common hospital disinfectants. Either independently or in combination, these 2 factors may increase the risk for transmission of pathogens in hospitals. These observations indicate the need to critically reevaluate current hospital cleaning practices associated with reuse of cloth towels.

Hospital housekeeping staff routinely use cloth towels soaked in a hospital disinfectant to clean patient rooms (including terminal cleaning) and other areas of the hospital. These cloth towels are soaked in a bucket containing hospital disinfectants until use, wrung out, and used to clean surfaces inside patient rooms. The towels are then either washed in-house or sent out to a central laundering facility, and the clean towels are stored and then reused in the same manner. A previous report linked the reuse of laundered cleaning cloths to an outbreak of *Bacillus cereus* in a Japanese hospital.[1] Studies of microbial survival in towels have indicated that the more absorbent a cloth towel, the longer the microorganisms can survive, as was previously reported in the case of *Staphylococcus aureus*.[2] Several studies have found that *Staphylococcus* can survive for 19-21 days in cotton cloths.[3] Methicillin-resistant *S aureus* (MRSA) strains capable of causing serious life-threatening infections have been isolated from reused cloth hospital towels.[4]

The goal of this project was to examine the effects of laundry and cleaning practices commonly used in hospitals for washing, storing, and disinfecting cloth towels on the microbial loads in the towels. Ten hospitals were surveyed regarding their cleaning procedures and use of disinfectants for sanitizing rooms after terminal discharge. Clean towels intended for cleaning purposes were collected in triplicate from each participating institution to evaluate both the towels' ability to harbor possible infectious agents and the effectiveness of the laundering practices in removing microorganisms. Swab samples were also collected from the inside surfaces of the buckets in which the towels were soaked in disinfectant. The towels and swabs were cultured for the presence of colony-forming units (CFU) of aerobic spore-forming bacteria, *Clostridium difficile*, molds, heterotrophic bacteria, *S aureus* (including MRSA), total coliforms, and *Escherichia coli*.

METHODS

Ten major hospitals in Arizona, selected at random, were invited and agreed to participate in the study. A survey of cleaning

* Address correspondence to David W. Koenig, PhD, Corporate Research & Engineering, Kimberly-Clark Corporation, PO Box 349, Neenah, WI 54957.
E-mail address: dwkoenig@kcc.com (D.W. Koenig).

Conflict of interest: None to report.

0196-6553/$36.00 - Copyright © 2013 by the Association for Professionals in Infection Control and Epidemiology, Inc. Published by Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.ajic.2013.01.015

Table 1
Culture methods used for all microbial isolation

Organism	Culture method	Incubation conditions	Volume assayed	Further analysis
Heterotrophic bacteria	Spread plating on R2A medium (BD Diagnostics, Sparks, MD)	24°C for 5 days	0.1 mL	
Coliforms and *E coli*	Assayed using the Colilert method (IDEXX; Westbrook, ME)	35°C for 24 h	100 mL	
C difficile	Incubation for 7 days in 0.1% sodium taurocholate and cycloserine-cefoxitin fructose broth	Anaerobic conditions at 37°C for up to 5 days	0.1 mL	A 2 mL aliquot of culture was mixed with an equal amount of absolute ethanol. Bacteria were concentrated by centrifugation, and pellets were used to inoculate cycloserine-cefoxitin fructose agar.
MRSA	TSA amended with 5% sheep's blood, 10 mg/L colistin, and 15 mg/L naladixic acid using the spread-plate method	35°C for 24-48 h	0.1 mL	β-hemolytic colonies were isolated and subcultured on TSA plates with no amendments and incubated at 35°C for 24-48 h.
Molds	Spread-plating 1 mL of eluent on Sabouraud dextrose agar with chloramphenicol (Neogen, Lansing, MI)	24°C for 2-7 days	1 mL	
Aerobic spore-formers	Heat-shocking samples in a water bath at 80°C for 10 minutes, followed by spread-plating on TSA media (BD Diagnostics)	35°C for 24 h	0.1 mL	

TSA, trypticase soy agar.

practices was conducted at each hospital, and 3 clean towels were obtained from each location. Swab samples were also collected from the inside surface of a bucket used to soak the towels in disinfectant at each hospital. The survey of cleaning practices included questions about the protocols used for cleaning rooms, towel use, and laundry procedures. Other questions involved the disinfectant(s) used, whether the towels were soaked or sprayed in the disinfectant, exposure time, frequency of disinfectant changes, fabric content of the cleaning towels, towel washing and drying practices, and towel storage conditions.

The average surface area of the cleaning towels from all participating hospitals was calculated as approximately 1040 ± 284 cm^2. Because of the substantial variability in towel sizes, all bacterial analyses were conducted on a per-towel basis. Each towel was placed into a Stomacher bag with 300 mL of buffered peptone water (EMD, Gibbstown, NJ), based on towel size and absorbance, to ensure complete saturation of the towel. Each towel was manually kneaded until the liquid was completely absorbed, after which the peptone broth was extracted from the towel by wringing. The extract was assayed using selected media for isolation of the various bacteria.

At each hospital, a disinfectant soaking bucket was swabbed just above the disinfectant liquid line using a sponge stick containing Letheen broth (3M, St Paul, MN). After sampling, the broth was extracted from the sponge stick by manual agitation, and then 4 mL of extracted broth was assayed using selected media for isolation of the various bacteria. Samples from the towels and buckets were cultured for total bacteria (heterotrophic bacteria), coliform bacteria, *E coli, C difficile,* MRSA, molds, and aerobic spore-forming bacteria. Test methods for each organism are presented in Table 1.

Gram-positive cocci and catalase-positive, tube coagulase-positive, slide-coagulase positive, and polymixin B-resistant colonies were then cultured on CHROMagar MRSA (BD Diagnostics, Sparks, MD) to confirm identification as MRSA. Selected coliforms and presumptive *E coli* isolates were identified using API 20E bacterial identification test kits (bioMérieux; Marcy l'Etoile, France). The data were log-transformed, and ANOVA was used to assess relationships between the use of towels and towel characteristics. Completely randomized designs were used to perform the ANOVA, with a rejection region of 5% using the *F* distribution.

RESULTS

In the questionnaires on cleaning and laundry practices, 8 of the 10 hospitals reported using cotton towels, and the other 2 (sites 3 and 6) reported using microfiber towels. Two hospitals (sites 2 and 3) sent their linens to be laundered in a central facility, and the others laundered their towels in-house. All but 1 of the hospitals reported a quaternary ammonium compound as their disinfectant of choice; the lone exception was a rehabilitation hospital (site 9) that reported using bleach for terminal cleaning under all circumstances. In addition, all but 1 of the hospitals (site 6) reported soaking their cleaning towels in a bucket with disinfectant.

Table 2
Frequency of microbial isolation from cleaning towels and buckets

	Viable microbes	Total coliform bacteria	*E coli*	Aerobic spore-forming bacteria	Fungi
Towels	28/30 (93)	7/30 (23)	1/30 (3)	17/30 (56)	4/30 (13)
Soak buckets	6/9 (67)	1/9 (12)	ND	4/9 (44)	ND

ND, not detected.
NOTE. Data are number positive per number sampled (% positive).

Table 3
Microbial contamination of soak buckets (n = 9)

Parameter	Heterotrophic bacteria	Total coliform bacteria	Aerobic spore-forming bacteria
Mean, CFU/100 cm^2	269	0.15	153
Maximum, CFU/100 cm^2	1,300	1.3	1,320
Minimum, CFU/100 cm^2	ND	ND	ND

ND, not detected.

The microbial load was higher on the clean towels than on the swab samples taken from the buckets containing disinfectant. The overall results for the towels and swabs collected from the 10 hospitals are presented in Tables 2, 3, and 4. The mean total number of bacteria found on the towels was 133 CFU/cm^2, whereas the mean total number of bacteria found on the inside surface of the disinfectant buckets was 0.605 CFU/cm^2. Viable bacteria were detected on 93% of the towels, but on only 67% of the soak buckets. Spore-forming bacteria were isolated from 56% of the towels, coliform bacteria from 23%, *E coli* from 3.3%, and mold from 13%. Spore-forming bacteria were isolated from 44% of the soak buckets; and coliform bacteria from 12% (Table 2).

Neither MRSA nor *C difficile* were isolated from the towels or the soak buckets, but interestingly, total coliforms were recovered from

Table 4
Microbial contamination of reusable cleaning towels (mean ± SD log CFU/towel; n = 3)

Hospital	Heterotrophic bacteria	Total coliform bacteria	Aerobic spore-forming bacteria	Fungi
1	4.1 ± 0.2	0.5 ± 0.5	3.3 ± 0.2	0.9 ± 1.6
2	1.1 ± 1.9	ND	1.7 ± 1.5	ND
3	3.8 ± 0.8	0.3 ± 0.5	1.0 ± 1.7	ND
4	3.9 ± 0.3	ND	1.0 ± 1.7	ND
5	3.5 ± 0.6	ND	1.9 ± 1.6	ND
6	5.0 ± 0.1	1.3 ± 0.5	3.6 ± 0.3	3.3 ± 0.3
7	3.0 ± 0.1	ND	ND	ND
8	3.7 ± 0.5	ND	1.5 ± 1.3	ND
9	3.8 ± 0.1	ND	3.9 ± 0.6	ND
10	2.3 ± 2.0	ND	ND	ND

ND, not detected.

both sources. Bacteria identified from the towels included *Pseudomonas luteola*, *Pantoea* spp, *Klebsiella oxytoca*, *Klebsiella pneumoniae*, *Serratia plymuthica*, *Pasteurella pneumotropica*, *Aeromonas hydrophilica*, and *Micrococcus luteus.* Molds identified from the towels included *Aspergillus niger*, *Fusarium* spp, and *Cladosporium* spp.

Statistical analyses indicated significant differences in total bacteria, mold, coliform bacteria, and aerobic spore-forming bacteria in the towels (Table 5). Along with the overall differences, classification of the towels into 4 groups for analysis based on their fabric content revealed statistical differences between cotton and microfiber towels for all microbial contaminants (Table 5). The microfiber towels harbored greater numbers of bacteria compared with the cotton towels.

Table 5
Statistical differences in towel materials (mean + SD log CFU/towel; n = 24)

	Cotton		Microfiber		
	n	Mean ± SD	n	Mean ± SD	*P* value
Heterotrophic bacteria	24	3.17 ± 1.29	6	4.39 ± 0.88	.0381
Total coliform	24	0.07 ± 0.23	6	0.78 ± 0.70	.0002
Aerobic spore-forming bacteria	24	1.66 ± 1.63	6	2.28 ± 1.80	.4152
Fungi	24	0.12 ± 0.58	6	1.67 ± 1.84	.0012

DISCUSSION

In the 10 hospitals participating in this study, almost all (93%) sampled cleaning towels contained viable microorganisms even after laundering. There were significant differences among hospitals in terms of the numbers and types of microorganisms recovered. Possible explanations for these findings include the substantial variation in laundering and cleaning practices among the hospitals, as well as variations in methods of disinfectant application, towel materials, and conditions for storage of the cleaning towels, resulting in habitats more or less conducive to microbial proliferation.

The questionnaire data facilitated comparison of different factors influencing the microbial loads of cleaning towels used in the study hospitals. Significant differences in the presence of bacteria and mold were observed based on the disinfectant application method used. Spraying of towels with a power sprayer was associated with a higher microbial load than soaking, likely because spraying does not completely saturate the towel fibers with disinfectant. But even though soaking resulted in a smaller overall microbial load on the towels, coliforms were still isolated from the disinfectant buckets.

Some of the isolated bacteria are known to have significant involvement in nosocomial infections. *Klebsiella* infections are primarily associated with hospital care,[5] and in this study both *K pneumoniae* and *K oxytoca* were isolated from the hospital towels. *K pneumoniae*, the most significant species, is known to cause respiratory diseases[6] and bloodstream infections.[7] More recently, the extended-spectrum β-lactamase–producing *K pneumoniae* was shown to be highly resistant to antibiotics and a contributor to nosocomial infections.[8] *K oxytoca* has also been implicated in hospital outbreaks, primarily in immunocompromised individuals and frequently involving environmental sources.[9,10] One outbreak attributed to *K oxytoca* occurred at a university hospital in Turkey and involved the spread of bloodstream infections.[5] Extended-spectrum β-lactamase–producing *K oxytoca* infections were recently attributed to contaminated handwashing sinks in the intensive care unit of a hospital.[11] The isolation of *K oxytoca* from cleaning towels in this study suggests a real potential for the towels to serve as a reservoir for this nosocomial pathogen.

P luteola is also a significant nosocomial pathogen that can cause cutaneous abscess and bacteremia.[12] Although *S plymuthica* is identified primarily in plants,[13] it is also encountered in nosocomial infections,[14,15] specifically wound and community-acquired infections.[16] Other bacteria identified in this study, including *Pantoea* spp, are not known to cause nosocomial infections, but were recently associated with hospital outbreaks.[17]

A hydrophilica is involved in nosocomial infections, presenting as necrotizing fasciitis.[18] Another potential source of nosocomial infections isolated from the cleaning towels, *M luteus*, is known to cause pneumonia, septic arthritis, and meningitis.[19] All of the bacterial species isolated from the cleaning towels and soak buckets have reported significance in nosocomial infections. Interestingly, aerobic spore-forming bacteria were isolated more frequently in the towels compared with other bacterial contaminants, indicating that spore-forming bacteria are better able to survive the laundering process, including the washing and drying. In a recent study, *B cereus* present in linens after in-house laundering was a major source of contamination, and was isolated from clean towels, washing machines, and dryers.[1]

A significant difference was observed in the bacterial numbers recovered from cotton and microfiber towels. Bacteria have been shown to adhere more tenaciously to microfiber towels, allowing them to spread or transfer onto different surfaces as the towels are used.[20] In a recent study evaluating the efficacy of reusable towels for decontamination of surfaces, microfiber towels showed superior results when used in new condition, but after reprocessing, the cotton towels more effectively removed bacteria from surfaces. The decontamination efficacy of microfiber towels was reduced after just 20 washing cycles, contrary to the manufacturer's indications of sustained efficacy after 500 washes.[21]

Typical hospital laundering practices are not sufficient to remove all viable microorganisms and spores from towels, regardless of whether they are sent to a central laundering facility or laundered in-house. It is unclear whether bacteria remain trapped in the towel fibers through the laundering process or are reintroduced through subsequent storage or handling. Although hospital disinfectants show efficacy against the organisms found in the towels, these findings suggest that current treatment practices should be reevaluated. Our results indicate that future studies should evaluate the potential role of cloth towels as a reservoir for nosocomial pathogens, along with their possible role in overall cleaning procedures at hospitals, clinics, and long-term care institutions. Furthermore, the development of guidelines for the reuse of cloth towels in health care environments should be considered as part of the larger picture of medical institution cleaning.

References

1. Dohmae S, Okubo T, Higuchi W, Takano T, Isobe H, Baranovich T, et al. *Bacillus cereus* nosocomial infection from reused towels in Japan. J Hosp Infect 2009;69:361-7.
2. Olier AR, Mitchell A. *Staphylococcus* recovery from cotton towels. J Infect Developing Countries 2009;3:224-8.
3. Neely AN, Maley MP. Survival of enterococci and staphylococci on hospital fabrics and plastic. J Clin Microbiol 2000;38:724-6.
4. Takei Y, Yokoyama K, Katano H, Tsukiji M, Ezaki T. Molecular epidemiological analysis of methicillin-resistant staphylococci in a neonatal intensive care unit. Biocontrol Sci 2010;15:129-36.
5. Sardan YC, Zarakolu P, Altun B, Yildirim A, Yildirim G, Hascelik G, et al. A cluster of nosocomial *Klebsiella oxytoca* bloodstream infections in a university hospital. Infect Control Hosp Epidemiol 2004;25:878-82.
6. Pfaller AM, Jones RN, Doern GV, Kugler K. Bacterial pathogens isolated from patients with bloodstream infection: frequencies of occurrence and antimicrobial susceptibility patterns from the SCENTRY anti-microbial surveillance program. Antimicrob Agents Chemother 1998;42:1762-70.
7. Gales AC, Bolmstrom A, Sampaio J, Jones RN, Sader HS. Antimicrobial susceptibility of *Klebsiella pneumoniae*—producing extended-spectrum beta-lactamase (ESBL) isolated in hospitals in Brazil. Braz J Infect Dis 1997;4: 196-203.
8. Marra AR, Wey SB, Castelo A, Gales AC, Cal RGR, Do Carmo Filho JR, et al. Nosocomial bloodstream infections caused by *Klebsiella pneumoniae*: impact of extended-spectrum beta-lactamase (ESBL) production on clinical outcome in a hospital with high ESBL prevalence. BMC Infect Dis 2006;6: 24-32.
9. Schulz-Stubner S, Kniehl E. Transmission of extended-spectrum β-lactamase *Klebsiella oxytoca* via the breathing circuit of a transport ventilator: root cause analysis and infection control recommendations. Infect Control Hosp Epidemiol 2011;32:828-9.
10. Zarate MS, Gales AC, Picao RC, Pujol GS, Lanza A, Smayevsky J. Outbreak of OXY-2—producing *Klebsiella oxytoca* in a renal transplant unit. J Clin Microbiol 2008;46:2099-101.
11. Lowe C, Willey B, O'Shaughnessy A, Lee W, Lum M, Pike K, et al. Outbreak of extended-spectrum β-lactamase—producing *Klebsiella oxytoca* infections associated with contaminated handwashing sinks. Emerg Infect Dis 2012;18:1242-7.
12. Dalamaga M, Karmaniolas K, Chavelas C, Liatis S, Matekovits H, Migdalis I. *Pseudomonas luteola* cutaneous abscess and bacteraemia in a previously healthy man. Scand J Infect Dis 2004;36:495-7.
13. Berg G. Diversity of antifungal and plant-associated *Serratia plymuthica* strains. J Appl Microbiol 2000;88:952-60.
14. Domingo D, Limia A, Alarcon T, Sanz JC, Del Rey MC, López-Brea M. Nosocomial septicemia caused by *Serratia plymuthica*. J Clin Microbiol 1994;32:575-7.
15. Martinez J, Carrascosa M. Shock septico por *Serratia plymuthica*. Enferm Infec Microbiol Clin 1997;15:114-5.
16. Reina J, Borell N, Lompart I. Community-acquired bacteremia caused by *Serratia plymuthica*. Diagn Microbiol Infect Dis 1992;15:449-52.
17. Liberto MC, Matera G, Puccio R, Russo TL, Colosimo E, Foca E. Six cases of sepsis caused by *Pantoea agglomerans* in a teaching hospital. New Microbiol 2009;32: 119-23.
18. Cheng NC, Horng SY, Chang SC, Tang BY. Nosocomial infection of *Aeromonas hydrophila* presenting as necrotizing fasciitis. J Formos Med Assoc 2004;103:53-7.
19. Peces R, Gago E, Tejada F, Laures AS, Alvarez-Grande J. Relapsing bacteraemia due to *Micrococcus luteus* in a haemodialysis patient with a Perm-Cath catheter. Nephrol Dial Transplant 1997;12:2428-9.
20. Bergen LK, Meyer M, Hog M, Rubenhagen B, Andersen LP. Spread of bacteria on surfaces when cleaning with microfiber cloths. J Hosp Infect 2009;71:132-7.
21. Diab-Elschahawi M, Assadian O, Blackly A, Stadler M, Pernicka E, Berger J, et al. Evaluation of decontamination efficacy of new and reprocessed microfiber cleaning cloth compared with other commonly used cleaning cloths in the hospital. Am J Infect Control 2010;38:289-92.

Rev. Latino-Am. Enfermagem
2015 July-Aug.;23(4):708-17
DOI: 10.1590/0104-1169.0459.2607
www.eerp.usp.br/rlae

Original Article

Hand hygiene technique quality evaluation in nursing and medicine students of two academic courses[1]

Manuela Škodová[2]
Alfredo Gimeno-Benítez[3]
Elena Martínez-Redondo[4]
Juan Francisco Morán-Cortés[5]
Ramona Jiménez-Romano[6]
Alfredo Gimeno-Ortiz[6]

Objective: because they are health professionals, nursing and medical students' hands during internships can function as a transmission vehicle for hospital-acquired infections. Method: a descriptive study with nursing and medical degree students on the quality of the hand hygiene technique, which was assessed via a visual test using a hydroalcoholic solution marked with fluorescence and an ultraviolet lamp. Results: 546 students were assessed, 73.8% from medicine and 26.2% from nursing. The area of the hand with a proper antiseptic distribution was the palm (92.9%); areas not properly scrubbed were the thumbs (55.1%). 24.7% was very good in both hands, 29.8% was good, 25.1% was fair, and 20.3% was poor. The worst assessed were the male, nursing and first year students. There were no significant differences in the age groups. Conclusions: hand hygiene technique is not applied efficiently. Education plays a key role in setting a good practice base in hand hygiene, theoretical knowledge, and in skill development, as well as good practice reinforcement.

Descriptors: Students; Medicine; Nursing; Hand Disinfection; Evaluation.

[1] Paper extracted from doctoral dissertation "Evaluación de la Calidad de la Técnica de Higiene de Manos en los Profesionales Sanitarios del Complejo Hospitalario Universitario Infanta Cristina de Badajoz y en los Estudiantes de Grado de Enfermería y Grado de Medicina del Campus Universitario de Badajoz de la Universidad de Extremadura, periodo de 2012 a 2014", presented to Universidad de Extremadura, Badajoz, Extremadura, Spain.

[2] Doctoral student, Faculdad de Medicina, Universidad de Extremadura, Badajoz, Extremadura, Spain. Associate Professor, Servicio de Medicina Preventiva, Hospital Infanta Cristina, Badajoz, Spain.
[3] PhD, Associate Professor, Departamento de Enfermería, Universidad de Extremadura, Badajoz, Extremadura, Spain.
[4] Master's student, Faculdad de Medicina, Universidad de Extremadura, Badajoz, Extremadura, Spain. RN, Servicio Extremeño de Salud, Badajoz, Extremadura, Spain.
[5] MSc, RN, Servicio Extremeño de Salud, Badajoz, Extremadura, Spain.
[6] PhD, Associate Professor, Servicio de Medicina Preventiva, Hospital Infanta Cristina, Badajoz, Extremadura, Spain.

Corresponding Author:
Juan Francisco Morán Cortés
Universidad de Extremadura. Departamento de Enfermería
C/ Ordesa, 5
06006, Badajoz, Extremadura, España
E-mail: juanfmoran@gmail.com

Introduction

Hospital-acquired infections (HAIs) are one of the main causes for morbility and mortality in the health field, which constitute one of the main issues in global public health[1].

Health professionals' hands are one of the main transmission mechanisms for HAIs. Hand washing with water and antiseptic soap before and after patient contact is the most efficient technique proven to prevent hospital-acquired infection[2].

However, in everyday clinical practice, hand hygiene (HH) is happening less often than desired[3].

The World Health Organizations' (WHO) recommendations about enhancement strategies and better HH practice are considered as reference criteria, setting up several educational interventions targeting health professionals[4].

Both in Spain[5] and in the Autonomous Community of Extremadura[6], promotion and knowledge development as well as a culture of patient safety are being stressed among professionals and patients in all health service levels. While performing its working lines on a local stage, the Complejo Hospitalario Universitario Infanta Cristina de Badajoz, the Sociedad Española de Medicina Preventiva, Salud Pública e Higiene (SEMPSPH) planned educational seminars and workshops about hand hygiene and its assessment.

Because they are health professionals, nursing and medical students' hands during internships can function as a transmission vehicle for hospital-acquired infections, and can cause patient, object and surface contamination[7].

In this study we plan to assess the current state of HH in nursing and medicine students, enrolled to the Facultad de Medicina del Campus de Badajoz of the Universidad de Extremadura (UEX), who were doing an internship at the Complejo Hospitalario Universitario Infanta Cristina de Badajoz (CHUICB).

Method

Our study was a descriptive, cross-sectional study that occurred in two periods of time, and a sample was limited by the UEX, namely the Medicine Campus where medicine (six courses) and nursing (four courses) undergraduate studies are available. Three hundred seventeen students were enrolled in the nursing degree 2012/13 class, and 294 students in the 2013/14 class. For the medicine degree, there were 877 students for the 2012/13 class and 878 for the 2013/14 class.

The CHUICB is integrated with the Hospital Infanta Cristina, Hospital Perpetuo Socorro, Hospital Materno-Infantil and the Specialty Center. This complex belongs to the Health Department of Badajoz, which served a populace of 276, 154 people; it owned 831 beds, had a total of 40, 434 hospital admissions, 31, 533 surgical procedures, 2,430 deliveries and the mean stay was 6.84 days[8].

No selection of the student' sample was conducted. All students attending preventive medicine and public health classes of the biomedical sciences department and community nursing I and II classes of the nursing department were included. Student participation was voluntary.

Nursing and medical students from the Medicine Campus of Badajoz who participated in our study were: nursing degree students in the second and third years, medicine degree students in second and fifth year, and medicine baccalaureate students in sixth year (last class of the old program).

The study occurred in two periods of time: Academic year 2012/213 and 2013/2014

The study was conducted by the same professionals in the preventive medicine and public health service, on several days and different schedules in order to study the whole sample of students. A one-hour theory lesson about the foundations of hand, object, and surface contamination, epidemiology on the chain of bacteria transmission, and the different kinds of HH (instructions, material and technique) were taught during the school year of 2012/13 and 2013/14. The lesson focused on hygienic hand washing, antiseptic hand washing and hand rubbing with hydroalcoholic solutions. Likewise, instructions on applying HH, following the methodology of the "five moments of hand hygiene" proposed by the WHO were stressed.

During practical teaching, nursing and medical students attended a simulated specialty medical practice session. Small groups were established with five students. The reason for visit was explained (nausea) and students were asked to care for the patient (taking vital signs); asking them to perform a correct HH following WHO commendations. There was no sink or water and soap for performance of the HH, only hydroalcoholic solution was available which students had to use, applying knowledge acquired in the theoretical class.

Identifying variables included: date, center, academic course, nursing or medicine, sex and age.

An alcohol-based mix marked with fluorescence and an ultraviolet (UV) lamp (Dermalux®, Derma LiteCheck by Dermalux – Training) were used to assess HH.

A visual assessment of the correct fluorescence-marked hydroalcoholic solution (HAS) distribution (categories yes/no) was performed. Five main sections were considered: palms, back of the hand, between the fingers, finger tips/nails separately for each hand (right and left) and for both hands.

For the final quality assessment of the HH technique, some categories were established: "very good" if HAS was spread throughout all sections, "good", if four sections were exposed, "fair" if two sections were not exposed, and "poor" if three or more regions were left without HAS exposure (Likert-type scale with four categories). Subsequently, they were divided in two categories: "proper HH" when the right hand, left hand and both hands obtained a "very good" or "good" notation; "inadequate HH" when the right hand, left hand or both hands obtained a "fair" or "poor" notation.

Limitations to the study included: lack of a randomized sample, as well as the concomitant differences in year of education, which could bias the study.

A separate descriptive analysis of the variables was conducted, presenting the mean corresponding to the qualitative variables, and centralizing measures as well as dispersion of the quantitative variables.

A chi-square ($\chi 2$) was used for the bivariant analyses of the qualitative variables and a Student t-test for the quantitative variables, considering as significative the values $p>0.05$.

Excel of Microsoft Office 2007 was used for the coding of the obtained data, and SPSS version 15.0 for the statistical analysis.

Ethical factors: Participation of all subjects in the study was voluntary. Confidentiality of data (Organic Law 15/1999, of December 13, of the Protection of Personal Character Data) and statistics (group coding, analysis and results) were kept secret at all times; likewise, the compliance was maintained with the Hospital Infanta Cristina de Badajoz's (Spain) Ethics Committee's research protocols.

Results

A total of 546 students participated in the study, 403 (73.8%) of them were medical students and 143 (26.2%) were nursing students; 216 (39.6%) students were from the 2012/2013 class and 330 (60.4%) students were from the 2013/2014 class. Males accounted for 30.45% (144), and 69.6% (380) were female. The mean age of the sample was 21.4 ± 3.73 years of age.

In general, HAS distribution on the right hand was correct in 96.5% of cases on the palm, 86.1% between the fingers, 72.7% on the back of the hand, 70.3% on the finger tips, and 56.9% on the thumbs. For the left hand: 95.2% on the palm, 82.6% between the fingers, 80.4% on the back of the hand, 68.7% on the finger tips, and 63% on the thumbs. Considering both hands, th eHAS covered: 92.9% on the palms, 78.02% between the fingers, 65.2% on the finger tips, 64.2% on the back of the hand, and 55.1% on the thumbs.

Through direct observation, right hand, left hand and both hand HH technique quality was obtained. It was noted that 34.1% performed HH on the right hand by spreading HAS on five sections properly, 29.5% performed good HH, 21.7% achieved a fair score, and 14.6% achieved a poor score. For the left hand, 38.5% obtained a very good HH score, 30.9% had one mistake a 19.9% had two mistakes, 20.4% had three or more mistakes. Thus, 24.7% in both hands was very good, 29.8% was good, 25.1% was fair, and 20.3% was poor.

Category results were as follows: right hand HH was appropriate in 63.5%, 69.4% on left hand and HH for both hands was accurate in 50.2% of the students.

In terms of bivariant analysis by sex, men spread HAS worse than women in between the fingers and the back of the hand, on both the right and left hand (table 1). Observation for both hands showed that men did not spread HAS to the thumbs and in between the fingers as often as women did. Likewise, it was the men who obtained a "fair" notation on the right hand and "poor" on both hands, with significant differences versus women. These differences kept grouping the evaluation into two HH categories, which were: inappropriate HH on the right hand, and both hands, for men (table 1). There were no difference in the men and women groups based on year, course or age.

Table 2 shows that nursing students performed inappropriate HH on the right hand 2.2 times and on the left hand 1.7 times ($p<0,05$) more often than medical students. Future nurses obtained a "fair" and "poor" notation on the right hand and "poor" on the left hand, with significant differences compared to the medical students. Hand sections most often left without HAS by nursing students versus medical students were the palm, thumb and in between fingers of right hand; back of the hand and between the fingers on left hand, leaving back of hands, thumbs and in between fingers poorly washed on both hands (Table 2, $p<0,05$).

Hand hygiene technique quality was significatively better for the 2013/14 class versus the previous class and in women; there were no differences per year of study or age (Table 3). Table 3 shows how a lack of rubbing HAS in between the fingers and thumbs stood out as a factor most involved in inappropriate HH.

Table 1 - HAS spreading on students' hands as per sex, marked section and degree of sanitation. Facultad de Medicina de Badajoz. Badajoz. Spain. 2012/2014

Sections		Value	Male		Female		OR	CI 95%
			N	%	N	%		
Palm	Right	No	7	4.2	12	3.2	1.35	0.52-3.49
		Yes	159	95.8	368	96.8		
	Left	No	12	7.2	14	3.7	2.04	0.92-4.51
		Yes	154	92.8	366	96.3		
Thumb	Right	No	78	47	157	41.3	1.26	0.87-1.82
		Yes	88	53	223	58.7		
	Left	No	67	40.4	135	35.5	1.23	0.85-1.79
		Yes	99	59.6	245	64.5		
Interdigital	Right	No	34	20.5	42	11.1	2.07	1.26-3.40
		Yes	132	79.5	338	88.9		
	Left	No	42	25.3	53	13.9	2.09	1.33-3.29
		Yes	124	74.7	327	86.1		
Heel of the hand	Right	No	49	29.5	113	29.7	0.99	0.66-1.48
		Yes	117	70.5	267	70.3		
	Left	No	54	32.5	117	30.8	1.08	0.73-1.60
		Yes	112	67.5	263	69.2		
Back of the hand	Right	No	57	34.3	92	24.2	1.64	1.10-2.44
		Yes	109	65.7	288	75.8		
	Left	No	42	25.3	65	17.1	1.64	1.06-2.55
		Yes	124	74.7	315	82.9		
Both hands		**Value**	**Male**		**Female**		**OR**	**CI 95%**
			N	**%**	**N**	**%**		
Palm		No	17	10.2	21	5.5	1.95	0.99-3.79
		Yes	149	89.8	358	94.5		
Thumb		No	104	62.7	197	51.8	1.56	1.08-2.26
		Yes	62	37.3	183	48.2		
Interdigital		No	51	30.7	69	18.2	1.99	1.31-3.04
		Yes	115	69.3	311	81.8		
Heel of the hand		No	63	38	127	33.4	1.22	0.83-1.78
		Yes	103	62	253	66.6		
Back of the hand		No	67	40.4	128	33.7	1.33	0.92-1.94
		Yes	99	59.6	252	66.3		
Assessment - 4 categories			**Male**		**Female**		**OR**	**CI 95%**
Hand			**N**	**%**	**N**	**%**		
Right	Very good		50	30.1	136	35.8	1	-
	Good		37	22.3	124	32.6	0.85	0.59-1.23
	Regular		49	29.5	70	18.4	1.53	1.11-2.11
	Bad		30	18.1	50	13.2	1.39	0.96-2.01
Left	Very good		55	33.1	155	40.8	1	-
	Good		53	31.9	116	30.5	1.19	0.87-1.64
	Regular		38	22.9	71	18.7	1.33	0.94-1.18
	Bad		20	12	38	10	1.31	0.86-2.00
Both hands	Very good		35	21.1	100	26.3	1	-
	Good		40	24.1	123	32.4	0.94	0.63-1.40
	Regular		49	29.5	88	23.2	1.37	0.96-1.98
	Bad		42	25.3	69	18.2	1.45	1.01-2.11

(continue...)

Table 1 - (continuation)

Assessment - 2 categories		Male		Female		OR	CI 95%
Hand		N	%	N	%		
Right	Inappropriate	79	47.6	120	31.6	1.97	1.35-2.86
	Proper	87	52.4	260	68.4		
Left	Inappropriate	58	34.9	109	28.7	1.33	0.90-1.97
	Proper	108	65.1	271	71.3		
Both hands	Inappropriate	91	54.8	157	41.3	1.72	1.19-2.49
	Proper	75	45.2	223	58.7		
Observations	Some	37	22.3	108	28.4	1.38	0.90-2.12
	None	129	77.7	272	71.6		

Table 2 - HAS spreading on students' hands as per nursing and medicine studies, year, sex, age and section. Facultad de Medicina de Badajoz. Badajoz. Spain. 2012/2014

	Value	Nursing		Medicine		OR	CI 95%
		N	%	N	%		
Year	2012/2013	71	49.7	145	36.0	1.76	1.19-2.58
	2013/2014	72	50.3	258	64.0		
Gender	Male	45	31.5	121	30.0	1.07	0.71-1.62
	Female	98	68.5	282	70.0		
Age	Mean (years)	21.2	± 4.77	21.43	± 3.2	NS	
Right Hand	**Value**	**Nursing**		**Medicine**		**OR**	**CI 95%**
		N	%	N	%		
Finger Tips	No	43	30.1	119	29.5	1.03	0.68-1.56
	Yes	100	69.9	284	70.5		
Back of the hand	No	48	33.6	101	25.1	1.51	0.99-2.28
	Yes	95	66.4	302	74.9		
Palm	No	11	7.7	8	2.0	4.12	1.62-10.45
	Yes	132	92.3	395	98.0		
Thumb	No	77	53.8	158	39.2	1.81	1.23-2.66
	Yes	66	46.2	245	60.8		
Between the fingers	No	47	32.9	29	7.2	6.31	3.78-10.56
	Yes	96	67.1	374	92.8		
Left Hand	**Value**	**Nursing**		**Medicine**		**OR**	**CI 95%**
		N	%	N	%		
Finger Tips	No	46	32.2	125	31.0	1.06	0.70-1.59
	Yes	97	67.8	278	69.0		
Back of the hand	No	39	27.3	68	16.9	1.85	1.18-2.90
	Yes	104	72.7	335	81.1		
Palm	No	9	6.3	17	4.2	1.53	0.66-3.50
	Yes	134	93.7	386	95.8		
Thumb	No	62	43.4	140	34.7	1.44	0.97-2.12
	Yes	81	56.6	263	65.3		
Between the fingers	No	40	28.0	55	13.6	2.46	1.58-3.90
	Yes	103	72.0	348	86.4		
Both hands	**Value**	**Nursing**		**Medicine**		**OR**	**CI 95%**
		N	%	N	%		
Finger Tips	No	54	37.8	136	33.7	1.19	0.80-.77
	Yes	89	62.2	267	66.3		
Back of the hand	No	62	43.4	133	33.0	1.55	1.05-2.29
	Yes	81	56.6	270	67.0		
Palms	No	14	9.8	24	6.0	1.71	0.86-3.40
	Yes	129	90.2	378	94.0		

(continue...)

Table 2 - (continuation)

Thumbs	No	97	66.8	204	50.6	2.06	1.38-3.07
	Yes	46	32.2	199	49.4		
Between the fingers	No	48	33.6	72	17.9	2.32	1.51-3.57
	Yes	95	66.4	331	82.1		
Assessment - 4 categories	**Value**	**Nursing**		**Medicine**		**OR**	**CI 95%**
Hand		**N**	**%**	**N**	**%**		
Right	Very good	33	23.1	153	38.8	1	-
	Good	38	26.6	123	30.5	1.34	0.88-2.03
	Regular	34	23.8	85	21.1	1.62	1.07-2.47
	Bad	38	26.6	42	10.4	2.7	1.84-3.98
Left Hand	Very good	45	31.5	165	40.9	1	-
	Good	42	29.4	127	31.5	1.16	0.80-1.67
	Regular	32	22.4	77	19.1	1.37	0.92-2.02
	Bad	24	16.8	34	8.4	1.93	1.29-2.88
Both hands	Very good	20	14.0	115	28.5	1	-
	Good	55	38.5	108	26.8	2.27	1.44-3.60
	Regular	13	9.1	124	30.8	0.64	0.33-1.13
	Bad	55	38.5	56	13.9	3.34	2.14-5.22
Assessment - 2 categories	**Value**	**Nursing**		**Medicine**		**OR**	**CI 95%**
Hand		**N**	**%**	**N**	**%**		
Right	Inappropriate	72	50.3	127	31.5	2.2	1.49-3.25
	Proper	71	49.7	276	68.5		
Left Hand	Inappropriate	56	39.2	111	27.5	1.69	1.13-2.52
	Proper	87	60.8	292	72.5		
Both hands	Inappropriate	68	47.6	180	44.7	1.12	0.77-1.65
	Proper	75	52.4	223	55.3		

Table 3 – Degree of HH performance in nursing and medical students' hands as per class, year, gender, age and section. Facultad de Medicina de Badajoz. Badajoz. Spain. 2012/2014

	Value	**HH Inappropriate**		**HH Proper**		**OR**	**CI 95%**
		N	**%**	**N**	**%**		
Year	2012/2013	128	51.6	88	29.5	2.55	1.79-3.62
	2013/2014	120	48.4	210	70.5		
Course	Nursing	68	27.4	75	25.2	1.12	0.77-1.65
	Medicine	180	72.6	223	74.89		
Gender	Male	91	36.7	75	25.2	1.72	1.19-2.49
	Female	157	63.3	223	74.8		
Age	Mean (years)	21.18	±3.54	21.54	± 3.88	NS	
Right Hand		**HH Inappropriate**		**HH Proper**		**OR**	**CI 95%**
		N	**%**	**N**	**%**		
Finger Tips	No	116	46.8	46	15.4	4.81	3.22-7.19
	Yes	132	53.2	252	84.6		
Back of the hand	No	115	46.4	34	11.4	6.71	4.34-10.38
	Yes	133	53.6	264	88.6		
Palm	No	15	6	4	1.3	4.73	1.55-14.45
	Yes	233	94	294	98.7		
Thumb	No	179	72.2	56	18.8	11.21	7.50-16.56
	Yes	69	27.8	242	81.2		
Between the fingers	No	73	29.4	3	1	41.02	12.74-132.12
	Yes	175	70.6	295	99		

(continue...)

Table 3 - (continuation)

Left Hand		HH Inappropriate		HH Proper		OR	CI 95%
		N	%	N	%		
Finger Tips	No	120	48.4	51	17.1	4.54	3.07-6.71
	Yes	128	51.6	247	82.9		
Back of the hand	No	80	32.3	27	9.1	4.78	2.97-7.69
	Yes	168	67.7	271	90.9		
Palm	No	24	9.7	2	0.7	15.86	3.71-67.80
	Yes	224	90.3	296	99.3		
Thumb	No	161	64.9	41	13.8	11.6	7.62-17.66
	Yes	87	35.1	257	86.2		
Between the fingers	No	89	35.9	6	2	27.24	11.66-63.67
	Yes	159	64.1	292	98		
Both hands		**HH Inappropriate**		**HH Proper**		**OR**	**CI 95%**
		N	**%**	**N**	**%**		
Finger Tips	No	152	61.3	38	12.8	10.83	7.08-16.58
	Yes	96	38.7	260	87.2		
Back of the hand	No	155	62.5	40	13.4	10.75	7.06-16.37
	Yes	93	37.5	258	86.6		
Palms	No	34	13.7	4	1.3	11.64	4.07-33.29
	Yes	214	86.3	293	98.7		
Thumbs	No	219	88.3	82	27.5	19.89	12.51-31.62
	Yes	29	11.7	216	72.5		
Between the fingers	No	110	44.4	10	3.4	22.96	11.65-45.24
	Yes	138	55.6	288	96.6		

Discussion

HH is recognized globally as a key factor in the reduction of hospital-acquired infection occurrence. The WHO recommends that research and publications focus on the establishment of hydroalcoholic solution and assessment of its use via diverse strategies. Educational and awareness programs, workshops, reminder posters, direct observation to assess completion and adherence stand out among them[7, 9], as well as indirect assessment via proxy variables such as HAS use and hospital-acquired infection rates.

However, routine checking[10] of methodology quality to improve HH adherence in order to reduce hospital-acquired infection is still inadequate to prove the efficiency of this approach; in addition to maintaining the biases in this type of study[11].

Currently, the use of a motivational tool named positive deviation is suggested. This tool identifies groups of individuals that solve problems better than others without additional resources, which in a study conducted by Mara AR et al. [12] obtained an improvement, although no conclusive results were obtained in another routine revision [13].

In another HH compliance study [14] with interns in a Brazilian hospital, 50% lower adherence was obtained, but this is no guarantee of performed hand-washing efficiency via verification/assessment of proper HH technique. Likewise, nursing students had their internship in different hospitals, which prevented a follow-up; the introduction of this assessment in an undergraduate program becomes justified along with the five-step HH proposed by the WHO, complete with adherence studies during the clinical internship and career.

There are few studies that assess the HH technique via marked HAS spreading. This is probably due to the HH guide provided by the WHO and other institutions that describe the solutions, their efficiency, and application sequence, but which do not provide statements about quality assessment.

Macdonald[15] assessed marked-HAS distribution in three sections (fingers, palms and thumbs) in trained staff, but the study does not detail the percentage of the sample who rubbed each individual section properly. In another study by the same author, the surface of a practice workshop was assessed before and after in the traumatology service, providing an estimate of the palm and back of the hand sections.

Widmer[16] found a great improvement and correlation between HAS covered areas scores and hand

colony-forming units (CFUs), before and after specific training, which was compulsory for the staff.

Hautmaniere[17] and Sutter[18] performed a before-after assessment of specific HH training programs for medical students, improving sections covered with HAS and CFU spreading; they concluded that this tool is easy and trustworthy for gauging the HH technique.

Kampf[19] found that 53% of subjects studied left out at least one section during HH, using the reference technique in the EN1500 norm; although the sample was small (55 people) and had many comparisons (16 variables).

Via a compulsory educational course, Szilágy[20] obtained an assessment of 67-72% from 4642 participants with a "good" notation; in that study, the sections forgotten most frequently were the top section of the fingers close to the nails, the thenar eminence, and the wrist. These results are similar to the present study, although this last one was performed on students and was voluntarily.

In Spain, only the study conducted by Ramon-Canton[21] assessed HH technique in healthcare professionals at their work post, with no previous compulsory workshop. The results showed that 95.2% of people assessed left at least one section unclean, and the sections with the worst scores were the thumbs and fingers. In our study, the same assumption gives a result of 75.27% with at least one section of the hand left unclean, and the sections with worst scoring were the thumbs and in between the fingers.

Other studies[17, 22] involving medical and nursing students obtained a rating of inadequate HAS HH of 78.5% and 81.5%, much higher than our study (49.82%).

Furthermore, 26.6% of the students were observed to have attended the practicum with long nails, with nail polish or artificial nails, watches or bracelets; these circumstances complicate correct HH performance, and were not taken into account in other studies.

It is important to point out that the right hand on its own was better cleaned with HAS than the left one, except the thumb; considering that most of the human population is right-handed, this entails that the dominant hand is washed less properly. Therefore, emphasis should be placed on raising awareness and training the non-dominant hand on HH.

Likewise, comments and questions of the students attending were heeded, this helped identify the fact that they had difficulty in recognizing the opportunities for HH according to the different procedures that form their usual clinical practice. All these elements must be taken into account and incorporated into cross-disciplinary education during undergraduate studies.

Knowledge that health care students must have about hand, object and surface contamination and HH issues in hospital-acquired infection prevention and control is key to improve HH quality and adherence [23-24] to provide safe health services.

Conclusions

All staff in a health institution, and specially heath care professionals, including students during their internship, must deliver safe health services that prevent hospital-acquired infection in their everyday practice.

Therefore, proper education and training in proper HH technique performance and regular creation of campaigns and workshops remains a priority.

Moreover, effectiveness of HH also depends on quality technique, and we believe that regular practicum and assessment using this immediate feedback method could provide a simple, quick tool with large effect in students and professionals; it can ascertain HH technique quality at an individual level, after a course/workshop or at their place of work, giving them the necessary skills and knowledge as well as awareness and better adherence, which need improvement.

Hand hygiene improvement must be a priority for healthcare authorities in all levels, be it undergraduate, graduate studies or ongoing training, where there is an individual responsibility for each healthcare professional. All HH programs must include different actions, such as alcoholic solution introduction, staff education and motivation, as well as assessment and counselling in HH technique quality.

References

1. Pittet D, Allegranzi B, Boyce J. The World Health Organization Guidelines on Hand Hygiene in Health Care and their consensus recommendations. Infect Control Hosp Epidemiol. 2009 Jul;30(7):611–22.

2. Allegranzi B, Pittet D. Role of hand hygiene in healthcare-associated infection prevention. J Hosp Infect. 2009 Dec;73(4):305–15.

3. Creedon SA. Healthcare workers' hand decontamination practices: compliance with recommended guidelines. J Adv Nurs. 2005 Aug;51(3):208–16.

4. Chou DTS, Achan P, Ramachandran M. The World Health Organization "5 moments of hand hygiene":

the scientific foundation. J Bone Joint Surg Br. 2012 Apr;94(4):441–5.

5. Ministerio de Sanidad, Servicios Sociales e Igualdad. Plan de Calidad del Sistema Nacional de Salud. Fomentar la excelencia clínica. Estrategia 8.- Mejorar la seguridad de los pacientes atendidos en los centros sanitarios del SNS. [Internet]. [acesso 25 ago 2014]; Disponível em: http://www.msssi.gob.es/organizacion/sns/planCalidadSNS/ec03_doc.htm.

6. Junta de Extremadura (ES). Consejería de Sanidad y Dependencia. Servicio Extremeño de Salud. Plan Estratégico de Seguridad de Pacientes del Servicio Extremeño de Salud 2011-2016 [Internet]. Cáceres, 2011 [acesso 25 ago 2014]. Disponível em: http://www.msssi.gob.es/organizacion/sns/planCalidadSNS/ec03_doc.htm

7. Erasmus V, Daha TJ, Brug H, Richardus JH, Behrendt MD, Vos MC, et al. Systematic review of studies on compliance with hand hygiene guidelines in hospital care. Infect Control Hosp Epidemiol. 2010 Mar;31(3):283–94.

8. Gerencia del Área de Salud de Badajoz (ES). Servicio Extremeño de Salud. Memoria de Área de Salud de Badajoz [Internet]. 2012 [acesso 25 ago 2014]. Disponível em: http://www.areasaludbadajoz.com/index.php/component/flexicontent/11-atencion-al-usuario/17-memorias-anuales.

9. Rosenthal VD, Pawar M, Leblebicioglu H, Navoa-Ng JA, Villamil-Gómez W, Armas-Ruiz A, et al. Impact of the International Nosocomial Infection Control Consortium (INICC) Multidimensional Hand Hygiene Approach over 13 Years in 51 Cities of 19 Limited-Resource Countries from Latin America, Asia, the Middle East, and Europe. Infect Control Hosp Epidemiol. 2013;34(4):415-23.

10. Gould DJ, Moralejo D, Drey N, Chudleigh JH. Interventions to improve hand hygiene compliance in patient care. Cochrane Database of Systematic Reviews 2010, Issue 9. Art. No.: CD005186. DOI: 10.1002/14651858.CD005186.pub3.

11. Kohli E, Ptak J, Smith R, Taylor E, Talbot EA, Kirkland KB. Variability in the Hawthorne Effect With Regard to Hand Hygiene Performance in High- and Low-Performing Inpatient Care Units. Infect Control Hosp Epidemiol. 2009 Mar;30(3):222-5.

12. Marra AR, Noritomi DT, Westheimer Cavalcante AJ, Sampaio Camargo TZ, Bortoleto RP, Durao Junior MS, et al. A multicenter study using positive deviance for improving hand hygiene compliance. Am J Infect Control. 2013; 41:984-8.

13. Cherry MG, Brown JM, Bethell GS, Neal T, Shaw NJ. Features of educational interventions that lead to compliance with hand hygiene in healthcare professionals within a hospital care setting. A BEME systematic review: BEME Guide No. 22. Med Teach. 2012;34(6):e406-20. doi: 10.3109/0142159X.2012.680936.

14. Felix CC, Miyadahira AM. Evaluation of the handwashing technique held by students from the nursing graduation course. Rev Esc Enferm USP. 2009 Mar;43(1):139-45.

15. Macdonald DJM, McKillop ECA, Trotter S, Gray AJ. Improving hand-washing performance - a crossover study of hand-washing in the orthopaedic department. Ann R Coll Surg Engl. 2006 May;88(3):289–91.

16. Widmer AF, Conzelmann M, Tomic M, Frei R, Stranden AM. Introducing alcohol-based hand rub for hand hygiene: the critical need for training. Infect Control Hosp Epidemiol. 2007 Jan;28(1):50–4.

17. Hautemaniere A, Diguio N, Daval MC, Hunter PR, Hartemann P. Short-term assessment of training of medical students in the use of alcohol-based hand rub using fluorescent-labeled hand rub and skin hydration measurements. Am J Infect Control. 2009 May;37(4):338–40.

18. Tschudin Sutter S, Frei R, Dangel M, Widmer AF. Effect of teaching recommended World Health Organization technique on the use of alcohol-based hand rub by medical students. Infect Control Hosp Epidemiol. 2010 Nov;31(11):1194–5.

19. Kampf G, Reichel M, Feil Y, Eggerstedt S, Kaulfers P-M. Influence of rub-in technique on required application time and hand coverage in hygienic hand disinfection. BMC Infect Dis. 2008;8:149.

20. Szilagyi L, Haidegger T, Lehotsky A, Nagy M, Csonka E-A, Sun X, et al. A large-scale assessment of hand hygiene quality and the effectiveness of the "WHO 6-steps". BMC Infect Dis. 2013;13:249.

21. Ramon-Canton C, Boada-Sanmartin N, Pagespetit-Casas L. [Evaluation of a hand hygiene technique in healthcare workers]. Rev Calid Asist Organo Soc Espanola Calid Asist. 2011 Dec;26(6):376–9.

22. Kelcikova S, Skodova Z, Straka S. Effectiveness of hand hygiene education in a basic nursing school curricula. Public Health Nurs Boston Mass. 2012 Apr;29(2):152–9.

23. Molina-Cabrillana J, Alvarez-Leon EE, Quori A, Garcia-de Carlos P, Lopez-Carrio I, Bolanos-Rivero M, et al. [Assessment of a hand hygiene program on healthcare-associated infection control]. Rev Calid Asist Organo Soc Espanola Calid Asist. 2010 Aug;25(4):215–22.

24. Garcia-Vazquez E, Murcia-Paya J, Allegue JM, Canteras M, Gomez J. [Influence of a multiple

intervention program for hand hygiene compliance in an ICU]. Med Intensiva Soc Espanola Med Intensiva Unidades Coronarias. 2012 Mar;36(2):69-76.

Received: Sept 30th 2014
Accepted: Mar 1st 2015

Effectiveness of a hospital-wide programme to improve compliance with hand hygiene

Didier Pittet, Stéphane Hugonnet, Stephan Harbarth, Philippe Mourouga, Valérie Sauvan, Sylvie Touveneau, Thomas V Perneger, and members of the Infection Control Programme

Summary

Background Hand hygiene prevents cross infection in hospitals, but compliance with recommended instructions is commonly poor. We attempted to promote hand hygiene by implementing a hospital-wide programme, with special emphasis on bedside, alcohol-based hand disinfection. We measured nosocomial infections in parallel.

Methods We monitored the overall compliance with hand hygiene during routine patient care in a teaching hospital in Geneva, Switzerland, before and during implementation of a hand-hygiene campaign. Seven hospital-wide observational surveys were done twice yearly from December, 1994, to December, 1997. Secondary outcome measures were nosocomial infection rates, attack rates of meticillin-resistant *Staphylococcus aureus* (MRSA), and consumption of handrub disinfectant.

Findings We observed more than 20 000 opportunities for hand hygiene. Compliance improved progressively from 48% in 1994, to 66% in 1997 (p<0·001). Although recourse to handwashing with soap and water remained stable, frequency of hand disinfection substantially increased during the study period (p<0·001). This result was unchanged after adjustment for known risk factors of poor adherence. Hand hygiene improved significantly among nurses and nursing assistants, but remained poor among doctors. During the same period, overall nosocomial infection decreased (prevalence of 16·9% in 1994 to 9·9% in 1998; p=0·04), MRSA transmission rates decreased (2·16 to 0·93 episodes per 10 000 patient-days; p<0·001), and the consumption of alcohol-based handrub solution increased from 3·5 to 15·4 L per 1000 patient-days between 1993 and 1998 (p<0·001).

Interpretation The campaign produced a sustained improvement in compliance with hand hygiene, coinciding with a reduction of nosocomial infections and MRSA transmission. The promotion of bedside, antiseptic handrubs largely contributed to the increase in compliance.

Lancet 2000; **356:** 1307–12
See Commentary page 1290

Infection Control Programme, Department of Internal Medicine (Prof D Pittet MD, S Hugonnet MD, S Harbarth MD, P Mourouga MD, V Sauvan RN, S Touveneau RN)**; Quality of Care Programme** (T V Perneger MD) **University of Geneva Hospitals, and Institute of Social and Preventive Medicine, University of Geneva, Geneva, Switzerland**

Correspondence to: Prof Didier Pittet, Infection Control Programme, Department of Internal Medicine, University of Geneva Hospitals, 1211 Geneva 14, Switzerland
(e-mail: didier.pittet@hcuge.ch)

Introduction

Hand hygiene, either by handwashing or hand disinfection, remains the single most important measure to prevent nosocomial infections.[1] The importance of this simple procedure is not sufficiently recognised by health-care workers (HCWs),[2] and poor compliance has been documented repeatedly.[3–5] Although some previous interventions to improve compliance have been successful, none has achieved lasting improvement.[2,6,7] This situation led to the creation of a Handwashing Liaison Group[8] in the UK in 1997, whose mission is "to modify the behaviour of HCWs to produce sustained improvement in compliance with agreed handwashing standards and so improve the quality of patient care".[8]

In our hospital, we documented disappointing levels of hand hygiene compliance and identified several risk factors for non-compliance.[5] The observed relation between increased workload and reduced compliance suggested that promotion of bedside hand disinfection, less time-consuming than handwashing, may improve compliance.[5,9] Hence, we implemented a hospital-wide campaign to promote hand hygiene and, in particular, the use of alcohol-based handrubs.[7] We hypothesised that our programme would not only increase compliance with hand hygiene, but also diminish meticillin-resistant *Staphylococcus aureus* (MRSA) transmission and nosocomial infection rates. We describe the programme and its effectiveness.

Methods

Procedure

The University of Geneva Hospitals (UGH) is a large acute-care teaching hospital serving residents of Geneva, Switzerland, and the surrounding area. Handwashing facilities are available everywhere with one to three sinks in every patient's room together with unmedicated soap and paper towels.[5]

The hand-hygiene promotion programme started in January 1995 after a baseline survey.[5] The most prominent component was a visual display with A3-size colour posters that emphasised the importance of hand-cleansing, particularly hand disinfection, and performance feedback. The posters were displayed in 250 strategic areas within the institution, previously identified by visiting the wards and common areas with senior nurses. Location criteria were maximal visibility during daily work and during transit within the hospital.

The content of the promotional material (available at http://www.hopisaffe.ch, accessed Oct 3, 2000) was prepared in association with collaborative groups of HCWs across all wards and translated by an artist into a cartoon-like message. Subjects included: nosocomial infection, cross transmission, hand carriage, hand hygiene, hand disinfection, and hand protection with creams. Posters were selected for use during regular meetings (six to eight times per year) with a multidisciplinary group of HCWs. This group, the project team, included representatives (senior nurses and doctors) from each medical department, senior administrative managers, and representatives from other hospital service departments. Each poster featured the name of the ward that proposed the message so that

authorship could be recognised hospital-wide and hospital staff would have a sense of ownership of the campaign. 70 different posters were produced in multiple copies with three to five posters displayed simultaneously throughout the hospital at any given time. Housekeeping staff replaced the posters once to twice weekly during 1995, and weekly thereafter, according to a predetermined order of appearance.

Individual bottles of handrub solution (alcohol-based preparation with 0·5% chlorhexidine gluconate and skin emollients) were distributed in large amounts to all wards, and custom-made holders were mounted on all beds to facilitate access to hand disinfection. HCWs were also encouraged to carry a bottle in their pocket and, in 1996, a newly-designed flat (instead of round) bottle was made available to further facilitate pocket carriage.

Recognising that a strong institutional commitment was indispensable to implement behavioural changes among HCWs,[6] the infection-control programme, with the support of the medical and nursing directors, secured the approval of senior hospital management to have the programme designated as a hospital-wide priority. The human resources for the intervention were essentially those of the infection-control programme. Senior management provided funding to implement the programme and for an additional nurse for 4 months to start the programme; they also authorised the permanent use of hospital walls for poster display, encouraged the involvement of senior staff from various departments to participate in the programme development, participated themselves in regular meetings of the project team, and voiced publicly their support for the programme. There was no external source of funding during the study period.

Compliance with hand-hygiene procedures

We did seven surveys as previously described[5] twice yearly, in June and December, from 1994 to 1997. Infection-control nurses monitored hand-hygiene practice of HCWs with a structured protocol during 2–3 weeks. They recorded potential opportunities for hand hygiene according to recommended guidelines,[1,5,10] and the actual number of episodes of handwashes and handrubs. Handwashing referred to washing hands with either water alone or unmedicated soap and water, and hand disinfection to the use of an alcohol-based handrub solution.[1,10] Potential confounders of hand-hygiene compliance included: professional category, hospital ward, time of day/week, patient-to-nurse ratio at time of observation, and type and intensity of patient care according to the number of opportunities for hand hygiene per hour of care.[5]

Observations were done at prespecified time periods throughout the day and night during 20 min periods, distributed equally during the survey duration. HCWs did not know the schedule of observation periods. The observers were as unobtrusive as possible, but were not hidden. Interobserver variability was recorded during at least 10% of monitoring sessions in which two to three observers worked simultaneously.[5] Concordance among observers was excellent; sensitivity to detect predetermined opportunities for hand hygiene averaged 98% (SD 1) and interrater reliability was high for all variables (kappa values=0·92; range 0·79–1·0).

Performance feedback was reported in March and September of each year through the hospital newsletter distributed together with salary slips. In addition, grand rounds were given (by DP) in all medical departments at the time of the initial performance feedback (Spring 1995). Demonstration of correct hand-hygiene technique is an integral part of regular educational sessions for new employees at the hospital and was not further reinforced during the study period. In accordance with the institutional review board's requirements, we did not identify staff members observed during the surveys by unique identifier.[5]

Secondary outcome measures

Nococomial infections were identified by trained infection-control nurses as described elsewhere[11] and classified according to standard definitions of the Centers for Disease Control and Prevention.[12] Annual prevalence surveys for nosocomial infections have been carried out in our hospital since 1994 with standardised methods.[11] MRSA surveillance and control consisted of prospective follow-up of all colonised or infected patients, weekly screening of patients, weekly visits of the infection-control nurses, surveillance cultures from room-mates, and contact isolation for the duration of hospital stay and on readmission.[13] Selected patients were treated with nasal mupirocin ointment for 5 days, and daily chlorhexidine body cleansing for 10 days.[14] A computerised MRSA alert system allowed early isolation of newly identified patients and recognised known carriers during readmission. The attack rate of MRSA transmission was expressed as the number of new hospital-acquired MRSA cases per 100 hospital admissions.[12,13]

As additional process indicator, we examined the amount of alcohol-based handrub solution distributed in the hospital, as monitored by the Pharmacy Department. Information on hospital-wide antimicrobial use was summarised in daily defined doses, one daily defined dose being the standard adult daily dose of an antibiotic agent for one day's treatment.

Statistical analysis

Differences in proportions were compared by χ^2 tests and by means of odds ratios and corresponding 95% CIs. Modification of compliance over time was first estimated in an univariate analysis with the first survey as the reference point. We used logistic regression, with compliance versus non-compliance as the outcome variable, to control for factors that are already associated with compliance.[5] Linear trend tests were used to assess general trends in compliance and nosocomial infection rates during the study period. Changes in the incidence of MRSA infections and bacteraemia over time were analysed by Poisson regression with the generalised linear models procedure (STATA, version 6.0). Trends in compliance over time were analysed separately by type of ward, care, and HCW, and by activity index, and first-order interactions were tested. To account for interdependence of observations, we used robust estimates of variance by including each observation period as a cluster (generalised estimating equation[5,15]).

Two-tailed p values of less than 0·05 were considered to indicate statistical significance.

Results

Between 1994 and 1997, data were collected from 2629 scheduled observation periods, of which 120 (4·6%) produced no data, mostly during the night when no hand-hygiene opportunities occurred. The remaining 2509 periods totalled 833 h and 52 min of observation and lasted between 5 and 45 min, most being of 20 min duration (2384 [95%] of observations). We obtained data on 20082 opportunities for hand hygiene in total.

Hand-cleansing opportunities were spread evenly among the seven surveys, between hospital locations, and according to the level of contamination risk. The distribution of hand-hygiene opportunities according to

	Dec 1994	June 1995	Dec 1995	June 1996	Dec 1996	June 1997	Dec 1997
Opportunities	2834 (100)	3273 (100)	3019 (100)	2607 (100)	3044 (100)	2736 (100)	2569 (100)
Professional activity							
Nurses	2006 (71)	2068 (63)	2034 (67)	1736 (66)	2134 (70)	1977 (72)	1823 (71)
Doctors	281 (10)	332 (10)	301 (10)	216 (8·3)	208 (6·8)	196 (7·2)	152 (5·9)
Nursing assistants	378 (13)	621 (19)	535 (18)	543 (21)	557 (18)	504 (18)	493 (19)
Other*	169 (6·9)	252 (7·7)	149 (4·9)	112 (4·3)	145 (4·8)	59 (2·2)	101 (3·9)
Hospital location							
Medical ward	1118 (39)	1441 (44)	1163 (39)	1164 (45)	1375 (45)	982 (36)	1091 (42)
Surgical ward	980 (35)	1251 (38)	1175 (39)	908 (35)	1080 (35)	1117 (41)	970 (38)
Gynaecology/obstetrics	151 (5·3)	119 (3·6)	69 (2·3)	76 (2·9)	47 (1·5)	46 (1·7)	81 (3·2)
Paediatrics	133 (4·7)	85 (2·6)	83 (2·7)	115 (4·4)	118 (3·9)	139 (5·1)	130 (5·1)
Intensive care	458 (16)	375 (11)	529 (18)	344 (13)	424 (14)	452 (17)	297 (12)
Activity index†							
⩽20	473 (17)	663 (20)	708 (23)	758 (29)	642 (21)	571 (21)	678 (26)
21–40	1258 (44)	1371 (42)	1245 (41)	1284 (49)	1475 (48)	1383 (51)	1339 (52)
41–60	825 (29)	855 (26)	636 (22)	466 (18)	648 (21)	449 (16)	435 (17)
>60	278 (9·8)	384 (12)	430 (14)	99 (3·8)	279 (9·2)	333 (12)	117 (4·6)
Level of risk of contamination‡							
Low risk procedure	944 (36)	1307 (40)	1181 (39)	1046 (40)	1202 (39)	1052 (38)	909 (35)
Medium risk	1251 (48)	1468 (45)	1340 (44)	1156 (44)	1358 (45)	1170 (43)	1203 (47)
High risk	413 (16)	498 (15)	498 (16)	405 (16)	484 (16)	514 (19)	457 (18)

All data are number (%) of opportunities for hand hygiene (%). *Other includes: midwifes, respiratory and mobilisation therapists, radiology technicians, nutrition therapists, a well as HCWs of all professional categories apart from nurses, nursing assistants, and doctors. †Refers to the number of opportunities for hand hygiene per h of care. ‡Level of risk of contamination is ranked according to the scale proposed by Fulkerson.[2]

Table 1: **Observed opportunities for hand hygiene in consecutive observational studies, University of Geneva Hospitals, Switzerland, 1994–97**

parameters previously identified as influencing compliance was homogenous throughout the study period (table 1). Among major staff categories, nurses contributed an average of 68·8% (SD 3·3) of all opportunities; nursing assistants 18·0 (2·4); doctors 8·3 (1·7); and other HCWs 4·9 (1·8).

Overall compliance improved from 47·6% in 1994, to 66·2% in December 1997 (p<0·001; figure 1). Although compliance achieved through standard handwashing remained stable at around 30%, that associated with hand disinfection substantially increased from 13·6% to 37·0% (p<0·001) between the first and the last survey (figure 1). In support of this observation, the annual amount of alcohol-based handrub solution used increased from 3·5 L per 1000 patient-days in 1993, to 4·1 L in 1994, 6·9 L in 1995, 9·5 L in 1996; 10·9 L in 1997, and 15·4 L 1998 (p for linear trend, p<0·001). Compared with the first observation period, odds ratios for compliance increased progressively even after adjustment for factors independently associated with non-compliance (table 2).

Although average compliance differed between hospital locations, compliance improved significantly during the study period in medical, surgical, and intensive-care wards (all p<0·001). Although not statistically significant, similar trends were observed in gynaecology/obstetrics (p=0·17), and paediatric wards (p=0·12; figure 2A). We observed lower compliance rates for activities associated with a high risk of transmission, compared with a medium or low risk; however, compliance increased in all three groups after the intervention (all p<0·001; figure 2B).

The number of opportunities for hand cleansing per h of care was constant during the study period. We confirmed previous observations of a link between a higher demand and reduced compliance.[5] Compliance improved in the same manner at all levels of demand for hand cleansing (p=0·019 for the high-demand group, and p<0·001 for the others; figure 2C).

Compliance improvement with hand-hygiene practice differed significantly between HCWs (figure 2D). Remarkably, although it increased among nurses and nursing assistants (both p<0·001), average compliance remained low among doctors and other HCWs (31·1% [SD 5·3] and 39·5 [6·2], respectively) with no significant trends over time (linear trends, p=0·92 and p=0·54, respectively). Importantly, although doctors' overall compliance with hand cleansing did not improve, they switched from handwashing to hand disinfection during the study period. On average, from one survey to the next, the odds ratio for hand disinfection (as opposed to handwashing) was 1·12 (95% CI 1·02–1·24; p=0·023).

Based on annual hospital-wide surveys at our hospital, the prevalence of nosocomial infections decreased from 16·9% in 1994 to 9·9% in 1998 (p=0·04; figure 3). Furthermore, on-site surveillance showed that the attack rate of newly detected MRSA patients decreased from 1994 onwards (p=0·021). Between 1994 and 1998, the overall incidence of MRSA infections decreased from 2·16 to 0·93 episodes per 10 000 patient-days (p<0·001). In particular, the annual incidence of hospital-acquired MRSA

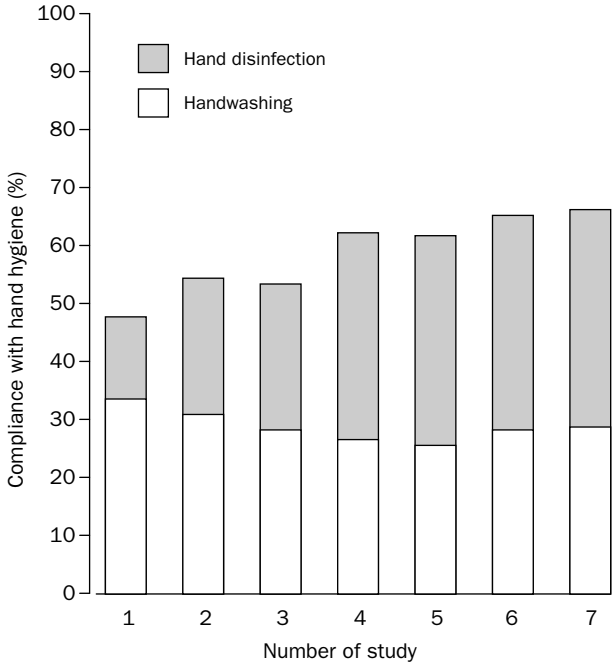

Figure 1: **Hand-hygiene compliance trend during seven consecutive hospital-wide surveys, University of Geneva Hospitals, 1994–97**

	Dec 1994	June 1995	Dec 1995	June 1996	Dec 1996	June 1997	Dec 1997
Overall compliance (95% CI)	47·6 (46·8–48·5)	54·2 (53·4–55·1)	53·4 (52·4–54·4)	62·2 (61·2–63·3)	61·8 (60·8–62·8)	65·1 (64·1–66·0)	66·2 (65·1–67·2)
Univariate odds ratios (95% CI)	1·00	1·30 (1·11–1·53)	1·26 (1·05–1·51)	1·81 (1·51–2·17)	1·78 (1·48–2·14)	2·05 (1·69–2·47)	2·15 (1·78–2·60)
Adjusted* odds ratios (95% CI)	1·00	1·31 (1·11–1·55)	1·26 (1·06–1·50)	1·65 (1·38–1·96)	1·70 (1·42–2·04)	1·97 (1·64–2·36)	1·92 (1·59–2·33)

*Adjusted for hospital ward, type of HCW, level of risk of transmission, and activity index categorised as shown in table 1.

Table 2: **Compliance with hand hygiene in successive observational surveys, and odds ratios for compliance, unadjusted and adjusted for known risk factors, University of Geneva Hospitals, Switzerland, 1994–97**

bacteraemia decreased from 0·74 to 0·24 episodes per 10000 patient-days (p<0·001).

No antimicrobial restriction or improvement programme was initiated during the study period. Between 1994 and 1997, we observed a decrease in the use of aminoglycosides and intravenous amoxicillin/clavulanate (16·97 to 12·57, and 44·92 to 19·43 daily defined doses per 1000 patient-days, respectively), whereas the use of imipenem and extended-spectrum β-lactam antibiotics increased from 13·85 to 20·07, and 21·42 to 27·18 daily defined doses per 1000 patient-days. The use of other agents did not change substantially.

Discussion

Compliance with hand-hygiene recommendations improved significantly following a hospital-wide education programme, coinciding with a reduction of nosocomial infections and MRSA transmission. The programme was mainly based on a poster campaign together with a generalised promotion of alcoholic handrubs as an alternative to soap-and-water handwashing. Improved adherence was sustained and observed across most hospital locations, in all types of patient-care activities, and among most HCWs present on the ward, with the notable exception of doctors.

Prior attempts to improve compliance with hand-cleansing practice have been associated with, at best, transient improvement.[2,7] The most effective measure has been routine observation and feedback,[16] but no intervention has reported a long-term effect.[16–18] We observed a sustained improvement that accompanied an equally sustained intervention. Whether improved hand-hygiene practice will outlast the intervention remains uncertain; we decided to refrain from testing this issue by maintaining a permanent component of the intervention.

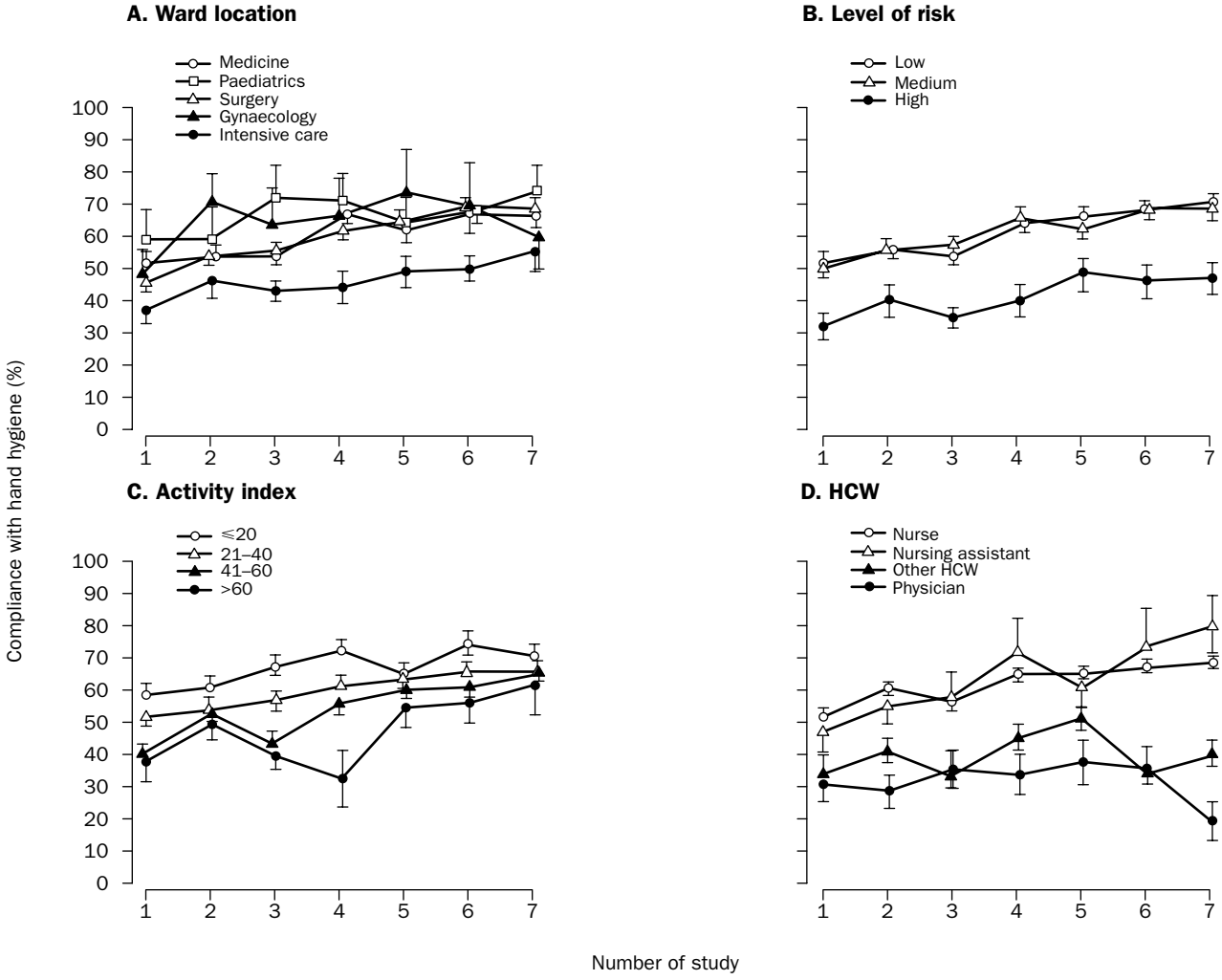

Figure 2: **Hand-hygiene compliance trends in seven consecutive hospital-wide surveys**
A, according to ward location; B, level of risk for contamination; C, level of activity at time of observation; D, type of HCW. Level of activity at time of observation refers to the number of opportunities for hand hygiene per h of care (activity index).

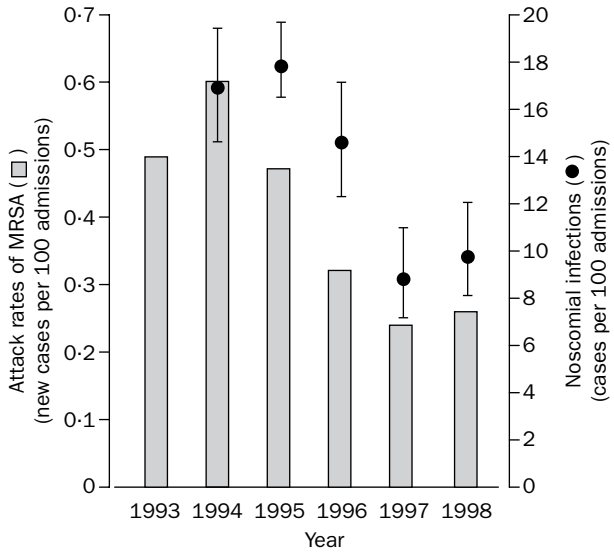

Figure 3: **Trends in prevalence of nosocomial infections and annual attack rate of MRSA, 1993–98, University of Geneva Hospitals**

Poor compliance with hand hygiene is common among HCWs. Reported reasons for not washing hands include skin irritation, inaccessible handwashing supplies, wearing gloves, "being too busy", or "not thinking about it".[2,6,16–18] Of note, some HCWs believed that they washed their hands when necessary even when observations indicated otherwise.[16] Our intervention targeted three of these reasons by facilitating hand hygiene through easy access to hand disinfection and through repeated reminders using the poster campaign.[7,17,18]

As high demand for hand cleansing is associated with low compliance,[5] and because full compliance with conventional guidelines may be unrealistic[5,9] we tested whether bedside hand antiseptics could help improve this situation. We found that most groups of HCWs modified their practice and compliance improved mainly as a result of the increasing use of alcohol-based handrub solution. HCWs were repeatedly encouraged to consult the employee health unit for any concern linked to the use of hand-hygiene products, but no case of substantial skin damage (excessive skin irritation and dryness with fissuring or cracking, severe irritant contact dermatitis, allergic or toxic reactions) was notified. Current experience with alcohol-based rubs confirms that hand disinfection reduces hand contamination more than handwashing in certain clinical conditions.[19,20] In addition, handrubs offer the advantage of being less time-consuming, probably a factor influencing compliance, especially in demanding situations.[5,9] Therefore, our results confirm the validity of the suggestion in the UK handwashing initiative to investigate the possible benefit of promoting bedside, alcohol-based handrub as the main hand-hygiene compliance tool.[7]

This intervention expands previous research experience on attempts to modify HCWs behaviour.[17] In our study, contributing factors to the success were: the multimodal and multidisciplinary approach, including communication and education tools, reminders in the work environment, active participation and feedback at both individual and organisational levels, and involvement of institutional leaders.[7,17,18,21] Furthermore, special care was taken to ensure that HCWs identified strongly with the institution's goals by involving them directly in the promotional campaign. For instance, the most visible components—ie, the posters—carried the name of the ward that had proposed the message.

Behavioural theories and interventions based on these theories have primarily targeted individuals. This may be insufficient to effect sustained change.[7,8,17] The inter-dependence of individual factors (eg, knowledge, attitudes), environmental constraints (eg, access to washing facilities), and organisational climate (eg, feedback, positive reinforcement) may have a key role in the success of behavioural interventions.[7,8,17,18]

As observed by others,[4] lower compliance rates were associated with activities with a high risk of cross-transmission. This is a troublesome problem, which may be explained by the difficulty in finding hand-hygiene opportunities in the sequence of busy patient care.[5,6,18] Our intervention was not focused primarily on improving compliance with high-risk activities, but subsequent educational efforts will specifically target this aspect.

Poor doctor compliance with hand hygiene remains an unsolved and vexing issue.[2,5,6,8] Whether increased staff rotation and lower campaign awareness among doctors compared with other HCWs could explain the low compliance in our study requires further research.[8] Previous interventions to change doctors' behaviour have included education, feedback, financial rewards and penalties, and administrative changes.[8,22] Research suggests that combinations of interventions targeted at multiple behavioural factors are more likely to suceed than isolated actions,[23] but the best way to improve hand hygiene among doctors remains to be determined.[18,21]

The decrease in nosocomial infections and MRSA transmission rates strengthens the case that our intervention was beneficial to patients. Seven quasi-experimental studies published between 1977 and 1995 assessed the impact of hand hygiene on the risk of hospital-acquired infection.[24] Although most reports showed a temporal relation between improved hand-hygiene practice and reduced infection rates, none achieved a lasting improvement in hand hygiene of more than 6 months. By contrast, the strength of our study lies in its hospital-wide approach and extended time frame. However, our infection-control programme uses additional measures other than the promotion of hand hygiene, including on-site surveillance, implementation of prevention guidelines, outbreak investigations, and issues related with disinfection, sterilisation, air and water control, and building construction.[25] The design of our study precludes ascertainment of the proportion of reduction in infection rates that was attributable to the hand-hygiene campaign alone. However, the latter was the only preventive measure applied hospital-wide during the entire study period.

Our findings confirm reports of the value of hand hygiene in the control of MRSA transmission,[26,27] even in the absence of a restrictive antibiotic-prescribing policy. Although the effect of the latter in preventing the spread of MRSA remains the subject of debate,[28] we still consider it as an important additional control measure, since certain antibiotic-prescribing patterns may promote multidrug-resistant MRSA.[29]

Our study has several limitations. First, randomisation was not feasible since the intervention was a hospital-wide, single-centre study. The ethical acceptibility of control groups in situations perceived as threatening to patients (high endemic nosocomial infection and MRSA transmission rates) was an additional obstacle. Second, because the intervention was multimodal, it is difficult to assess which part of the strategy was the most effective. However, partitioning the intervention effect may be irrelevant since a multimodal approach may be more effective than the sum of its parts.[17,18,21] Third, although our

field observations were as unobtrusive as possible, observation bias and the Hawthorne effect must be considered. However, a systematic bias is unlikely to have induced temporal trends. Furthermore, no such bias could have affected the secondary outcome variables. Since this study was not a controlled trial, unmeasured confounders perhaps accounted for some of the improvement in hand-hygiene compliance. However, this factor seems unlikely, given the stability of our institution and its surrounding community. Fourth, because flat bottles of handrub solution were introduced in 1996 amid a pattern of continued improvement in hand-hygiene compliance, we were not able to ascertain whether bottle design had an important role in the subsequent improvement in compliance. Fifth, even though the sample size was large overall, the study may have lacked power to detect significant changes in subgroups. Finally, whether the results and impact of our intervention can be generalised to other health-care institutions needs to be tested.

We did not collect prospective costing information for our intervention. Certainly, the major expense was personnel time. In addition, increased used of handrub solution from 1995 to 1997 represented extra costs of SFr 110 833, an average of SFr 101·15 per 1000 patient-days. Adding up crude direct costs (SFr 129 733 for artist work, posters, wall displays, and handrubs) and indirect costs (SFr 240 140 for salaries and fringe benefits of participating nurses, support staff, housekeeping personnel, project-team members, and expenses for office supplies) associated with our intervention, we estimate that the entire programme cost less than SFr 380 000. Given a conservative estimate of SFr 3500 saved per nosocomial infection averted,[11,30,31] prevention of 108 infections during the 1995–97 study period would have offset programme costs. Assuming that only 25% of the observed reduction in the infection rate has been associated with improved hand-hygiene practice, our intervention might have prevented more than 900 infections. These figures indicate that the programme was cost-effective from a societal perspective. However, a refined analysis is necessary to validate these crude estimates.

Contributors

Didier Pittet initiated the project, designed the study, did the field observations and the validation of the observers, did part of the data analysis, and wrote the paper. Stéphane Hugonnet, Philippe Mourouga, and Thomas Perneger did the data analysis and wrote the paper. Stéphane Hugonnet and Philippe Mourouga also participated in field observations. Stephan Harbarth analysed MRSA surveillance data, generated information on antibiotic prescribing practice, monitored surveillance of nosocomial infections, and helped with the revision of the paper. Valérie Sauvan and Sylvie Touveneau were involved in the study design and promotion campaign, the field observations, and on-site surveillance of nosocomial infections.

Acknowledgments

We thank HCWs and members of the Infection Control Programme, in particular N Colaizzi, A Alexiou, M N Constantin, N Henry, and P Herrault for doing the field observations; A Jacquemet, A Junod, G Gobet, N Fichter, Y Martin, Pécub, and the following members of the multidisciplinary team: R Auckenthaler, L Bartolomei, P Baud, J Bonnet, V Boscat, C Brasey, B Chapuis, L Cingria, P Cornuau, P Dayer, D Duvillaret, F Fargnier, C Gagelin, A Gervaix, W Griffiths, A Grivel, C Guillod, Ch Hegi, O Huber, B Laeng, I Lang, Ch LeRoy, M Louis-Simonet, V Maestri, S Merckli, J-L Nussbaum, U Paccaud, L Pammer, D Perrenoud, M Perruchoud, P-A Pessina, R Peter, P-A Piletta, K Posfay, B Ricou, E Sarrey, J C Schira, J Simon, C Tranchant-Poussin, J-B Tschanz, P Vasquez, B Vermeulen, G Zufferey; and R Sudan for editorial assistance.

References

1 Larson EL, and the Association for Professionals in Infection Control and Epidemiology 1992–1993 and 1994 APIC Guidelines Committee. APIC guideline for handwashing and hand antisepsis in health care settings. *Am J Infect Control* 1995; **23:** 251–69.

2 Jarvis WR. Handwashing—the Semmelweis lesson forgotten? *Lancet* 1994; **344:** 1311–12.

3 Albert RK, Condie F. Hand-washing patterns in medical intensive-care units. *N Engl J Med* 1981; **304:** 1465–65.

4 Thompson BL, Dwyer DM, Ussery XT, Denman S, Vacek P, Schwartz B. Handwashing and glove use in a long-term care facility. *Infect Control Hosp Epidemiol* 1997; **18:** 97–103.

5 Pittet D, Mourouga P, Perneger TV, and the members of the Infection Control Program. Compliance with handwashing in a teaching hospital. *Ann Intern Med* 1999; **130:** 126–30.

6 Larson E, Kretzer EK. Compliance with handwashing and barrier precautions. *J Hosp Infect* 1995; **30:** 88–106.

7 Teare EL, Cookson B, French GL, et al. UK handwashing initiative. *J Hosp Infect* 1999; **43:** 1–3.

8 Teare EL, Cookson B, French G, et al. Hand washing—a modest measure with big effects. *BMJ* 1999; **318:** 686–86.

9 Voss A, Widmer AF. No time for handwashing!? Handwashing versus alcoholic rub: can we afford 100% compliance? *Infect Control Hosp Epidemiol* 1997; **18:** 205–08.

10 Rotter ML. Hand washing and hand disinfection. In: Mayhall G, ed. Hospital epidemiology and infection control. Baltimore: Williams & Wilkins, 1996: 1052–68.

11 Pittet D, Harbarth S, Ruef C, et al. Prevalence and risk factors for nosocomial infections in four university hospitals in Switzerland. *Infect Control Hosp Epidemiol* 1999; **20:** 37–42.

12 Garner JS, Jarvis WR, Emori TG, Horan TC, Hughes JM. CDC definitions for nosocomial infections. *Am J Infect Control* 1988; **16:** 128–40.

13 Pittet D, Safran E, Harbarth S, et al. Automatic alerts for methicillin-resistant *Staphylococcus aureus* surveillance—role of a hospital information system. *Infect Control Hosp Epidemiol* 1996; **17:** 496–502.

14 Report of a combined working party of the British Society for Antimicrobial Chemotherapy. Revised guidelines for the control of methicillin-resistant *Staphylococcus aureus* infection in hospitals. *J Hosp Infect* 1998; **39:** 253–90.

15 Zeger SL, Liang K-Y. Longitudinal data analysis for discrete and continuous outcomes. *Biometrics* 1986; **42:** 121–30.

16 Dubbert PM, Dolce J, Richter W, Miller M, Chapman S. Increasing ICU staff handwashing: effects of education and group feedback. *Infect Control Hosp Epidemiol* 1990; **11:** 191–93.

17 Kretzer EK, Larson EL. Behavioural interventions to improve infection control practices. *Am J Infect Control* 1998; **26:** 245–53.

18 Pittet D. Improving compliance with hand hygiene in hospitals. *Infect Control Hosp Epidemiol* 2000; **21:** 381–86.

19 Ehrenkranz NJ, Alfonso BC. Failure of bland soap handwash to prevent hand transfer of patient bacteria to urethral catheters. *Infect Control Hosp Epidemiol* 1991; **12:** 654–62.

20 Pittet D, Dharan S, Touveneau S, Sauvan V, Perneger TV. Bacterial contamination of the hands of hospital staff during routine patient care. *Arch Intern Med* 1999; **159:** 821–26.

21 Larson EL, Bryan JL, Adler LM, Blane CB. A multifaceted approach to changing handwashing behaviour. *Am J Infect Control* 1997; **25:** 3–10.

22 Greco PI, Eisenberg JM. Changing physician practices. *N Engl J Med* 1993; **829:** 1271–74.

23 Solomon DH, Hashimoto H, Daltroy L, Liang MH. Techniques to improve physicians' use of diagnostic tests: a new conceptual framework. *JAMA* 1998; **280:** 2020–27.

24 Larson E. Skin hygiene and infection prevention: more of the same or different approaches? *Clin Infect Dis* 1999; **29:** 1287–94.

25 Scheckler WE, Brimhall D, Buck AS, et al. Requirements for infrastructure and essential activities of infection control and epidemiology in hospitals: a consensus panel report, Society for Healthcare Epidemiology of America. *Infect Control Hosp Epidemiol* 1998; **19:** 114–24.

26 Guiguet M, Rekacewicz C, Leclercq B, Brun Y, Escudier B, Andremont A. Effectiveness of simple measures to control an outbreak of nosocomial methicillin-resistant infections in an intensive care unit. *Infect Control Hosp Epidemiol* 1990; **11:** 23–26.

27 Webster J. Handwashing in a neonatal intensive care nursery: product acceptability and effectiveness of chlorhexidine gluconate 4% and triclosan 1%. *J Hosp Infect* 1992; **21:** 137–41.

28 Monnet DL. Methicillin-resistant *Staphylococcus aureus* and its relationship to antimicrobial use: possible implications for control. *Infect Control Hosp Epidemiol* 1998; **19:** 552–59.

29 Aubry-Damon H, Legrand P, Drun-Buisson C, Astier A, Soussy CJ, Leclercq R. Reemergence of gentamicin-susceptible strains of methicillin-resistant *Staphylococcus aureus*: roles of an infection control program and changes in aminoglycoside use. *Clin Infect Dis* 1997; **25:** 647–53.

30 Haley RW, Schaberg DR, Crossley KB, Von Allmen SD, McGowan JE Jr. Extra charges and prolongation of stay attributable to nosocomial infections: a prospective interhospital comparison. *Am J Med* 1981; **70:** 51–58.

31 Pittet D, Tarara D, Wenzel RP. Nosocomial bloodstream infection in critically ill patients: excess length of stay, extra costs, and attributable mortality. *JAMA* 1994; **271:** 1598–601.

American Journal of Infection Control 41 (2013) 368-70

Contents lists available at ScienceDirect

American Journal of Infection Control

journal homepage: www.ajicjournal.org

Brief report

Pilot evaluation of a ward-based automated hand hygiene training system

Anarta Ghosh PhD [a], Stefan Ameling MSc [a], Jiang Zhou PhD [a], Gerard Lacey PhD [a,*], Eilish Creamer PhD [b], Anthony Dolan MSc [b], Orla Sherlock PhD [b], Hilary Humphreys MD [b,c]

[a] School of Computer Science and Statistics, Trinity College, Dublin, Ireland
[b] Department of Clinical Microbiology, Education and Research Centre, Royal College of Surgeons in Ireland, Dublin, Ireland
[c] Department of Microbiology, Beaumont Hospital, Dublin, Ireland

Key Words:
Ward-based education
E-learning
Technique measurement
Artificial intelligence
Computer video analysis

A novel artificial intelligence (AI) system (SureWash; GLANTA, Dublin, Ireland) was placed on a ward with 45 staff members for two 6-day periods to automatically assess hand hygiene technique and the potential effectiveness of the automated training system. Two human reviewers assessed videos from 50 hand hygiene events with an interrater reliability (IIR) of 88% (44/50). The IIR was 88% (44/50) for the human reviewers and 80% (40/50) for the software. This study also investigated the poses missed and the impact of feedback on participation (+113%), duration (+11%), and technique (+2.23%). Our findings showed significant correlation between the human raters and the computer, demonstrating for the first time in a clinical setting the potential use of this type of AI technology in hand hygiene training.

The World Health Organization (WHO) guidelines on the effective decontamination of hands of health care workers (HCWs) recommend a 6-pose hand hygiene technique for hand hygiene with either alcohol-based hand rub or handwashing.[1] The need for, and benefits of, hand hygiene technique training and compliance assessment have been identified.[2-4] However, training in hand hygiene requires individual instruction, assessment, and feedback, the provision of which is often logistically challenging. The aim of the pilot study was to assess the suitability of an automated hand hygiene training system.

METHODS

A computer cart fitted with the SureWash system (GLANTA, Dublin, Ireland) automatically measured compliance with the WHO hand hygiene protocol for alcohol-based hand rub and provided training feedback in real time (Fig 1A). The artificial intelligence (AI) software compared the user's hand movements with a database containing examples identified by members of the research team. To pass each pose, the user needed to achieve 1 second of correct technique, or 1 second for each part in a pose with left and right parts.

The HCW using the system sees a live video of her hands on the screen. If feedback is being provided, she also sees a "traffic light" indicator for each pose of the WHO protocol (Fig 1B); the indicator turns from red to green when the software has verified the technique and duration for each pose. Where a pose has a left part and a right part, half of the indicator light changes color as each part is completed. The HCW has a maximum of 90 seconds to complete the protocol. At the end of a session, either by completing all of the poses or by reaching the 90-second limit, a final result is presented with a "pass" or "fail" grade and the time taken to complete the hand hygiene event.

Our evaluation used a quasi-experiment interrupted times series design in 2 phases of 6 days each on a clinical ward with 45 HCWs. In phase 1, a baseline was established by recording videos of hand hygiene events with no feedback provided to the HCWs. In phase 2, on-screen feedback was provided to the HCWs. Ethics approval for the study required that HCW participation be both voluntary and anonymous; consequently, the camera view was restricted to only the hands of the HCW.

Two researchers who were blinded to the study reviewed the videos of each hand hygiene event. If a HCW missed a pose or used incorrect technique, the hand hygiene event was judged a "fail."

* Address correspondence to Gerard Lacey, PhD, School of Computer Science and Statistics, O'Reilly Institute Trinity College Dublin, Dublin 2, Ireland.
E-mail address: gerard.lacey@scss.tcd.ie (G. Lacey).

Partially funded by Enterprise Ireland Project CP-2008-204 under the National Development Plan 2007-13 and Health Research Board Project TRA/2006/4.

Conflict of interest: H.H. has recent research collaborations with Steris Corporation, Inov8 Science, Pfizer, and Cepheid, and has also recently received lecture and other fees from Novartis, AstraZeneca, and Astellas. G.L. is a director of GLANTA Ltd.

0196-6553/$36.00 - Copyright © 2013 by the Association for Professionals in Infection Control and Epidemiology, Inc. Published by Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.ajic.2012.03.034

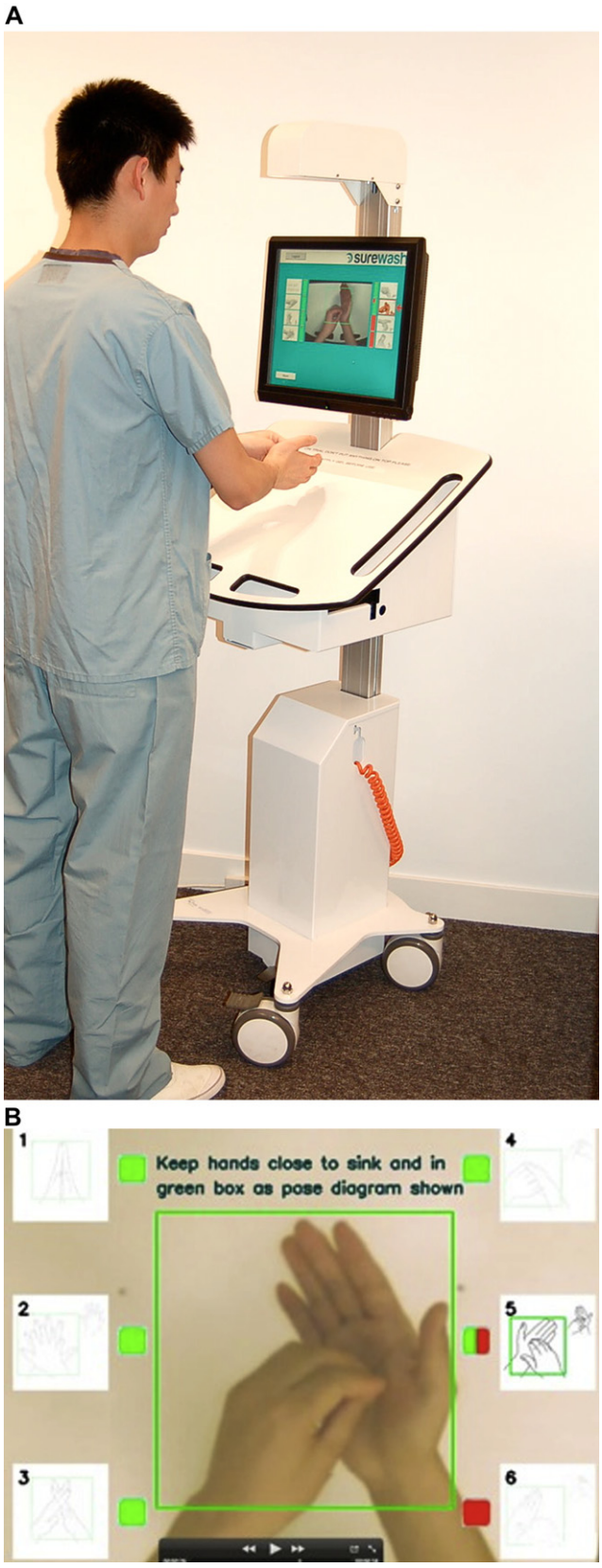

Fig 1. (A) The SureWash system uses a camera at the top of the system to capture video of the user's hands, which are displayed live on the screen. The tray area prevents the camera from seeing anything that could personally identify the user. (B) The on-screen feedback shows the WHO poses in images 1-6. The green and read indicators alert the user when the pose has been completed successfully.

Interrater reliability (IIR) was assessed based on the percentage of agreement, and Krippendorff's alpha (Kα) was calculated using ReCal software.[5] Jackknife resampling[6] was used to ensure stability of the pass rate comparison in our small sample set. The nonparametric Wilcoxon rank-sum test was used to determine statistical significance between the pass rates. The jackknife resampling and Wilcoxon rank-sum test results were calculated using Matlab (Mathworks, Natick, MA).

RESULTS

The IIR agreement between each human reviewer and the computer was 88% (44 of 50), Kα = 0.74 and 80% (40 of 50), Kα = 0.56, respectively. The IIR agreement between human reviewers was 88% (44 of 50), Kα = 0.76. In phase 2, using the real-time on-screen feedback resulted in a 113% increase in participation (from 16 to 34). The pass rate for the hand hygiene events increased from 62.5% (95% confidence interval [CI], 62.8-62.2) in phase 1 to 64.7% (95% CI, 64.6-64.9) in phase 2, a small but statistically significant difference ($P < .005$ at 95% confidence). The time taken to complete the hand hygiene event increased from 47.4 seconds to 52.5 seconds between phase 1 and 2, but this difference was not statistically significant. The system also provided information on which poses were most frequently missed (pose 6, thumbs and pose 5, fingertips) and the average time spent in each pose (Fig 2).

DISCUSSION

The Kα values in the pilot study showed substantial agreement ($\alpha = 0.61$-0.80)[7] and moderate agreement ($\alpha = 0.41$-0.60)[7] between each reviewer and the software, respectively. These initial results strongly suggest that the SureWash software is capable of reliably measuring hand hygiene technique; however, studies with larger sample sizes are needed to verify this. Assessment of the videos required significant concentration by the reviewers, who found that after 20 minutes, fatigue significantly compromised accuracy. Consequently, very large sample sizes and perfect agreement are very unlikely with human reviewers.

The pilot study was set in a busy clinical ward, and participation was voluntary. In this context, the 113% increase in participation in phase 2 demonstrates the positive impact of real-time feedback. This is similar to the reported impact of feedback in other studies.[8,9] We feel that selection bias and the Hawthorne effect affected the pass rates in both phases of the study, 62.5% and 64.7%, respectively, which are higher than those reported in other studies.[4] The additional information on pose failures and time spent in poses can be used to guide follow-up training and communication to HCWs.

This is the first study to use automated image analysis for hand hygiene quality assessment in a clinical setting. Despite the study's small size, our findings suggest that video analysis is a powerful and scalable new technology for hand hygiene training that will reduce the associated workload on Infection Control teams. Future studies will involve larger cohorts and will address the self-selection issue by tracking individual progress.

Acknowledgment

We thank Toney Thomas, John Walsh, and all the Beaumont Hospital staff who participated in the study.

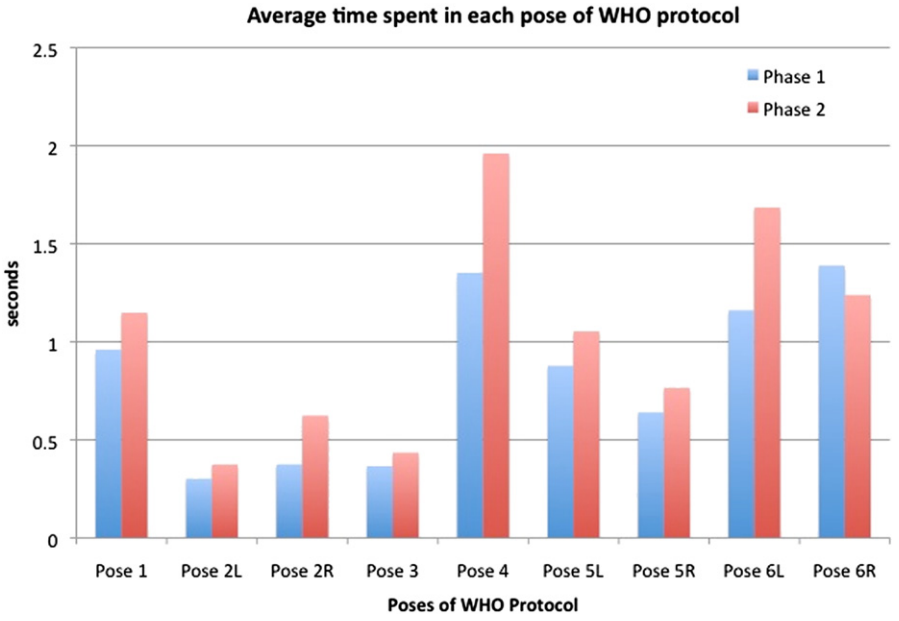

Fig 2. Bar chart showing the average time spent by HCWs between each pose of the WHO hand hygiene protocol in each of the 2 study phases. Pose 1: palm to palm; pose 2 (left and right): rub palm over dorsum with fingers interlaced; pose 3 (left and right): rub palm to palm with fingers interlaced; pose 4 (left and right): rub backs of the fingers onto opposing palm with fingers interlocked; pose 5 (left and right): rub finger tips on opposing palm; pose 6 (left and right): rotate thumb while clasped in palm.

References

1. World Health Organization. WHO guidelines on hand hygiene in healthcare: a summary. Geneva, Switzerland: World Health Organization; 2009.
2. Creamer E, Dorrian S, Dolan A, Sherlock O, Fitzgerald-Hughes D, Thomas T, et al. When are the hands of healthcare workers positive for meticillin-resistant *Staphylococcus aureus*? J Hosp Infect 2010;75:107-11.
3. Widmer AF, Conzelmann M, Tomic M, Frei R, Stranden AM. Introducing alcohol-based hand rub for hand hygiene: the critical need for training. Infect Control Hosp Epidemiol 2007;28:50-4.
4. Widmer AF, for the Basel Infection Control Team. International Conference on Prevention and Infection Control (ICPIC 2011), Geneva, Switzerland, June 29 to July 2, 2011. BMC Proc 2011;5(Suppl 6):123.
5. Freelon DG. ReCal: intercoder reliability calculation as a Web service. Int J Internet Sci 2010;5:20-33.
6. Effron B. Nonparametric estimates of standard error: the jackknife, the bootstrap and other methods. Biometrika 1981;68:589-99.
7. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics 1997;33:159-74.
8. Nishimura S, Kagehira M, Kono F, Nishimura M, Taenaka N. Handwashing before entering the intensive care unit: what we learned from continuous video-camera surveillance. Am J Infect Control 1999;27:367-9.
9. Armellino D, Hussain E, Schilling ME, Senicola W, Eichorn A, Dulgacz Y, et al. Using high-technology to enforce low technology safety measures: the use of third-party remote video auditing and real-time feedback in healthcare. Clin Infect Dis 2012;54:1-7.

OPEN ACCESS Freely available online

PLOS ONE

Efficacy of a New Educational Tool to Improve Handrubbing Technique amongst Healthcare Workers: A Controlled, Before-After Study

Andrew J. Stewardson[1]*, Anne Iten[1], Véronique Camus[1], Angèle Gayet-Ageron[1,2], Darren Caulfield[3], Gerard Lacey[3,4], Didier Pittet[1]

1 Infection Control Program and World Health Organization Collaborating Centre on Patient Safety, University of Geneva Hospitals and Faculty of Medicine, Geneva, Switzerland, **2** Division of Clinical Epidemiology, University of Geneva Hospitals and Faculty of Medicine, Geneva, Switzerland, **3** Glanta Ltd, Dublin, Ireland, **4** School of Computer Science and Statistics, Trinity College Dublin, Dublin, Ireland

Abstract

Introduction: Hand hygiene is a key component of infection control in healthcare. WHO recommends that healthcare workers perform six specific poses during each hand hygiene action. SureWash (Glanta Ltd, Dublin, Ireland) is a novel device that uses video-measurement technology and immediate feedback to teach this technique. We assessed the impact of self-directed SureWash use on healthcare worker hand hygiene technique and evaluated the device's diagnostic capacity.

Methods: A controlled before-after study: subjects in Group A were exposed to the SureWash for four weeks followed by Group B for 12 weeks. Each subject's hand hygiene technique was assessed by blinded observers at baseline (T_0) and following intervention periods (T_1 and T_2). Primary outcome was performance of a complete hand hygiene action, requiring all six poses during an action lasting $\geq$20 seconds. The number of poses per hand hygiene action (maximum 6) was assessed in a *post-hoc* analysis. SureWash's diagnostic capacity compared to human observers was assessed using ROC curve analysis.

Results: Thirty-four and 29 healthcare workers were recruited to groups A and B, respectively. No participants performed a complete action at baseline. At T_1, one Group A participant and no Group B participants performed a complete action. At baseline, the median number of poses performed per action was 2.0 and 1.0 in Groups A and B, respectively ($p = 0.12$). At T_1, the number of poses per action was greater in Group A (post-intervention) than Group B (control): median 3.8 and 2.0, respectively ($p<0.001$). In Group A, the number of poses performed twelve weeks post-intervention (median 3.0) remained higher than baseline ($p<0.001$). The area under the ROC curves for the 6 poses ranged from 0.59 to 0.88.

Discussion: While no impact on complete actions was demonstrated, SureWash significantly increased the number of poses per hand hygiene action and demonstrated good diagnostic capacity.

Citation: Stewardson AJ, Iten A, Camus V, Gayet-Ageron A, Caulfield D, et al. (2014) Efficacy of a New Educational Tool to Improve Handrubbing Technique amongst Healthcare Workers: A Controlled, Before-After Study. PLoS ONE 9(9): e105866. doi:10.1371/journal.pone.0105866

Editor: John Conly, University of Calgary, Canada

Received January 24, 2014; **Accepted** July 28, 2014; **Published** September 2, 2014

Funding: This study was conducted without dedicated funding. Glanta Ltd. provided the Surewash unit on temporary loan for the duration of the study. AS and DP acknowledge recent funding by subside 3200B0-122324/1 from the Swiss National Science Foundation for partial financial support for hand hygiene research activities. Glanta Ltd. provided support in the form of salaries for authors GL and DC, but did not have any additional role in the study design, data collection and analysis, decision to publish, or preparation of the manuscript. The specific roles of these authors are articulated in the 'author contributions' section.

Competing Interests: Trinity College Dublin has been granted patents related to SureWash in USA (US 8090155 B2, Hand washing monitoring system) and EU (EP 2015665 B1, A Hand Washing Monitoring System). These are licensed to Glanta Ltd, a Trinity College Dublin spin-out company that markets the device. DC is a paid employee of Glanta Ltd. GL is co-inventor of SureWash, and founder and chairman of Glanta Ltd. The other authors declare no conflicts of interest. This does not alter the authors' adherence to all the PLoS ONE policies on sharing data and materials. AS and DP had full access to all data and vouch for the results.

* Email: andrew.stew@rdson.net

Introduction

Hand hygiene is widely regarded as the single most important intervention to reduce the burden of health care-associated infections and the transmission of antimicrobial resistance within the hospital setting [1]. The contemporary approach to promotion of hand hygiene amongst healthcare workers involves a multi-modal strategy incorporating the use of alcohol-based handrub at the point of care [1,2]. The WHO 'My 5 Moments for Hand Hygiene' methodology defines *when* healthcare workers should perform hand hygiene during patient care [3,4]. Healthcare worker compliance with these indications is part of routine performance feedback, an essential strategy for behaviour change [5]. WHO recommendations also exist for *how* to perform hand hygiene, but these are rarely monitored or included in performance feedback programs. This technique is based on European standards (EN 1500) and involves six distinct steps, or poses [1]. Correct performance of this technique results in increased product coverage and greater reductions of bacterial colony forming units when compared with incomplete actions [6,7].

SureWash (Glanta Ltd, Dublin, Ireland) is a commercially available device that combines e-learning and patented video

measurement technology to teach healthcare workers how to perform a hand hygiene action. It uses interactive on-screen feedback to encourage grounded cognition and reflection on the technique of hand hygiene. The aim of this approach of situated cognition is that the physical act of hand hygiene becomes a prompt to the actions of good technique. The device can be left in a clinical area to be used independently by healthcare workers, and provides immediate and individualised performance feedback.

The primary objective of this study was to assess the efficacy of SureWash to improve hand hygiene technique amongst healthcare workers in an institution with a long history of hand hygiene promotion [2]. Our secondary objective was to evaluate the ability of SureWash to assess the adequacy of hand hygiene actions performed by healthcare worker staff compared to assessment by trained human observers.

Methods

Ethics statement

We followed the principles expressed in the Declaration of Helsinki. This study was approved by the Ethics Commission for Human Research at the University of Geneva (protocol 12–258).

Design

We performed a controlled before-after study with blinding of assessors (**Figure 1**). Allocation was not randomised and there was no placebo intervention. First, baseline assessment (T_0) of hand hygiene technique was performed in two healthcare worker groups (A and B) to ensure that they did not have significantly different pre-intervention hand hygiene technique. The first follow-up (T_1) assessment was then performed after Group A (intervention group) had received the intervention but Group B (control group) had not. Subsequently, Group B was exposed to the intervention, and a second follow-up (T_2) measurement of both groups was performed. The application of the intervention to Group B (the original control group) and T_2 measurement was performed to 1) examine the persistence post-intervention of any improvement in Group A technique, 2) demonstrate reproducibility of intervention effect in two groups of subjects, and 3) allow Group B to benefit from this quality improvement intervention. This design has been referred to as the "untreated-control group design that uses dependent pretest and posttest samples and switching replications" [8].

Setting

The University of Geneva Hospitals is a 2200-bed primary and tertiary care hospital in Geneva, Switzerland with a long history of hand hygiene promotion [2,9]. Healthcare workers are exposed to training in hand hygiene technique during an infection control education session on employment commencement, posters throughout the hospital, and guidelines on the infection control intranet site. This study was performed in four acute care wards within the department of internal medicine, consisting of two pairs of adjacent wards on different hospital floors. In 2013, healthcare worker compliance with indications for when to perform hand hygiene was 75.8% (95% confidence interval [CI], 70.7–80.4) as measured by direct observation according to WHO methodology [3,4].

Participants

All healthcare workers with patient-care responsibilities in the four participating acute-care wards were eligible to participate on a voluntary basis. Subjects were required to provide written, informed consent and were excluded if 1) unlikely to remain in the study wards throughout the study period, or 2) if they currently worked – or were likely to work during the study period – in wards in both study groups. Healthcare workers that were not recruited were able to use the SureWash during the intervention phase, but were not monitored for the study.

Intervention

The intervention involved self-directed use of the SureWash unit, which was left unsupervised in the staff tea room. Healthcare workers were able to use it in both 'training mode' and 'assessment mode' throughout the intervention phase (four weeks in Group A and 12 weeks in Group B). 'Training mode' consisted of a slideshow with information regarding when and how to perform hand hygiene, and required healthcare workers to practice their own technique in the presence of immediate feedback. 'Assessment mode' involves healthcare workers performing a hand hygiene action and receiving a score (in percentage format) reflecting degree to which each pose was performed correctly and for adequate duration.

Procedure and data collection

The study was implemented from March to September 2013. The study design is presented in **Figure 1**. At baseline (T_0), participants completed a brief survey including age, sex, profession, number of years spent working at HUG, and prior participation in the institutional infection control training course. They were then invited by the investigators to perform a hand hygiene action as recommended by hospital guidelines using alcohol-based handrub. This action was recorded by the SureWash device in a purpose-built "study mode" whereby it captured video of the hand hygiene action, but provided no feedback other than to indicate to the user that their hands were in the correct position. The action was assessed by the device and the video stored for subsequent assessment by observers. Immediately after recording this action, each healthcare worker was asked to mime the 6 poses by following an on-screen demonstration.

Following the one-week recruitment and baseline assessment period (T_0), Group A was exposed to the intervention for four weeks. During this time, the SureWash unit was left in the staff tea room, available for self-directed hand hygiene technique education and training (as described in the intervention section above) at healthcare workers' convenience. Each participant was able to use the device according to their interest and availability: there was no minimum or maximum number of uses required.

Subsequently, during the first follow-up (T_1), each participant was again asked to perform a hand hygiene action as at T_0. Group B was then exposed to the intervention for twelve weeks followed by a final assessment of participants in both Group A and B (T_2).The intervention phase was longer in Group B because whereas the two wards in Group A shared a common tea room, those in Group B did not. In addition, Group B was exposed to the intervention during the summer period when healthcare workers take leave and are therefore frequently absent. Both factors translated to decreased exposure of Group B subjects to the intervention.

Following each of the three assessments, two observers (AS and VC) independently reviewed the hand hygiene videos in random order, assessing duration and performance of each pose (**Figure 2**). A purpose-built interface was developed to facilitate this review process. For bilateral poses, performance of each side was assessed separately. The observers were blinded to study group and the SureWash assessment of the action. Following the review process, data could be exported from the device for analysis. This dataset included the following information for every

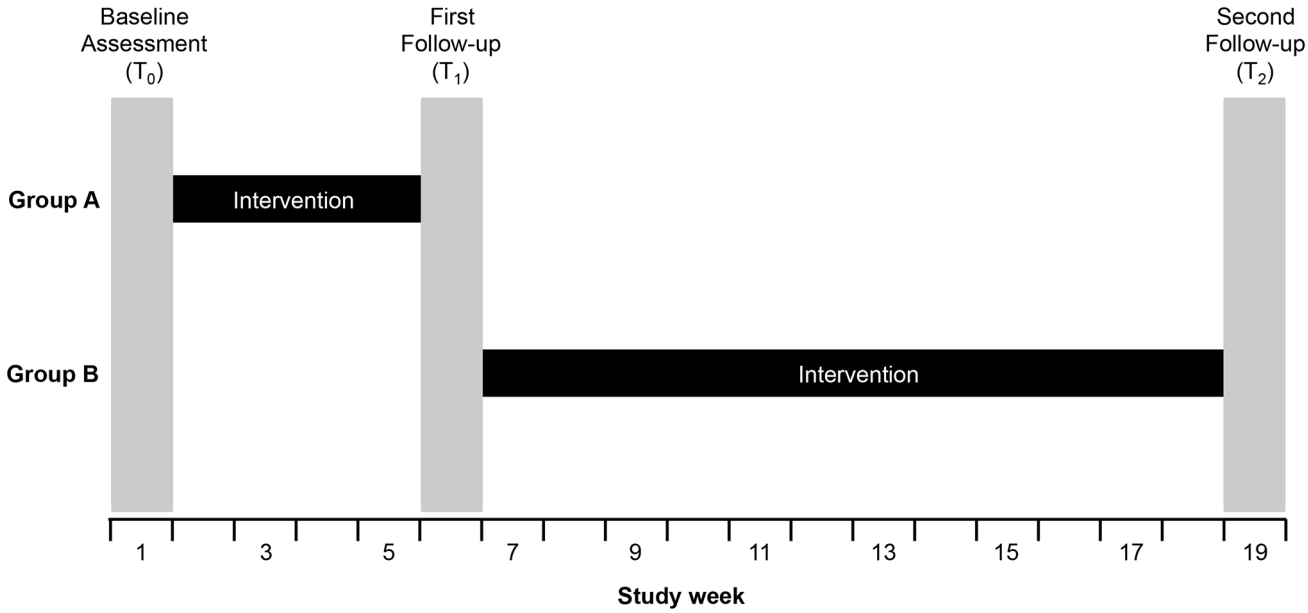

Figure 1. Study design.
doi:10.1371/journal.pone.0105866.g001

pose: study group, date, the SureWash unit's automatic assessment of pose performance (measure of "effort") and both reviewers' binary assessment of whether the pose was performed correctly.

Outcomes

Primary objective. The predefined outcome used to assess the impact of the SureWash unit on hand hygiene technique was performance of a complete hand hygiene action as rated by both observers. A hand hygiene action was judged as complete if all six

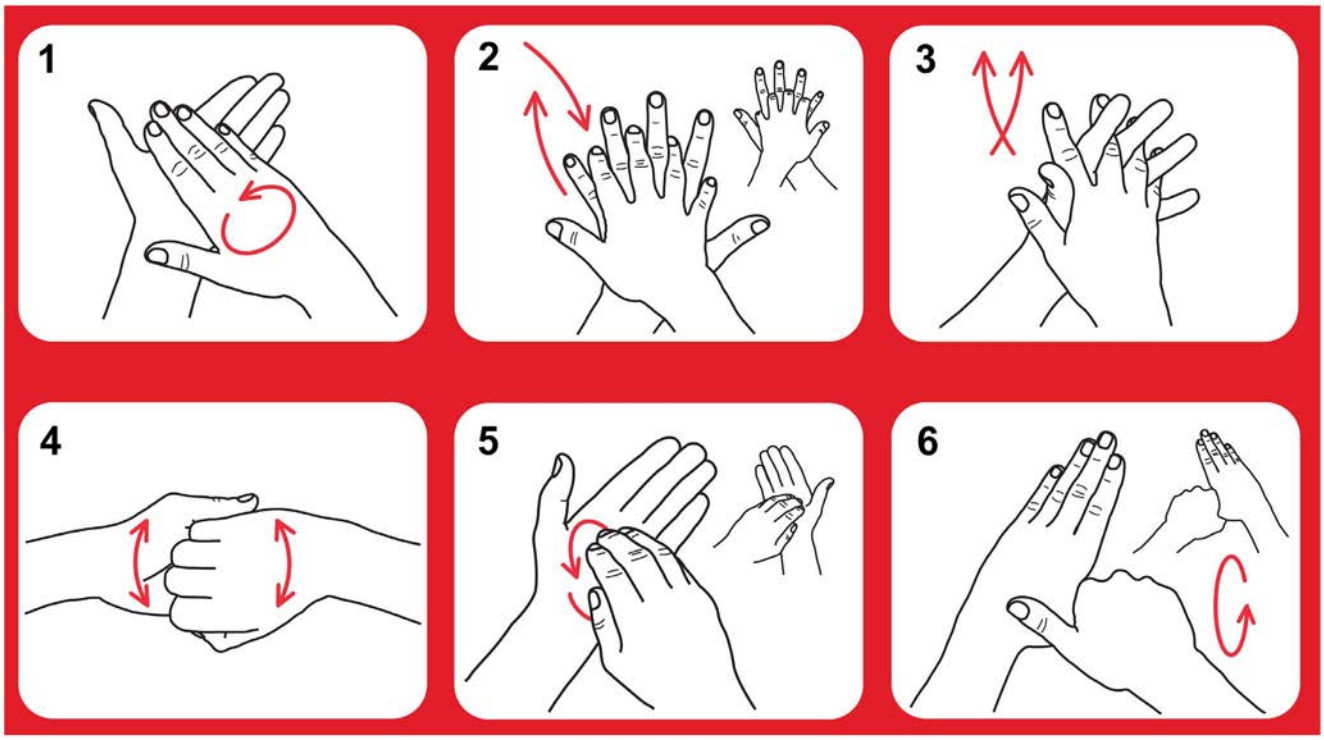

Figure 2. Poses recommended for hand hygiene actions. After applying a palmful of the product in a cupped hand; 1) rub hands palm to palm; 2) right palm over left dorsum with interlaced fingers and vice versa; 3) palm to palm with fingers interlaced; 4) backs of fingers to opposing palms with fingers interlocked; 5) rotational rubbing, backwards and forwards with clasped fingers of right hand in left palm and vice versa; 6) rotational rubbing of left thumb clasped in right palm and vice versa. Text adapted from reference 1.
doi:10.1371/journal.pone.0105866.g002

recommended poses were performed and the action lasted for 20 seconds or more (**Figure 2**) [1]. For bilateral poses, both sides had to be performed in order for the posed to be accepted as correctly performed. Poses could be performed in any sequence. The number of times that the SureWash unit was used by each group was recorded as a process measure.

Secondary objective. To evaluate the diagnostic capacity of the SureWash unit we compared the human observer assessment (dichotomous) with the SureWash automated assessment (continuous). The SureWash unit produces a measure of the "effort" with which each pose is performed. This "effort" measure was a unitless continuous variable.

Statistical methods

The sample size calculation was based on the proportion of healthcare workers in each study group performing complete hand hygiene actions at the first follow-up (T_1). In the absence of prior data, we estimated that 60% of healthcare professionals would perform a complete hand hygiene action at baseline, and proposed that an absolute improvement of 30% following the SureWash intervention would be clinically pertinent. With a two-sided alpha of 0.05 and a power of 0.8, we required 38 participants in each arm. At baseline, however, we noted that no healthcare workers performed a complete hand hygiene action. We had recruited 34 and 29 subjects into the two groups. We therefore performed an estimation of study power based on this new information. Assuming a 10% loss to follow-up (30 and 26 subjects), we had a power of 0.80 to detect a delta of 30% using two sided alpha of 0.05.

Categorical baseline covariates were presented using counts and percentages, with subjects from the two groups compared using Fisher's exact test. Inter-rater agreement between the two blinded observers was computed using Cohen's kappa. These values were interpreted according to Fleiss [10].

Primary objective. The proportion of healthcare workers performing a complete hand hygiene action in each group was compared at T_0 to assess the assumption that the two groups had similar baseline hand hygiene technique. We then evaluated change in the proportion of healthcare workers performing a complete hand hygiene action from T_0 to T_1 in both Group A (intervention) and Group B (control). The initial control group was then exposed to the intervention, and we evaluated change in the proportion of healthcare workers performing a complete hand hygiene action from T_1 to T_2 in both Group B (now intervention) and Group A (now control). For each comparison, the null hypothesis of no difference between the two groups was tested using Fisher's exact test.

Secondary objective. We used the subset of poses for which the two human observers provided the same assessment. We used Receiver Operating Characteristic (ROC) curve analysis to assess the diagnostic performance of this measure, summarised using area under the curve (AUC). The cutoff value for the SureWash "effort" measure that best discriminated between adequate and inadequate performance (as determined by the human raters) was determined independently for each pose. These optimal cutoffs were selected as the value that maximised Youden's J statistic. We described performance of the device using these optimal cutoffs by presenting sensitivity, specificity, positive predictive value, negative predictive value and accuracy when compared to the human observer. Accuracy is calculated as the number of poses correctly judged by the SureWash device as either adequate or inadequate divided by the total number of poses. The other parameters were calculated as usual. Confidence intervals (CIs) were computed using the Clopper-Pearson method [11].

Statistical analyses were performed using the R software/environment, version 3.0.1 (R Foundation for Statistical Computing), including 'irr' and 'ROCR' packages [12,13].

Results

Sixty-three healthcare workers were recruited, 34 in Group A and 29 in Group B. No eligible healthcare workers refused to participate (due to scheduled rotations only one doctor was eligible), producing a 100% participation rate. Baseline characteristics are presented in **Table 1**. Follow-up was incomplete. Details of follow-up and reasons for missed data are outlined in the flow diagram (**Figure 3**). Data were missing for six subjects at T_1 and 14 subjects as T_2. Two subjects refused to participate on three occasions and were therefore classified as having withdrawn from the trial. The SureWash unit was used 213 and 151 times by healthcare workers in Group A and Group B, respectively, during their intervention phases.

Primary outcome: Impact of intervention on hand hygiene technique

Agreement between the two human raters for each pose is presented in **Table 2**. According to Fleiss's qualitative descriptors for kappa values, agreement was "fair to good" for poses 1 and 3, and "excellent" for the other four poses.

The primary outcome measure was performance of a complete hand hygiene action. No participants performed a complete hand hygiene action at baseline (T_0): 0/34 (0.0% [95% CI; 0.0%, 10.3%]) and 0/29 (0.0% [95% CI; 0.0%, 11.9%]) in Groups A and B, respectively. The two groups were therefore similar at baseline ($p>0.99$).

Between T_0 and T_1, Group A received the intervention and Group B acted as control (**Figure 1**). The number of Group A participants that performed a complete action increased from 0/34 (0.0% [95% CI; 0.0%, 10.3%]) at T_0 to 1/30 (3.3% [95% CI; 0.1%, 17.2%]) at T_1 ($p = 0.47$). There was no change in Group B at T_1, as none of 27 participants (0.0% [95% CI; 0.0%, 12.8%]) performed a complete action ($p>0.99$).

Between T_1 and T_2, Group B received the intervention and Group A acted as control (**Figure 1**). No Group B participants performed a complete action post-intervention 0/24 (0.0% [95% CI; 0.0%, 14.3%]) at T_2 compared to 0/27 (0.0% [95% CI; 0.0%, 12.8%]) at T_1 ($p>0.99$). There was also no change in Group A: 1/30 (3.3% [95% CI; 0.1%, 17.2%]) at T_1 to 1/25 (4.0% [95% CI; 0.1%, 20.3%]) at T_2 ($p>0.99$).

Post-hoc analysis: Impact of intervention on hand hygiene poses per action

Given the rarity of this primary outcome, we performed a post-hoc assessment of the number of poses performed correctly during each hand hygiene action. The rationale for this post-hoc analysis was that not all incomplete actions are equal: an incomplete action with one pose performed is likely to be less effective in removing organisms from the hand than an incomplete action with five poses, for example. Therefore it is of interest to evaluate the impact of the intervention on the number of poses performed per action, as it is plausible that such an effect may have a positive impact on quality of care. However, as a *post-hoc* analysis, these results should be considered exploratory.

First, the proportion of subjects performing each pose, stratified by intervention status, is presented as a descriptive result in **Table 3**. Prior to exposure to the intervention, all poses except pose 2 were performed by less than half of the subject. Pose 4 was performed least frequently. At baseline, healthcare workers

Table 1. Baseline characteristics of study participants.

	Group A (n = 34)	Group B (n = 29)	p-value
Female gender	26 (76)	23 (85)	0.522
Age category			0.022
<20	0 (0)	0 (0)	
20–29	1 (4)	4 (20)	
30–39	16 (64)	5 (25)	
40–49	8 (32)	11 (55)	
Profession			0.574
Nurse assistant	10 (29)	5 (19)	
Nurse	21 (62)	19 (70)	
Doctor	1 (3)	0 (0)	
Other	2 (6)	3 (11)	
Years worked at HUG*			0.338
<1	1 (3)	0 (0)	
1–5	4 (13)	4 (15)	
6–10	7 (22)	2 (7)	
>10	20 (63)	21 (78)	
Infection control course completed			0.347
No	9 (26)	12 (44)	
Yes, in 2013	0 (0)	0 (0)	
Yes, in 2012	3 (9)	1 (4)	
Yes, before 2012	22 (65)	14 (52)	

Counts are presented with percentages in parentheses. Responses to each question may not sum to total number of participants due to unanswered questions.
*HUG, University of Geneva Hospitals.
doi:10.1371/journal.pone.0105866.t001

generally performed a hand hygiene action comprising of a continuous movement, with infrequent distinct and repeated poses. Improvements were observed in all six poses in the post-intervention period.

Second, the number of poses performed per action by the two groups were compared (**Figure 4**). The two groups performed a similar number of poses correctly at T_0, before either had been exposed to the intervention: median 2.0 (IQR, 1.5) in Group A and median 1.0 (IQR, 1.5) in Group B ($p = 0.12$).

The number of poses performed by Group A (intervention) subjects increased from median 2.0 (IQR, 1.5) at T_0 to 3.8 (IQR, 2.3) immediately post-intervention at T_1 ($p<0.001$). Over the same period, there was a lesser absolute increase in the number of poses performed by Group B (control) subjects: median 1.0 (IQR, 1.5) at T_0 to 2.0 (IQR, 1.8) at T_1 ($p = 0.03$). At T_1, Group A performed more poses that Group B ($p<0.001$).

Group B was then exposed to the intervention. The number of poses performed by Group B subjects increased from median 2.0 (IQR, 1.8) at T_1 to 4.0 (IQR, 2.1) at T_2 ($p<0.001$). Over the same period, there was no significant change in the number of poses performed by Group A (now control) subjects: median 3.8 (IQR, 2.3) at T_1 to 3.0 (IQR, 1.5) at T_2 ($p = 0.49$). The number of poses performed by Group A subjects at T_2 remained significantly higher than baseline ($p<0.001$). At T_2, Group A and Group B subjects performed a similar number of poses per action ($p = 0.89$).

Secondary outcome: Diagnostic capacity of SureWash

ROC curves for each pose are presented in **Figure 5**. Performance characteristics when the optimal cutoff (which maximised Youden's J statistic) was employed are presented in **Table 4**.

Discussion

This trial was performed to assess the utility of SureWash in improving hand rubbing technique in a healthcare institution with a long history of hand hygiene promotion [2,9]. Baseline (T_0) results demonstrated a need for such an intervention, with no healthcare workers able to perform a hand hygiene action as recommended by WHO [14]. This trial did not demonstrate an impact of the SureWash device on the proportion of healthcare workers able to perform a complete hand hygiene action using strict criteria. However, a *post-hoc* analysis demonstrated that exposure to this device had a significant and (in Group A) durable impact on the number of poses performed correctly per hand hygiene action. Finally, the device demonstrated good diagnostic capacity when compared to human observers.

These findings are consistent with and extend those of two previous publications using the SureWash unit. Gosh *et al*. used the device in one clinical ward during two six-day phases; the first without feedback (16 subjects) and the second with feedback (34 subjects) [15]. Inter-rater agreement between two human observers was 0.76 (Krippendof's alpha), with agreement of 0.74 and 0.56 for each observer with the device. Using a less strict definition of complete hand hygiene action (1 second for each pose), the pass rate for hand hygiene actions increased modestly from 62.5% to 64.7% ($p<0.05$). Higgins *et al*. used the SureWash device as part of an institution-wide multimodal hand hygiene promotion campaign [16]. The pass rate for handwashing (rather than hand

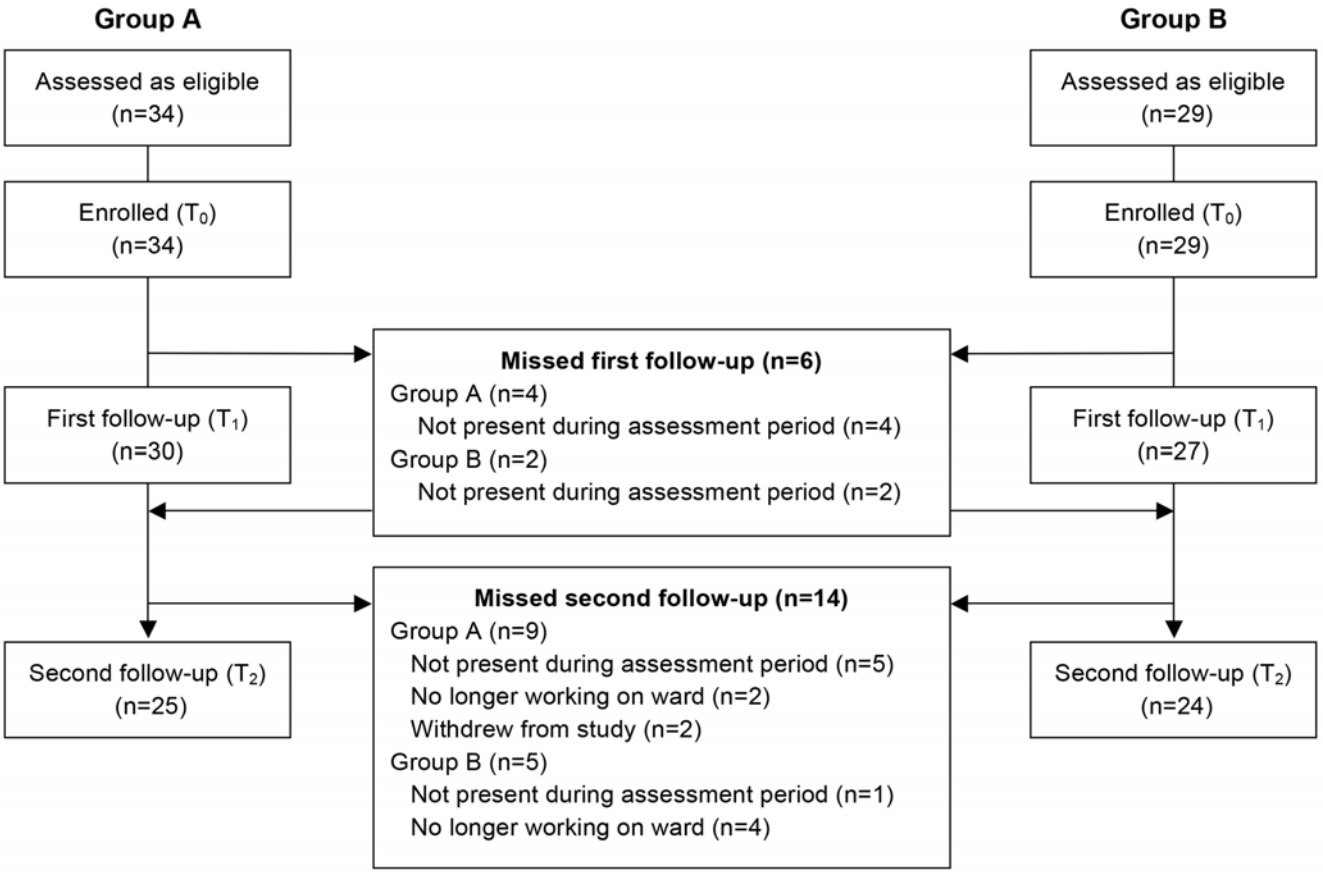

Figure 3. Study flow diagram. All eligible subjects agreed to participate.
doi:10.1371/journal.pone.0105866.g003

rubbing) technique using adenosine triphosphate monitoring increased from 52% before implementation of training with SureWash to 79% after ($p<0.001$). Compliance with the six recommended poses was not specifically assessed. Our study confirms the diagnostic capacity of SureWash using a larger sample size that Gosh *et al.* and builds on data from both studies regarding its impact on hand hygiene technique by using a controlled study design implemented in the absence of concurrent interventions, with assessment of each pose, and by using hand rubbing, the preferred technique for routine hand hygiene [1].

The importance of hand hygiene technique with regard to product coverage and reduction in bacterial counts on hands has been demonstrated previously [6,7,17]. The baseline results of this trial suggests that an infection control course on employment commencement, educational posters in clinical areas and availability of guidelines are not sufficient to teach hand hygiene technique. Monitoring and performance feedback is a key strategy to improving healthcare worker hand hygiene behaviour [1,5], but this traditionally focuses on *when* to perform it rather than *how*. More intensive training can be resource intensive [7]. For example, in a recent study using UV-light technology to assess hand hygiene technique immediately following training, 5200 healthcare workers were exposed to 15-minute education sessions in groups of five to eight [18]. This was a major logistic operation and required at least 160 hours work. In contrast, a potential strength of the SureWash unit is that it can be left in clinical areas

Table 2. Pass rate and interrater agreement between the two human observers regarding performance of each pose.

Pose	Kappa	Descriptor
1	0.735	Fair to good
2 (left/right)	0.974/0.950	Excellent/Excellent
3	0.586	Fair to good
4	0.776	Excellent
5 (left/right)	0.817/0.807	Excellent/Excellent
6 (left/right)	0.813/0.773	Excellent/Excellent

All kappa values were computed using 169 subjects, and were significant, with p-values computed as <0.001. Poses are illustrated in Figure 2.
doi:10.1371/journal.pone.0105866.t002

Table 3. Number of poses performed correctly according to the two observers, stratified by subject intervention status.

Pose	Pre-intervention		Post-intervention	
	Observer 1	Observer 2	Observer 1	Observer 2
1	24 (39.3%)	26 (42.6%)	43 (79.6%)	43 (79.6%)
2 (Left)	40 (65.6%)	39 (63.9%)	40 (74.1%)	41 (75.9%)
2 (Right)	37 (60.7%)	36 (59.0%)	38 (70.4%)	39 (72.2%)
3	23 (37.7%)	23 (37.7%)	44 (81.5%)	37 (68.5%)
4	9 (14.8%)	4 (6.6%)	18 (33.3%)	11 (20.4%)
5 (Left)	21 (34.4%)	16 (26.2%)	31 (57.4%)	30 (55.6%)
5 (Right)	21 (34.4%)	17 (27.9%)	31 (57.4%)	31 (57.4%)
6 (Left)	11 (18.0%)	7 (11.5%)	22 (40.7%)	23 (42.6%)
6 (Right)	11 (18.0%)	5 (8.2%)	22 (40.7%)	25 (46.3%)

"Pre-intervention" includes Group A subjects at T_0 and Group B subjects at T_1 (n = 61). "Post-intervention" includes Group A subjects at T_1 and Group B subjects at T_2 (n = 54). Poses are illustrated in Figure 2.
doi:10.1371/journal.pone.0105866.t003

for independent use by healthcare workers, liberating infection control professionals for other activities. This benefit needs to be counter-weighed against the operating cost of the device.

We did not demonstrate an impact on the number of healthcare workers performing a complete hand hygiene action. In fact, only two such actions were observed during the study. This may reflect the stringency of the outcome measure definition: six poses (three of which must be repeated bilaterally) performed correctly during at least 20 seconds as judged by two independent human raters. We would consider "poses per action" or a microbiologic measure a preferable outcome measure when designing future studies. However this result belies a change in behaviour that occurred nevertheless. At baseline, when asked to perform a hand hygiene action, the overwhelming majority of healthcare workers slid one hand over the other in a continuous, seemingly random movement. Following the intervention, we observed that partic-

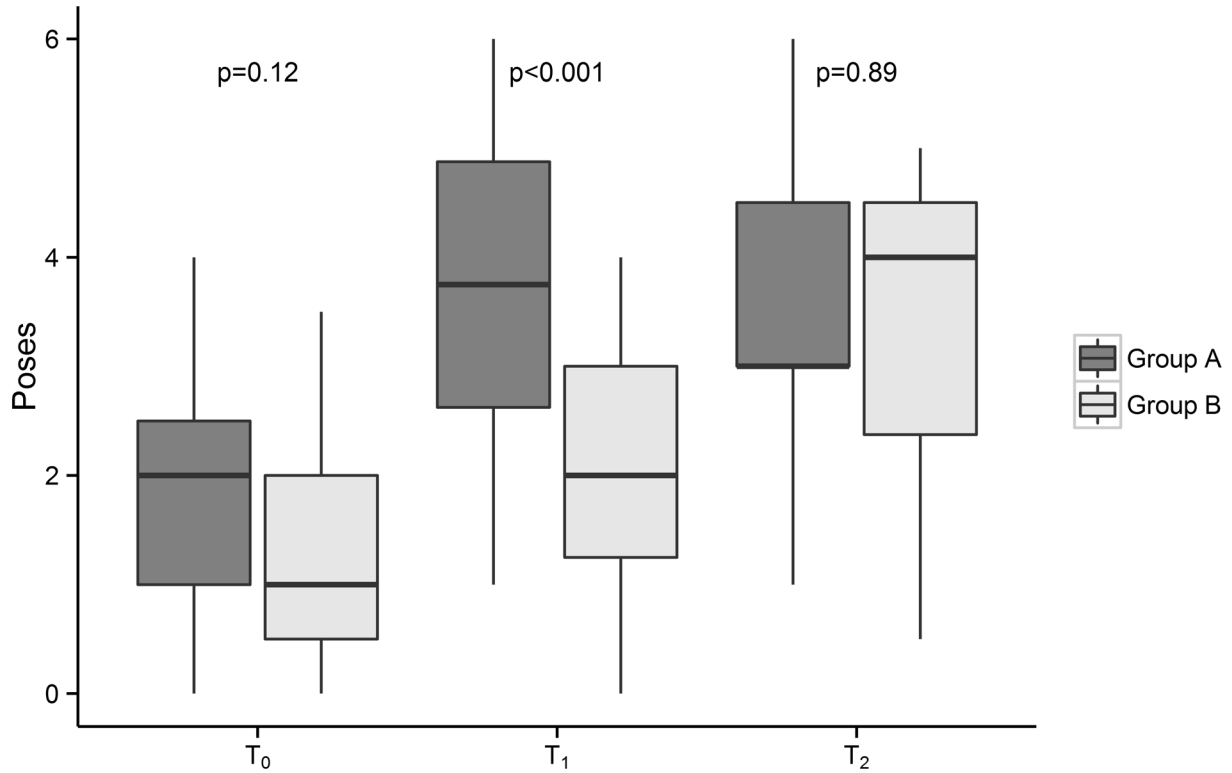

Figure 4. Number of poses performed correctly per hand hygiene action, by study group and study phase. Group A was exposed to the intervention for four weeks between baseline (T_0) and the first follow-up (T_1). Group B was exposed to the invention for 12 weeks between the first follow-up (T_1) and the second follow-up (T_2). Median and interquartile ranges are represented by the horizontal line and box, respectively. Upper and lower whiskers extend to minimum and maximum values that lie within 1.5 times the interquartile range from the 75th and 25th percentile, respectively. Each p-value relates to the null hypothesis that the two groups perform the same number of poses correctly at that time point.
doi:10.1371/journal.pone.0105866.g004

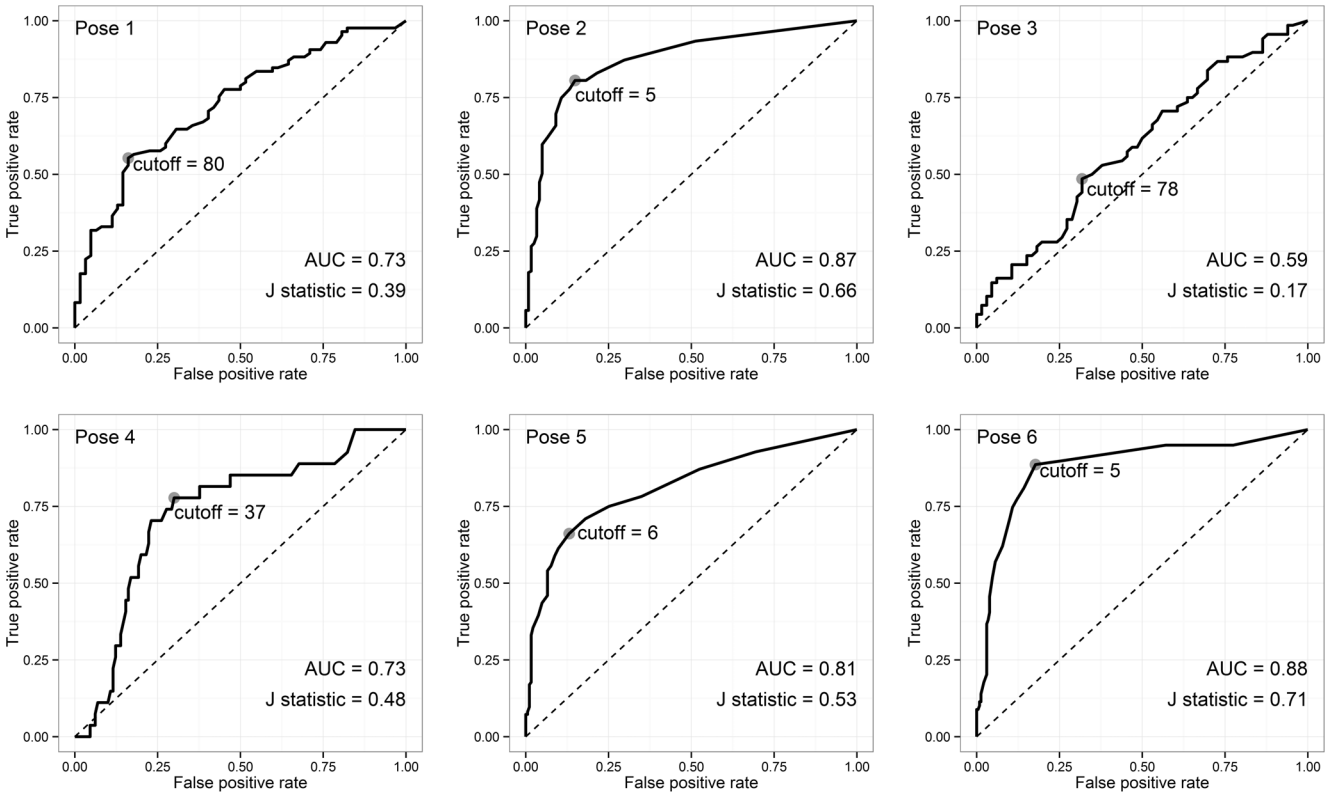

Figure 5. Receiver operating characteristic curves for each pose. Grey points indicate the diagnostic cutoff that maximises Youden's J statistic. AUC, area under the curve.
doi:10.1371/journal.pone.0105866.g005

ipants instead made repeated stereotyped poses. This can be appreciated in the *post-hoc* analysis of poses per action. Several approaches could be considered to optimise the impact of this intervention in busy clinical settings: alternative placement or longer exposure to the device; ward based role-models or 'champions' to inspire friendly competition, benchmarking of results against other wards; or a more formal credentialing requirement. Uptake is likely to vary between settings, and a flexible approach involving frontline ownership may be most effective.

This trial demonstrates that SureWash has good capacity to distinguish between correctly and incorrectly performed poses. However, two issues should be considered when reviewing these data. First, this analysis was performed on recordings made during the three assessment periods (in "study mode"), when immediate feedback was not provided to healthcare workers. During standard use, healthcare workers receive immediate feedback in the form of green bars that extend when the pose is being correctly performed. Thus healthcare workers quickly refine their technique by making minor adjustments to hand position or movement, and agreement between the device and human observers could be expected to increase. Second, though good inter-rater agreement between the two observers supports their reliability as a reference diagnostic technique, the human review process was clearly imperfect, involving a degree of subjective judgement.

These data must be interpreted in the context of the study design. First, this trial was designed to assess the efficacy of SureWash as an educational tool. Consequently, we assessed

Table 4. Performance characteristics of SureWash as a diagnostic test when compared to human observers.

Pose	n	Sensitivity	Specificity	Accuracy	PPV	NPV
Pose 1	147	0.55 (0.44–0.66)	0.84 (0.72–0.92)	0.67 (0.59–0.75)	0.82 (0.7–0.91)	0.58 (0.47–0.68)
Pose 2	332	0.81 (0.75–0.86)	0.85 (0.78–0.91)	0.82 (0.78–0.86)	0.90 (0.85–0.94)	0.72 (0.63–0.79)
Pose 3	134	0.49 (0.36–0.61)	0.68 (0.56–0.79)	0.58 (0.49–0.67)	0.61 (0.47–0.74)	0.56 (0.45–0.67)
Pose 4	157	0.78 (0.58–0.91)	0.70 (0.61–0.78)	0.71 (0.64–0.78)	0.35 (0.23–0.48)	0.94 (0.87–0.98)
Pose 5	307	0.66 (0.57–0.74)	0.87 (0.81–0.91)	0.79 (0.73–0.83)	0.77 (0.68–0.85)	0.79 (0.73–0.85)
Pose 6	310	0.89 (0.79–0.95)	0.82 (0.77–0.87)	0.84 (0.79–0.88)	0.63 (0.53–0.72)	0.95 (0.92–0.98)

Computed using cutoff values selected to maximise Youden's J statistic. Estimations provided with 95% confidence intervals in parentheses. Poses are illustrated in Figure 2.
PPV, positive predictive value; NPV, negative predictive value.
doi:10.1371/journal.pone.0105866.t004

healthcare workers' capacity to perform hand hygiene technique on request, rather than covertly monitoring actual hand hygiene technique during routine patient care. Second, this trial does not provide data regarding the importance of performing hand hygiene as per WHO recommendations. However, the superiority of the WHO technique with regard to product coverage and reduction in bacterial colony forming units has been demonstrated previously [7]. Third, human review of video images was used to assess the primary outcome and also as "gold-standard" reference test to evaluate the device's diagnostic performance (secondary objective). Whilst we attempted to quantify reliability of human observers by presenting inter-rater agreement, we acknowledge that this "gold standard" is imperfect. Finally, due to anonymity considerations, we were unable to track individual healthcare workers' performance through each of the three assessments and correlate improvement with their use of the SureWash unit.

In summary, no healthcare workers were able to perform a complete hand hygiene action at baseline despite a long institutional history of hand hygiene promotion. While we were unable to demonstrate an increase in complete hand hygiene actions, exploratory *post-hoc* analysis suggested that exposure to SureWash significantly increased the number of poses performed per action, and this effect persisted 12 weeks post intervention. This study identifies a need for further study of hand hygiene technique and demonstrates the potential utility of the SureWash device. Future studies should explore methods to maximise the uptake and effectiveness of this device as well as the impact of improved hand hygiene technique on transmission events or laboratory surrogates.

Acknowledgments

The authors gratefully acknowledge Prof Arnaud Perrier and Mme Sandra Merkli for their support, and sincerely thank Mme Sophie Robert, Mme Soraya Hamache, M. Pierre-André Berret, Mme Murielle Tarpin-Lyonnet and the healthcare workers of the internal medicine department for their participation. We are grateful to Erik von Elm for his careful reading of this manuscript and thoughtful comments.

Author Contributions

Conceived and designed the experiments: AS AI VC AGA DC GL DP. Performed the experiments: AS AI VC DP. Analyzed the data: AS. Wrote the paper: AS. Developed trial-specific software: DC. Critical review and revision of the manuscript: AI VC AGA DC GL DP.

References

1. World Health Organization (2009) WHO Guidelines on Hand Hygiene in Healthcare. Geneva: World Health Organization Press.
2. Pittet D, Hugonnet S, Harbarth S, Mourouga P, Sauvan V, et al. (2000) Effectiveness of a hospital-wide programme to improve compliance with hand hygiene. Infection Control Programme. Lancet 356: 1307–1312.
3. Sax H, Allegranzi B, Uckay I, Larson E, Boyce J, et al. (2007) 'My five moments for hand hygiene': a user-centred design approach to understand, train, monitor and report hand hygiene. J Hosp Infect 67: 9–21.
4. Sax H, Allegranzi B, Chraiti MN, Boyce J, Larson E, et al. (2009) The World Health Organization hand hygiene observation method. Am J Infect Control 37: 827–834.
5. Anderson J, Gosbee LL, Bessesen M, Williams L (2010) Using human factors engineering to improve the effectiveness of infection prevention and control. Crit Care Med 38: S269–281.
6. Widmer AE, Dangel M (2004) Alcohol-based handrub: evaluation of technique and microbiological efficacy with international infection control professionals. Infect Control Hosp Epidemiol 25: 207–209.
7. Widmer AF, Conzelmann M, Tomic M, Frei R, Stranden AM (2007) Introducing alcohol-based hand rub for hand hygiene: the critical need for training. Infect Control Hosp Epidemiol 28: 50–54.
8. Harris AD, Bradham DD, Baumgarten M, Zuckerman IH, Fink JC, et al. (2004) The use and interpretation of quasi-experimental studies in infectious diseases. Clin Infect Dis. Jun 1;38(11):1586–91.
9. Pittet D, Sax H, Hugonnet S, Harbarth S (2004) Cost implications of successful hand hygiene promotion. Infect Control Hosp Epidemiol 25: 264–266.
10. Fleiss JL (1981) Statistical methods for rates and proportions. New York: John Wiley.
11. Clopper C, Pearson ES (1934) The use of confidence or fiducial limits illustrated in the case of the binomial. Biometrika 26: 404–413.
12. R Core Team (2013) R: A Language and Environment for Statistical Computing. Vienna, Austria: R Foundation for Statistical Computing.
13. Sing T, Sander O, Beerenwinkel N, Lengauer T (2005) ROCR: visualizing classifier performance in R. Bioinformatics 21: 3940–3941.
14. World Health Organization (2006) WHO Guidelines for Hand Hygiene in Health Care. Geneva: World Health Organization.
15. Ghosh A, Ameling S, Zhou J, Lacey G, Creamer E, et al. (2013) Pilot evaluation of a ward-based automated hand hygiene training system. Am J Infect Control 41: 368–370.
16. Higgins A, Hannan MM (2013) Improved hand hygiene technique and compliance in healthcare workers using gaming technology. J Hosp Infect 84: 32–37.
17. Kampf G, Reichel M, Feil Y, Eggerstedt S, Kaulfers PM (2008) Influence of rub-in technique on required application time and hand coverage in hygienic hand disinfection. BMC Infect Dis 8: 149.
18. Szilagyi L, Haidegger T, Lehotsky A, Nagy M, Csonka EA, et al. (2013) A large-scale assessment of hand hygiene quality and the effectiveness of the "WHO 6-steps". BMC Infect Dis 13: 249.

Journal of Hospital Infection 84 (2013) 32–37

Available online at www.sciencedirect.com

Journal of Hospital Infection

journal homepage: www.elsevierhealth.com/journals/jhin

Improved hand hygiene technique and compliance in healthcare workers using gaming technology

A. Higgins [a,*], M.M. Hannan [b]

[a] Infection Prevention and Control Department, Mater Private Hospital, Dublin 7, Ireland
[b] Department of Clinical Microbiology, Mater Misericordiae University Hospital, University College Dublin, Dublin 7, Ireland

ARTICLE INFO

Article history:
Received 6 August 2012
Accepted 5 February 2013
Available online 14 March 2013

Keywords:
Hand hygiene
Handwashing
SureWash
Gaming technology
ATP
Multi-modal strategy

SUMMARY

Background: In 2009, the World Health Organization recommended the use of a 'multi-faceted, multi-modal hand hygiene strategy' (Five Moments for Hand Hygiene) to improve hand hygiene compliance among healthcare workers. As part of this initiative, a training programme was implemented using an automated gaming technology training and audit tool to educate staff on hand hygiene technique in an acute healthcare setting.
Aim: To determine whether using this automated training programme and audit tool as part of a multi-modal strategy would improve hand hygiene compliance and technique in an acute healthcare setting.
Methods: A time-series quasi-experimental design was chosen to measure compliance with the Five Moments for Hand Hygiene and handwashing technique. The study was performed from November 2009 to April 2012. An adenosine triphosphate monitoring system was used to measure handwashing technique, and SureWash (Glanta Ltd, Dublin, Ireland), an automated auditing and training unit, was used to provide assistance with staff training and education.
Findings: Hand hygiene technique and compliance improved significantly over the study period ($P < 0.0001$).
Conclusion: Incorporation of new automated teaching technology into a hand hygiene programme can encourage staff participation in learning, and ultimately improve hand hygiene compliance and technique in the acute healthcare setting.

Introduction

Although Semmelweis discovered the link between unwashed hands and hospital-acquired infections in the 1800s,[1] the healthcare profession still struggles with hand hygiene compliance in the 21st Century.[2,3]

In 2009, the World Health Organization (WHO) recommended the use of a 'multi-faceted, multi-modal hand hygiene strategy' (Five Moments for Hand Hygiene) to improve hand hygiene compliance among healthcare staff. It provided a strategy to assist with hand hygiene, recommending interventions such as healthcare worker (HCW) training and education, monitoring of alcohol hand rub usage, auditing of hand hygiene practices with feedback, reminders in the work place, and increased availability of handwash sinks and alcohol-based hand rubs at point of care. The importance of cultivating an environment where senior management support a culture of patient safety was also stressed.

This paper describes the use of automated teaching technology (SureWash, Glanta Ltd, Dublin, Ireland) combined with adenosine triphosphate (ATP) as part of a multi-modal

* Corresponding author. Address: Infection Prevention and Control Department, Mater Private Hospital, Eccles Street, Dublin 7, Ireland. Tel.: +353 1 8858371; fax: +353 1 8858631.
E-mail address: ahiggins@materprivate.ie (A. Higgins).

0195-6701/$ – see front matter
http://dx.doi.org/10.1016/j.jhin.2013.02.004

approach to educate all grades of HCWs on hand hygiene technique and compliance.

Literature review

Healthcare-associated infections (HCAIs) remain a concern in Europe and worldwide.[4] It is also an accepted fact internationally that hand hygiene is linked to prevention of HCAIs,[1,5–7] and is the most effective intervention to reduce infection rates.[8–10] However, HCWs' compliance with hand hygiene is still far from perfect.[2,11]

A Cochrane review of the evidence relating to those interventions found to be most effective was undertaken by Gould *et al*.[12] They found a dearth of evidence regarding the best methods to employ due to the poor design of the majority of published papers. However, others have argued that research demonstrates that practice improves when staff are educated and audited, with feedback provided.[10,13] It is evident that levels of hand hygiene decrease once interventions cease.[3,11,12]

Numerous research papers have attempted to explain why people do not wash their hands.[12,14–17] The unanswered question remains, what can be done to ensure that HCWs are convinced once and for all that 'clean hands save lives'?[12,16,17]

There is agreement among behavioural researchers that an individual's experience of an effect from not washing their hands is of greater importance than formal education in improving hand hygiene behaviour.[17,18] This would imply that HCWs need to personally experience an effect from not washing their hands in order to ensure sustained practice change. Nicol *et al*. noted that HCWs themselves agreed that a personal experience or experimental learning was more powerful in changing their practice.[18] However, the Cochrane review by Gould *et al*. found that, in practice, HCWs are trained rather than educated in hand hygiene.[12]

The authors attempted to improve hand hygiene compliance in their acute care private hospital, and identified poor technique as a second issue. Unable to provide the individualized training needed to tackle this, ATP and gaming technology were used to capture the imagination of HCWs with the aim of improving both hand hygiene compliance and technique.

Intervention

A baseline audit of HCWs' compliance with the Five Moments for Hand Hygiene[10] was carried out between November and December 2009.

In January 2011, a multi-faceted approach to hand hygiene[3,10] was implemented. This involved monthly hand hygiene audits of the Five Moments for Hand Hygiene, the design of new posters, increased supplies of alcohol hand rubs, and the use of ATP to demonstrate visually and numerically the level of contamination on the hands of staff in clinical areas. Commitment from management at the highest level was essential, and thus hand hygiene audit results were provided not just to ward and department managers, but also to the hospital executive team and board.

In early 2010, compliance with the Five Moments for Hand Hygiene improved to 58%, but this had decreased to 29% by the end of 2010. The audits also identified another issue, as ATP used to assess the level of hand contamination identified poor handwashing technique. Visual observation of HCWs using alcohol hand rubs confirmed a similar problem. The individualized training and assessments needed to improve practice were not feasible within available resources. As such, SureWash, a mobile computer-based unit using gaming technology, was purchased. SureWash, a mobile stand-alone computer system, guides the user through the seven steps of hand hygiene,[10] demonstrating each position and allowing the user to practice. Next, it video audits the user as they move through all the steps, and provides them with an instant percentage score.

In February 2011, an advertising campaign about SureWash was carried out in the hospital through e-mails and general hospital mail. The unit was set up outside the staff canteen, and all those entering the canteen were encouraged to try it. Fob watches were provided as spot prizes. An information leaflet was designed and copies were left in the canteen, at nurses' stations, in staff meeting rooms etc.

The SureWash unit was deployed to each ward and department for periods of one week at a time. Once all departments had been reached, the unit was redeployed to each area. Over a 12-month period, it spent two weeks in each unit. All HCWs were asked to use the unit for hand hygiene training and to practice their handwashing technique. This training was in addition to the annual hand hygiene training provided to all HCWs by the infection prevention control (IPC) team.

Throughout the study period, random audits of HCWs' handwashing technique were undertaken using ATP to ascertain if any improvements in technique had occurred. Monthly hand hygiene audits continued. All patient areas of the hospital were included in the study, and all HCWs working in clinical areas were included. ATP testing was only carried out after handwashing with soap and water. Administration staff working in non-clinical areas such as consultant secretaries and office-based staff were not included.

Methods

Hand hygiene audits

The monthly hand hygiene audits of the Five Moments for Hand Hygiene were performed using an audit tool based on the WHO audit tool. Verbal feedback was provided directly to staff during the audits. Reports detailing results by HCWs' grade and department were provided monthly to each ward manager, hospital executive team and board. The audits were performed by IPC nurses who completed a recognized training course on the use of the audit tool. The course was designed to ensure that auditors nationally were using the tool accurately, and competence was only confirmed following reliability testing. There was no change in the auditing method or in the lead auditor for the duration of the study.

Adenosine triphosphate

In conjunction with these audits, ATP was used in the clinical area during spot audits and also at regular intervals outside the staff canteen. HCWs were selected at random and asked to wash their hands with soap and water. Once the hands were completely dry, the swab was rubbed against the tips of each finger, in between each finger and then in an S-shape along the palm of one hand. The swab was then placed in the monitor and

the results recorded. An explanation of the score achieved was given and the results were discussed, highlighting improvements in technique to achieve cleaner hands and thus a better ATP result. Using ATP in this way personalized the results and increased the emotional impact of poor handwashing technique for HCWs.

The ATP monitoring system (Hygiena International, Watford, UK) chosen was SystemSURE Plus (Trafalgar Scientific, Leicester, UK) due to its ability to provide a zero baseline and its ease of use in the clinical setting. When ATP is brought into contact with the reagent in the Ultrasnap testing device, light is emitted in direct proportion to the amount of ATP present. As ATP is the universal energy molecule found in all animal, plant, bacteria, yeast and mould cells, residues contain large amounts of ATP. After cleaning, all sources of ATP should be significantly reduced. Thus the higher the reading, the more contamination present. The manufacturer recommended a score <25 as a pass.

The ATP testing provided a physical measurement of the level of contamination on HCWs' hands after washing. The numerical score helped HCWs recognize the effect of poor technique. ATP was not used after application of alcohol hand rub as the alcohol in the rub reacts with the reagent, making the test inaccurate.

Reminders

Posters displaying hand hygiene technique and information about the Five Moments for Hand Hygiene were placed at key locations throughout the hospital. These included above all handwash sinks, in all clinical rooms, at entry and exit points to wards and departments, and on the back of toilet doors in all staff and public toilets.

Alcohol hand rubs

Alcohol hand rubs were already located at the entry and exit points to all wards. As part of the intervention, these units were also placed at the end of all patient beds and on portable blood pressure monitoring devices following feedback from staff.

Measurement of impact of interventions

A time-series quasi-experimental design was considered an appropriate method to measure the impact of the interventions on hand hygiene technique and compliance. This design is similar to a pre–post test design but with multiple pre-tests and multiple post-tests. The advantage of this approach is that it provides greater confidence that the change in the dependent variable was caused by the manipulation and was not just a random fluctuation.[19]

Auditing of HCWs' compliance with the Five Moments for Hand Hygiene was ongoing each month. Percentage compliance was correlated for each quarter of 2010, and compared with percentage compliance in 2011 and then separately for the first quarter of 2012 to assess sustainability.

Measurement of technique was calculated based on random audits of HCWs' technique using ATP and a mobile handwash sink. Four audits were performed before implementation of SureWash and four were performed after implementation of SureWash. The mobile sink, Hygieneus (Patron, Dublin, Ireland), had a refillable water container that provided hot water for up to 50 handwashing episodes. It had a timed 30-s water dispensing system providing water to wet hands, then a 30-s period without water and then 30 s with water for rinsing hands. This unit was placed outside the hospital staff canteen, and all HCWs entering the restaurant were asked to participate. Participation was encouraged by providing a fob watch to all HCWs who volunteered.

All those who agreed to take part were asked to wash their hands at the portable sink using soap and water and then dry them with paper towel. Hands were swabbed using the ATP monitor as described above. Numerical results were recorded and the percentage of scores >25 (fail) and <25 (pass) were correlated.

Rates of compliance with the Five Moments for Hand Hygiene and ATP pass rates throughout 2010 were compared with rates in 2011 and the first quarter of 2012 using homogeneity tests. The *P*-value was computed using 10,000 Monte Carlo simulations.

Results

HCWs' compliance with the Five Moments for Hand Hygiene increased from a baseline of 20% to 58% in early 2010. Unfortunately, the rates dropped gradually during the remainder of 2010 (Figure 1). In the first quarter of 2011, rates increased significantly to 86% and remained $>80\%$ for the rest of the year. The figure for the first quarter of 2012 was 80.7% (Figure 1).

In the 12 months prior to the implementation of SureWash, the rate of compliance with the Five Moments for Hand Hygiene was recorded as 42% (204 of 491 moments audited). In the 12 months following implementation, the compliance rate was recorded as 84% (618 of 735 moments audited) (Table I). This was a significant increase ($P < 0.0001$).

Handwashing technique, as measured by ATP results, showed a month-on-month improvement over the two years (Figure 2). The mean pass rate prior to implementation of SureWash was 52% (94 staff had scores <25). This increased to 79% (201 staff had scores <25) in the year following implementation ($P < 0.0001$).

Discussion

The study hospital is a tertiary referral acute care private hospital in Ireland with a well-established IPC programme. In 2010, the hospital commenced the implementation of a multimodal hand hygiene programme. This intervention initially improved the compliance rate by 20% (Figure 1). However, this improvement declined gradually from 58% at the beginning of 2010 to 29% by the fourth quarter of 2010 (Figure 1). Nicol *et al.* found that successful programmes needed to connect with individuals on an emotional level to ensure sustained improvement.[18]

The use of ATP to demonstrate contamination levels on HCWs' hands in the clinical area did assist with technique improvements (Figure 2), but the need for increased training on correct technique was also highlighted. WHO recommends that education and audit of HCWs' handwashing technique and alcohol hand rub application should be included in hand hygiene education programmes.[10] However, the IPC team did not have the resources to increase the frequency of their education sessions. With over 1000 staff working in the

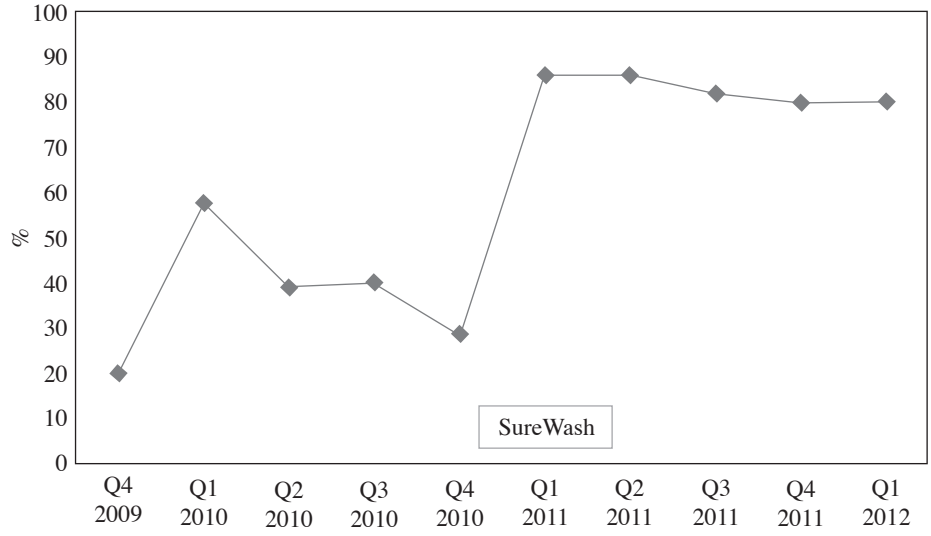

Figure 1. Percentage compliance with the World Health Organization's Five Moments for Hand Hygiene.

hospital, provision of this type of one-to-one training and audit was not feasible.

The implementation of SureWash used gaming technology to demonstrate and audit technique became an essential part of the IPC programme. It provided the much needed focus on technique training and allowed HCWs the opportunity to practice at a time that suited them. This training was available 24 h/day, 365 days/year. In the first eight months, 287 h of audit and training were recorded. The usage levels did not reduce over time. Regardless of the department where SureWash was placed, HCWs used the unit and practiced their technique in equal numbers, although nursing staff and doctors recorded better technique initially than untrained workers.

Following one week in each area, reports were run detailing the numbers and grades of HCWs who used the unit. Reports run from the unit demonstrated that individual HCWs returned again and again until they achieved 100%. The gaming design of SureWash provided an individual, experimental, fun way to learn the correct handwashing technique. Behavioural science has identified the need for individual experimental learning.[19] Research has identified that this individual experience is essential if behaviour is to be changed in the long term.[12,18] This individual experience of the impartial computerized response to incorrect technique was a powerful educational tool for HCWs.

The quarterly audits of technique using ATP showed a significant increase in the proportion of HCWs reaching acceptable ATP scores after washing. This was an indication of the improvements in their technique (Figure 2), and evidence that SureWash was having a positive impact.

What was surprising and unexpected was the sudden and sustained improvement in compliance with the Five Moments for Hand Hygiene that occurred at the same time (Figure 1). Improved compliance rates achieved in early 2010 had dwindled to 29% in the last quarter of 2010 (Figure 2). However, rates rose to >80% for the first time in March 2011, and remained consistently >80% for the rest of the year (Figure 2). This indicates that the SureWash system, although tackling technique, increased overall awareness of hand hygiene.

The study was conducted in the context of a working clinical environment, and multiple IPC activities may have confounded the results. The extra alcohol hand rub stations in the clinical area in 2011 most likely had a confounding effect on the increased use of alcohol hand rubs noted during audits. However, handwashing also increased and both had a statistically significant impact on compliance rates ($P < 0.0001$). Ongoing audits by the same personnel will certainly have had a Hawthorn effect, with practice improving when HCWs knew they were being observed. However, this was true at all stages of the study. There was some attempt to control variables by ensuring that the same HCWs performed the audits in a consistent manner.

Table I
Compliance with the Five Moments for Hand Hygiene: audit results

Five Moments for Hand Hygiene audits	Q4 2009	Q1 2010	Q2 2010	Q3 2010	Q4 2010	Q1 2011	Q2 2011	Q3 2011	Q4 2011	Q1 2012
Number of opportunities audited	102	118	124	120	129	157	251	181	146	512
Missed opportunities	81	50	75	70	92	22	36	30	29	101
Compliance (%)	20	58	39	40	29	86	86	82	80	80

Q, quarter.

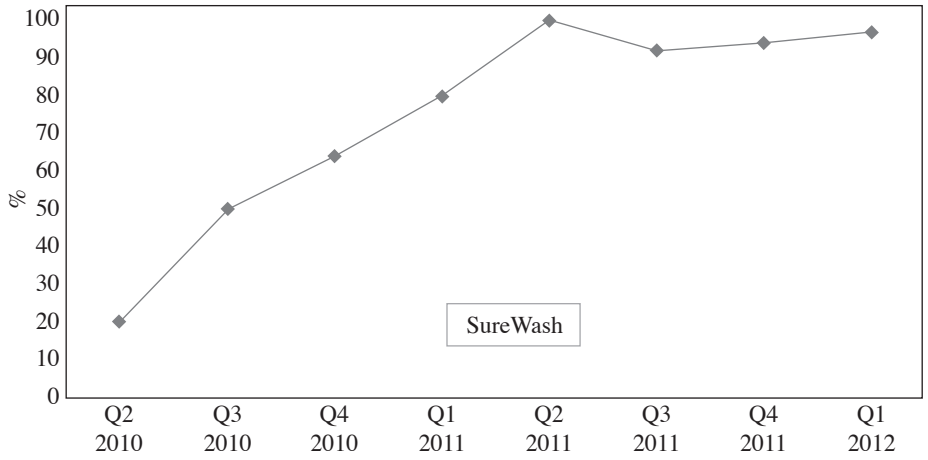

Figure 2. Percentage of passes (score <25) from adenosine triphosphate swabs of randomly selected healthcare workers' hands after washing.

No attempt was made to measure improvements in technique for application of alcohol hand rub, as the ATP method chosen is not effective in the presence of alcohol.

As the study was undertaken in a single acute care setting, it is not known if the results can be replicated in other hospitals or generalized to the population. Further studies examining the impact of SureWash in other settings would be useful to determine the benefits of using this type of gaming technology for other forms of education. Use of a crossover quasi-experimental approach in multiple sites would be more rigorous.

Conclusion

The use of gaming technology to provide education and assessment not only improved technique, but also increased compliance with the Five Moments for Hand Hygiene across the hospital. However, it is not a replacement for education, audit with feedback and reminders in the clinical area. It is a tool to capture the imagination of staff and engage HCWs in learning. It has a major role to play in a multi-faceted hand hygiene programme.

Acknowledgements

The authors wish to thank all the staff in the hospital who participated in the audits, and the Research and Innovation Department, Trinity College, Dublin for assistance with statistical analysis.

Conflict of interest statement
None declared.

Funding sources
None.

References

1. Semmelweis I. *Die Aetiologie der Bergriff und die Prophylaxix des kinderbettfiebers [The aetiology, concept and prophylaxis of childbed fever]*. Vienna and Leipzip: C.A. Hartleben's Verlag-Expedition; 1861.
2. Randle J, Arthur A, Vaughan N. Twenty-four-hour observational study of hospital hand hygiene compliance. *J Hosp Infect* 2010;**76**:252—255.
3. World Health Organization. *A guide to the implementation of the WHO multimodal hand hygiene improvement strategy*. Geneva: World Health Organization; 2011.
4. Humphreys H, Newcombe RG, Enstone J, *et al*. Four country healthcare-associated infection prevalence survey: pneumonia and lower respiratory tract infections. *J Hosp Infect* 2010;**74**: 266—270.
5. Larson E. A causal link between hand washing and risk of infection? Examination of the evidence. *Infect Control Hosp Epidemiol* 1988;**9**:28—36.
6. Grayson ML, Jarvie LJ, Martin R, *et al*. Significant reductions in methicillin-resistant *Staphylococcus aureus* bacteraemia and clinical isolates associated with a multisite, hand hygiene culture-change program and subsequent successful state-wide roll-out. *Med J Aust* 2008;**188**:633—640.
7. Allegranzi B, Pittet D. Role of hand hygiene in healthcare-associated infection prevention. *J Hosp Infect* 2009;**73**:305—315.
8. Teare EL, Cookson B, French GL, *et al*. UK hand washing initiative. *J Hosp Infect* 2009;**43**:1—3.
9. Pittet D, Hugonnet S, Mourouga P. Effectiveness of a hospital-wide programme to improve compliance with hand hygiene. *Lancet* 2000;**356**:1307—1312.
10. Pittet D, Allegranzi B, Boyce S. The World Health Organization guidelines on hand hygiene in health care and their consensus recommendation. *Infect Control Hosp Epidemiol* 2009;**30**: 611—622.
11. Storr J. Changing culture on the front line. *Clin Serv J* 2009; **8**(11):53—54.
12. Gould D, Chudleigh JH, Moralejo D, Drey N. Interventions to improve hand hygiene compliance in patient care. *Cochrane Database Syst Rev* 2007;**2**. CD005186.
13. Pessoa-Silva CL, Hugonnet S, Pfister R, *et al*. Reduction of healthcare associated infection risk in neonates by successful hand hygiene promotion. *Paediatrics* 2007;**120**: e382—e390.
14. Creedon SA. Hand hygiene compliance: exploring variations in practice between hospitals. *Nurs Times* 2008;**104**:32—35.
15. Barrett R, Randle J. Hand hygiene practices: nursing students' perceptions. *J Clin Nurs* 2008;**17**:1851—1857.

16. Lee H. *Essentials of behavioural science research, a first course in research methodology*. North Carolina: LULU Publications; 2009.
17. Whitby M, McLaws ML, Ross MW. Why healthcare workers don't wash their hands: a behavioural explanation. *Infect Control Hosp Epidemiol* 2006;**27**:484—492.
18. Nicol PW, Watkins RE, Donovan RJ, Wynaden D, Cadwallader H. The power of vivid experience in hand hygiene compliance. *J Hosp Infect* 2009;**72**:36—42.
19. World Health Organization. *WHO guidelines on hand hygiene in healthcare: first global patient safety challenge: clean care is safer care*. Geneva: World Health Organization; 2009. 157—171.

Microbial transmission in an outpatient clinic and impact of an intervention with an ethanol-based disinfectant

American Journal of Infection Control 47 (2019) 128–132

Contents lists available at ScienceDirect

American Journal of Infection Control

journal homepage: www.ajicjournal.org

Major Article

Microbial transmission in an outpatient clinic and impact of an intervention with an ethanol-based disinfectant

Kelly A. Reynolds PhD [a,*], Jonathan D. Sexton PhD [a], Trevor Pivo MS [b], Kyle Humphrey MS [a], Rachel A. Leslie MS [c], Charles P. Gerba PhD [b]

[a] Mel and Enid Zuckerman College of Public Health, University of Arizona, Tucson, AZ
[b] Department of Soil, Water and Environmental Science, University of Arizona, Tucson, AZ
[c] Research and Development, GOJO Industries, Akron, OH

Key words:
Disinfection
Outpatient clinic
Infection control
Phage tracer
MS2
Fomites

Background: Halting the spread of harmful microbes requires an understanding of their transmission via hands and fomites. Previous studies explored acute and long-term care environments but not outpatient clinics. Objectives of this study were to track microbial movement throughout an outpatient clinic and evaluate the impact of a disinfectant spray intervention targeting high-touch point surfaces.

Methods: At the start of the clinic day, a harmless viral tracer was placed onto 2 fomites: a patient room door handle and front desk pen. Patient care, cleaning, and hand hygiene practices continued as usual. Facility fomites (n = 19), staff hands (n = 4), and patient hands (n = 3-4) were sampled after 2, 3.5, and 6 hours. Tracer concentrations at baseline (before intervention) were evaluated 6 hours after seeding. For the intervention trials, high-touch surfaces were cleaned 4 hours after seeding with an ethanol-based disinfectant and sampled 2 hours after cleaning.

Results: At 2, 3.5, and 6 hours after seeding, virus was detected on all surfaces and hands sampled, with examination room door handles and nurses' station chair arms yielding the highest concentrations. Virus concentrations decreased by 94.1% after the disinfectant spray intervention ($P = .001$).

Conclusions: Microbes spread quickly in an outpatient clinic, reaching maximum contamination levels 2 hours after inoculation, with the highest contamination on examination room door handles and nurses' station chairs. This study emphasizes the importance of targeted disinfection of high-touch surfaces.

BACKGROUND

Health care-associated infections are a significant threat to the safety of patients seeking medical care. The United States Centers for Disease Control and Prevention (CDC) estimates that 721,800 health care-acquired infections occurred in the United States in 2011, equating to about 1 hospital-acquired infection in every 25 inpatients.[1] Organisms that are common causes of health care-associated infections are known to survive on surfaces for days to months.[2] Environmental contamination has also been demonstrated to play a role in the transmission of pathogens, including viruses such as norovirus,[3,4] coronaviruses, and influenza,[5] as well as bacteria such as methicillin-resistant *Staphylococcus aureus* and vancomycin-resistant enterococci.[6,7] Evidence indicates that contamination of environmental surfaces is linked with contamination of health care personnel hands and that improved terminal cleaning and disinfection practices lead to decreased infection rates.[8,9] Improving environmental cleaning and disinfection in health care settings therefore is a critical practice in reducing the incidence of health care-associated infections.

Outpatient health care has been steadily increasing in recent decades, shifting care from the inpatient to outpatient setting. Between 1997 and 2007, outpatient office visits increased by 25%.[10] Between 1996 and 2013, outpatient care spending increased by $324.9 billion, whereas inpatient care spending increased by $259.2 billion,[11] and in 2016, hospital care spending increased 4.7%, whereas outpatient services spending increased 5.4%.[12] As more care is provided in outpatient facilities, it is increasingly important to understand the potential for

* Address correspondence to Kelly A. Reynolds, PhD, University of Arizona, Department of Community Environment and Policy, Mel and Enid Zuckerman College of Public Health, Campus PO Box 245210, 1295 N Martin Ave, Tucson, AZ 85724.
E-mail address: reynolds@email.arizona.edu (K.A. Reynolds).
Funding/support: Funding provided by GOJO Industries, Akron, Ohio.
Conflicts of interest: None to report.

https://doi.org/10.1016/j.ajic.2018.06.017

disease transmission and study the practices that ensure infection prevention in this setting. Although disinfection interventions have been quantitatively evaluated in hospitals[13,14] and workplaces,[15,16] studies have not been published measuring their effect in health care facilities beyond hospitals, despite evidence of environmental contamination in outpatient care sites.[17,18] Understanding the dynamics of transmission and reservoirs of contamination in an outpatient setting can help inform effective infection control guidelines and practices. Previous studies in home and office environments demonstrated that human viruses and virus surrogates spread rapidly throughout a facility and may contaminate more than half of the surfaces within 4 hours.[16,19] Ethanol-based products, particularly those targeting hand hygiene, play a strong role in infection control because of rapid, broad-spectrum efficacy and ease of use. For surface disinfection, however, ethanol-based disinfectants have required high levels of alcohol (≥50%) for antimicrobial efficacy, which led to concerns with fast dry times and material compatibility.[9] The aim of this study was to quantify pathogen contamination potential and assess the impact of a high-touch point cleaning intervention with a 29.4% ethanol spray disinfectant on reducing the spread of a virus tracer in an outpatient clinic.

METHODS

Study design

This study site was an outpatient, urgent care clinic with approximately 3,000 square feet of total treatment area. Patients entering the facility signed in at a common front desk before evaluation by a triage nurse. After initial evaluation for care needs, patients typically waited in a common area in the front of the facility before moving through a common door to private examination rooms in the back of the facility.

To track transmission of microbes, a harmless virus tracer, bacteriophage MS2, was used. MS2 only infects specific strains of *Escherichia coli*, can be grown to high concentrations, and has been extensively used as a surrogate for human viruses and bacteria in a variety of transmission studies.[20-22] The MS2 bacteriophage has been shown to be an appropriate surrogate for both transmission of pathogenic viruses and susceptibility of more resistant viruses to disinfectants.[23-25] The outpatient clinic tracer study was reviewed and approved by the University of Arizona institutional review board.

This study was divided into 3 distinct phases (Table 1). Phase 1 was a pilot time series study evaluating the movement of the tracer virus through the facility over the course of the day. Patient care, surface cleaning practices, and hand hygiene practices continued as usual. Tracer virus (1×10^9 plaque-forming units [PFUs] of MS2) was inoculated onto 2 fomites in the clinic: the door handle exiting the patient care area and the sign-in pen at the front desk. Fomites throughout the facility (n = 19), hands of clinic staff (n = 4), and hands of patients (n = 3-4) were sampled at 2, 3.5, and 6 hours. Phase 2 was a baseline study during which fomite and hand samples were collected 6 hours after seeding while hygiene practices continued as usual by clinic staff, including use of the facility's current disinfectant wipe product. Phase 3 was an intervention study during which select surfaces (Table 2) were cleaned by study personnel 4 hours after seeding using an Environmental Protection Agency (EPA)–registered ethanol-based spray disinfectant (Purell Surface Disinfectant, 29.4% Ethanol; GOJO Industries, Akron, OH) with efficacy claims against bacteria, nonenveloped viruses and influenza, and fungi. As per manufacturer instructions for surface disinfection, product was sprayed 6-8 inches from surfaces until thoroughly wet. Treated surfaces remained wet for a minimum of 30 seconds and were then wiped with disposable dry paper towels. Samples were collected 2 hours after the targeted cleaning (6 hours after seeding). Phase 3 intervention was repeated twice, 3 days apart.

Table 1
Summary of study design and intervention

Study phase	Study design
1	Pilot time series study: Current cleaning practices and products used by clinic staff; hand/fomite sampling at 2, 3.5, and 6 hours after seeding
2	Baseline: Current cleaning practices and products used by clinic staff; hand/fomite sampling at 6 hours after seeding
3	Intervention: Clinic staff using disinfectant spray for typical use scenarios, plus targeted use of intervention disinfectant, by study staff, on high-touch surfaces at 4 hours after seeding; hand/fomite sampling at 6 hours after seeding

Table 2
Sample sites and surface areas

Sample sites	Area sampled (cm^2)
Bathroom inner and outer door handles (2)	100
Bathroom faucet (2)	100
Waiting room nurses' mouse	100
Waiting room counter	100
Waiting room survey computer mouse	100
Patient triage seat arms	30
Treatment area nurses' station mouse	100
Treatment area nurses' station chair arms	100
Patient room countertop storage canister lids (3)	100
Patient room exposed edge of examination table (3)	100
Patient room inner door handle (3)	50
Staff hands (4)	100
Patient hands (4)	100

Sample collection and processing

Before the clinic opening, targeted surfaces (Table 2) were disinfected with a 70% ethanol solution to eliminate any potential background contamination. Upon opening, 2 surfaces (front desk sign-in pen and door handle exiting patient care area) were seeded with 100 μL of 1×10^9 PFUs/mL of bacteriophage MS2. Clinic personnel continued their typical work practices throughout the day. Targeted cleaning and sample collection occurred 4 and 6 hours after seeding, respectively.

Samples were collected using a sponge-stick (3M, Maplewood, MN) containing 10 mL of neutralizing Letheen broth. Samples were transported on ice to the laboratory for immediate processing. Samples were assayed in duplicate using the top agar overlay technique and incubated at 37°C for 24 hours. After incubation, plaques were counted and total concentrations were calculated. If the number of PFUs was too numerous to count, within 24 hours the subsamples were diluted by a factor of 10 until a countable number was obtained.

Statistical analysis

This study used a within-subjects design to compare the effect of a disinfection intervention on the spread of a virus throughout an urgent care facility. In the analysis of phase 1 pilot time series, the percent of sites positive, represented by detection of a single PFU per volume assayed, compared with total sites sampled were calculated for total sites and also for segments of the facility, including nurses' station fomites, patient area fomites, and hands of nurses and patients. Average log virus concentrations (PFUs/surface) at each time point were compared using pairwise t tests and R software.[26] In addition, a linear mixed effects model with a random intersect for fomites was used to calculate the reduction coefficient.

PFUs were averaged across both subsample replicates, for each sample from each surface from each phase, and then divided by the

Table 3
Time series analysis of virus spread

	2 hours	3.5 hours	6 hours	Total (all time points)
Sample type (% positive over time)				
Nurses station fomites	50% (3/6)	67% (4/6)	50% (3/6)	56% (10/18)
Patient area fomites	77% (10/13)	31% (4/13)	46% (6/13)	51% (20/39)
Staff hands	75% (3/4)	75% (3/4)	100% (4/4)	83% (10/12)
Patient hands	100% (3/3)	75% (3/4)	33%(1/3)	70% (7/10)
All sample types	73% (19/26)	52% (14/27)	54% (14/26)	59% (47/79)
PFU concentration data type (PFUs/surface)				
PFU range	<1 to 1.8×10^4	<1 to 7.3×10^4	<1 to 3.4×10^3	<1 to 7.3×10^4
PFU mean of all sites	1.0×10^3	370	141*	496
PFU mean of contaminated sites only	1.4×10^3	634	261	824

PFU, plaque-forming unit.
*Estimated PFU reduction of 38% per hour over 4-hour sampling period.

area of the surface. These PFUs per unit area were averaged across both repeats of each phase (yielding the log of the geometric mean). Comparisons of the average log PFUs/cm^2 were made between phases 2 and 3 using pairwise t tests and R software.

RESULTS

In phase 1, a comparison of virus percent positive and PFU results was found to not differ significantly across various time points throughout the day, although there was a decrease of 38% every hour (reduction coefficient of −0.381) (Table 3). Maximum contamination levels were reached after only 2 hours. Throughout the day, staff and patient hands were frequently contaminated with the tracer, at times reaching 100%, although the sample size was low (n = 3-4). More than half (59%; 47 of 79) of all fomites and samples tested were positive for the tracer when averaged over all time points, showing that the tracer survived well and readily spread in the environment.

Specific sites, in phase 1, that showed the highest levels of contamination were typically from patient hands or patient surfaces. The top 5 most heavily contaminated sites in the time series experiment (phase 1) included patient door handles, patient hands, staff hands, nurses' station chair arms, and the waiting room survey computer mouse. Concentrations on these surfaces ranged from 1.04 PFUs/cm^2-4.40 PFUs/cm^2.

In phases 2 and 3, samples were collected at the 6-hour time point after contamination. This timing was designed to allow the tracer to spread throughout the facility for at least 2 hours before and after the high-touch point disinfection intervention. MS2 PFU/cm^2 concentrations under each intervention (boxplots) and geometric means across replicates of interventions (diamonds) are shown in Figure 1. Observations in each condition greater than 1.5 times the interquartile range are presented as separate points in the plot. The new intervention product's geometric mean viral count was 94.1% (95% CI, −71.4 to −98.8; $P = .001$) lower than that of the baseline.

In both the baseline (phase 2) and intervention (phase 3), the patient waiting room and the nurses' station were the most contaminated areas. Specific surfaces included the nurses' station chair arms (70.0 PFUs/cm^2; 8.24 ± 18.8 PFUs/cm^2), the waiting room counter (31.0 PFUs/cm^2; 3.12 ± 0.18 PFUs/cm^2), and the patient triage seat arms (63.0 PFUs/cm^2; 2.14 ± 10.1 PFUs/cm^2) for phases 2 and 3, respectively. Virus concentrations decreased on all surfaces after intervention, with the exception of the bathroom door handle and the bathroom faucet. Values for the bathroom door handle and the bathroom faucet before intervention ranged 0.03-21 PFUs/cm^2 and 0.065-0.17 PFUs/cm^2, respectively, whereas postintervention values ranged from 0.48-8.3 × 10^3 PFUs/cm^2 and 0.056-3.0 PFUs/cm^2, respectively.

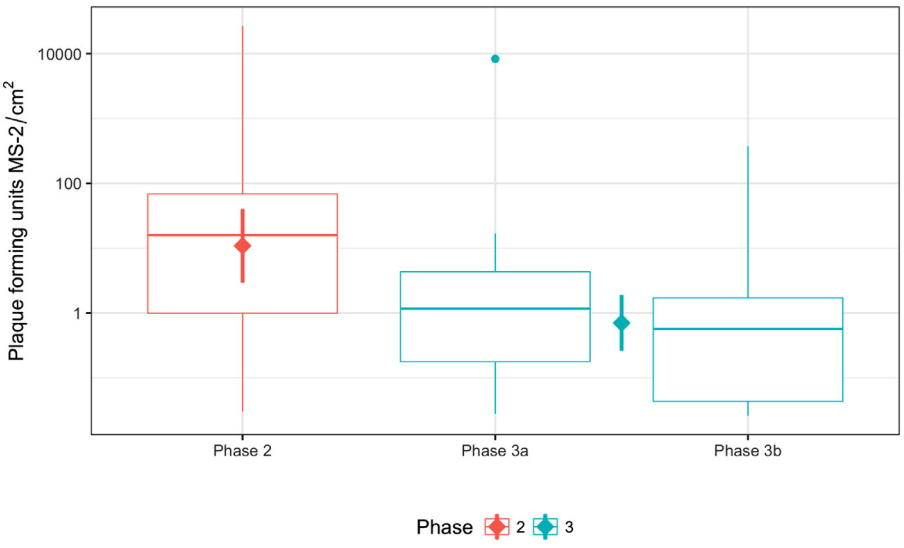

Fig 1. Outpatient clinic tracer concentration before and after disinfectant spray intervention.
Vertical lines represent 95% confidence intervals for the geometric means. Phase 2 refers to the baseline current cleaning practices by site staff, phase 3a refers to the first replicate of the spray disinfectant intervention. Phase 3b refers to the second replicate of the same intervention. Outliers are represented by a single point on the chart.

DISCUSSION

Guidelines for cleaning and disinfection in outpatient facilities are not specific regarding how often to clean and disinfect or what methods should be used to ensure adequate cleaning.[27] Rather, such facilities typically develop their own policies and procedures for routine cleaning and disinfecting of environmental surfaces. Tracer studies help to identify pathogen-spread potentials and demonstrate the involvement of both close patient contact surfaces and other environmental surfaces in infection transmission to support development of evidence-based disinfection guidelines.

The results from phase 1 of this tracer study showed that more than half of surfaces and hands were contaminated in less than 2 hours in an outpatient, urgent care clinic environment. Initial contamination of only 2 high-touch point surfaces (patient sign-in pen and common examination area exit door handle) resulted in spread to hands and fomites in both patient and restricted staff areas. Frequently touched surfaces, such as bathroom faucets, and patient room examination table sides and door handles had higher levels of contamination compared with less frequently touched items, such as canisters storing cotton swabs and other medical supplies in patient rooms. Contamination levels did decrease on sampled fomites and hands over the course of the day. Possible explanations for the decrease are that the tracer continues to be transferred to fomites not included in sampling and is transported out of the facility on the hands of exiting patients, reducing the numbers on the sampled areas. Additionally, the sampling itself at each time point reduces the available virus for transfer. In reality, it is likely that as patients who are ill or colonized with a pathogen visit the facility throughout the day, they will continually shed pathogens and contaminate surfaces.

High-touch point cleaning has been recommended in acute care settings to help prevent the spread of pathogens.[28,29] This approach also can be beneficial in other settings, particularly in outpatient clinics where a high volume of patients is treated. Based on comparisons of tracer PFU concentrations between phase 2 baseline and phase 3 intervention, a 94.1% reduction with a single cleaning event demonstrates the value of high-touch point cleaning in this environment. This single cleaning event was performed with a low ethanol–based disinfectant. Pure ethanol and water solutions require ethanol concentrations between 60% and 90% to be antimicrobial[30] but are fast drying, lack detergent properties, and have reduced material compatibility.[9] The data from this study demonstrate that products formulated with lower ethanol (ie, ≤30%) can be efficacious and used to reduce the spread of microorganisms in outpatient care facilities.

Although reduction of pathogen concentrations in the environment is expected to reduce exposures and risk of infection, information is not currently available to determine whether a 94.1% (<2-log) reduction would have a significant impact on health outcomes in the outpatient clinic environment. Currently, there are no standards for disinfection claims on surfaces in practice. Thus more research is needed to define contamination levels in real-world scenarios and appropriate disinfection targets to achieve specific health goals. Despite this data gap, longer contact times and more frequent use of disinfectants may be beneficial to further reduce pathogen concentrations on environmental surfaces.

This study demonstrated that 4 out of 5 of sites with the highest levels of contamination occurred on entry to the facility during phases 2 and 3 (waiting room mouse and counter; triage chair arms) or immediately after interaction with the patient (nurses' station chair arms). This result warrants a more active approach in disinfection of these areas throughout the day. The increase in contamination of the bathroom surfaces between phases 2 and 3 could be a result of increased hand hygiene and use of the sink influenced by the presence of the study staff during the intervention.

According to the CDC recommendations, patient care areas should be cleaned on a regular basis, after spills, and when surfaces are visibly soiled.[31] In this study, health care staff reported cleaning examination tables and other close-contact patient area surfaces after each patient contact using an EPA-registered disinfectant wipe or spray. Other surfaces were cleaned by environmental service personnel each evening after clinic hours. Although site staff reported frequent cleaning with disinfecting products throughout the day, product weight analysis showed little or no change at the end of the day compared with the beginning of the day, indicating limited product use. Based on the spread of contamination observed in the facility, including high levels in the patient care area, proper disinfection of the patient room between patients should be emphasized.

Many health care interventions and research studies focus on health care personnel hand hygiene compliance and the desire to achieve a target of 90%-100%.[32] In reality, despite extensive education and intervention, a maximum compliance rate of 57%, after interventions, and a mean of 34%, as a routine, are documented.[33] Given the deficiencies in hand hygiene compliance, the known relationship between surface and hand cross-contamination, and the demonstrated link between contaminated surfaces and disease contraction, a more holistic approach to hygiene that includes improvements in surface disinfection is needed to prevent health care-associated infections.[34,35] Further concerns related to the lack of hygiene compliance include the potential presence of the more resilient spore-forming bacteria. CDC guidelines for prevention of *Clostridium difficile*, for example, include the supplemental use of specific EPA-approved, spore-killing disinfectants where patients with *C difficile* are treated. Questions remain regarding the relationship between hygiene compliance and the impact on health care-associated infection rates. Data from this study can be used to inform risk assessment models designed to predict health outcomes and quantitatively assess disinfection targets for meeting infection control goals.

This study emphasizes the importance of a comprehensive approach to hygiene that includes not only frequent hand hygiene but also targeted disinfection of high-touch surfaces and patient care areas to reduce microbial cross-contamination and exposure risks. A single disinfection of targeted surfaces by study staff, 4 hours after clinic opening, was shown to significantly reduce the overall microbial load on hands and environmental surfaces. Thus we recommend that site staff be more intentional about surface disinfection practices throughout the workday. In addition, patient hands were contaminated as often as clinic staff but at higher concentration levels. Therefore promotion of routine hand hygiene among patients should be encouraged, as well as among health care staff, to prevent disease transmission from infected patients to fomites and other staff, patients, and visitors.

Acknowledgments

The authors thank Daniel Troup, MS, for providing assistance with the field study and laboratory sample analysis, and extend a special thanks to the urgent care study site personnel for their cooperation in the study.

References

1. Magill SS, Edwards JR, Bamberg W, Beldavs ZG, Dumyati G, Kainer MA, et al. Multistate point-prevalence survey of health care–associated infections. N Engl J Med 2014;370:1198-208.
2. Weber DJ, Rutala WA, Miller MB, Huslage K, Sickbert-Bennett E. 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:S25-33.
3. Repp KK, Keene WE. A point-source norovirus outbreak caused by exposure to fomites. J Infect Dis 2012;205:1639-41.
4. Hall AJ. Noroviruses: The perfect human pathogens? J Infect Dis 2012;205:1622-4.

5. Otter JA, Donskey C, Yezli S, Douthwaite S, Goldenberg SD, Weber DJ. Transmission of SARS and MERS coronaviruses and influenza virus in health care settings: The possible role of dry surface contamination. J Hosp Infect 2016;92:235-50.
6. Kramer A, Schwebke I, Kampf G. How long do nosocomial pathogens persist on inanimate surfaces? A systematic review. BMC Infect Dis 2006;6:130.
7. Huang SS, Datta R, Platt R. Risk of acquiring antibiotic-resistant bacteria from prior room occupants. Arch Intern Med 2006;166:1945-51.
8. Weber DJ, Anderson D, Rutala WA. The role of the surface environment in health care-associated infections. Curr Opin Infect Dis 2013;26:338-44.
9. Rutala WA, Weber DJ. Selection of the ideal disinfectant. Infect Control Hosp Epidemiol 2014;35:855-65.
10. Schappert SM, Rechtsteiner EA. Ambulatory medical care utilization estimates for 2007. Vital Health Stat 2011;13(169):1-38.
11. Dieleman JL, Baral R, Birger M, Bui AL, Bulchis A, Chapin A, et al. US Spending on personal health care and public health1996-2013. JAMA 2016;316:2627-46.
12. Centers for Medicare & Medicaid Services. National health expenditure data: Historical. https://www.cms.gov/research-statistics-data-and-systems/statistics-trends-and-reports/nationalhealthexpenddata/nationalhealthaccountshistorical.html. Accessed December 11, 2017.
13. Goodman ER, Piatt R, Bass R, Onderdonk AB, Yokoe DS, Huang SS. Impact of an environmental cleaning intervention on the presence of methicillin-resistant *Staphylococcus aureus* and vancomycin-resistant enterococci on surfaces in intensive care unit rooms. Infect Control Hosp Epidemiol 2008;29:593-9.
14. Boyce JM. Environmental contamination makes an important contribution to hospital infection. J Hosp Infect 2007;65(Suppl):50-4.
15. Reynolds KA, Beamer PI, Plotkin KR, Sifuentes LY, Koenig DW, Gerba CP. The healthy workplace project: Reduced viral exposure in an office setting. Arch Environ Occup Health 2016;71:157-62.
16. Beamer PI, Plotkin KR, Gerba CP, Sifuentes LY, Koenig DW, Reynolds KA. Modeling of human viruses on hands and risk of infection in an office workplace using micro-activity data. J Occup Environ Hyg 2015;12:266-75.
17. Grabsch EA, Burrell LJ, Padiglione A, O'Keeffe JM, Ballard S, Grayson ML. Risk of environmental and health care worker contamination with vancomycin-resistant enterococci during outpatient procedures and hemodialysis. Infect Control Hosp Epidemiol 2006;27:287-93.
18. Smith TL, Iwen PC, Olson SB, Rupp ME. Environmental contamination with vancomycin-resistant enterococci in an outpatient setting. Infect Control Hosp Epidemiol 1998;19:515-8.
19. Boone SA, Gerba CP. Significance of fomites in the spread of respiratory and enteric viral disease. Appl Environ Microbiol 2007;73:1687-96.
20. Verhougstraete M, Reynolds K. Use of a portable air disinfecting system to remove seeded coliphage in hospital rooms. Am J Infect Control 2016;44:714-5.
21. Sassi HP, Sifuentes LY, Koenig DW, Nichols E, Clark-Greuel J, Wong LF, et al. Control of the spread of viruses in a long-term care facility using hygiene protocols. Am J Infect Control 2015;43:702-6.
22. Valdez MK, Sexton JD, Lutz EA, Reynolds KA. Spread of infectious microbes during emergency medical response. Am J Infect Control 2015;43:606-11.
23. Dunkin N, Weng S, Schwab KJ, McQuarrie J, Bell K, Jacangelo JG. Comparative inactivation of murine norovirus and MS2 bacteriophage by peracetic acid and monochloramine in municipal secondary wastewater effluent. Environ Sci Technol 2017;51:2972-81.
24. Dawson DJ, Paish A, Staffell LM, Seymour IJ, Appleton H. Survival of viruses on fresh produce, using MS2 as a surrogate for norovirus. J Appl Microbiol 2005;98:203-9.
25. D'Souza DH, Su X. Efficacy of chemical treatments against murine norovirus, feline calicivirus, and MS2 bacteriophage. Foodborne Pathog Dis 2010;7:319-26.
26. Ihaka R, Gentleman R. R: A Language for Data Analysis and Graphics, J Computational Graphical Stat 1996;5:299-314
27. National Center for Emerging and Zoonotic Infectious Diseases, Division of Healthcare Quality Promotion, US Centers for Disease Control and Prevention. Guide to Infection Prevention for Outpatient Settings: Minimum Expectations for Safe Care. Published September 2016. https://www.cdc.gov/infectioncontrol/pdf/outpatient/guide.pdf. Accessed August 4, 2017.
28. Huslage K, Rutala WA, Sickbert-Bennett E, Weber DJ. A quantitative approach to defining "high-touch" surfaces in hospitals. Infect Control Hosp Epidemiol 2010;31:850-3.
29. Hayden MK, Blom DW, Lyle EA, Moore CG, Weinstein RA. Risk of hand or glove contamination after contact with patients colonized with vancomycin-resistant enterococcus or the colonized patients' environment. Infect Control Hosp Epidemiol 2008;29:149-54.
30. Harrington C, Walker H. The germicidal action of alcohol. Boston Med Surg J 1903;148, 548-52.
31. Rutala WA, Weber DJ. HICPAC. CDC Guideline for disinfection and sterilization in health care facilities. https://www.cdc.gov/infectioncontrol/guidelines/disinfection/index.html. Accessed February 27, 2018.
32. Bradley CW, Holden E, Garvey MI. Hand hygiene compliance targets: what are we actually targeting? J Hosp Infect 2017;95:359-60.
33. Kingston L, O'Connell NH, Dunne CP. Hand hygiene-related clinical trials reported since 2010: A systematic review. J Hosp Infect 2016;92:309-20.
34. Weber DJ, Anderson D, Rutala WA. The role of the surface environment in health care-associated infections. Curr Opin Infect Dis 2013;26:338-44.
35. Otter JA, Yezli S, French GL. The role played by contaminated surfaces in the transmission of nosocomial pathogens. Infect Control Hosp Epidemiol 2011;32:687-99.

Journal of Hospital Infection xxx (2011) 1–4

Available online at www.sciencedirect.com

Journal of Hospital Infection

journal homepage: www.elsevierhealth.com/journals/jhin

Presence of biofilm containing viable multiresistant organisms despite terminal cleaning on clinical surfaces in an intensive care unit

K. Vickery [a,*], A. Deva [a], A. Jacombs [a], J. Allan [a], P. Valente [a], I.B. Gosbell [b,c]

[a] Surgical Infection Research Group, Australian School of Advanced Medicine, Macquarie University, New South Wales, Australia
[b] Antibiotic Resistance and Mobile Elements Group (ARMEG), Microbiology and Infectious Diseases Unit, School of Medicine, University of Western Sydney, New South Wales, Australia
[c] Department of Microbiology and Infectious Diseases, Sydney South West Pathology Service – Liverpool, New South Wales, Australia

ARTICLE INFO

Article history:
Received 15 March 2011
Accepted 3 July 2011
by J.A. Child
Available online xxx

Keywords:
Biofilm
Enterococci
Environmental contamination
Healthcare-associated infections
Intensive care unit
Multiresistant organisms
Staphylococcus aureus

SUMMARY

Despite recent attention to surface cleaning and hand hygiene programmes, multiresistant organisms (MROs) continue to be isolated from the hospital environment. We hypothesize that reservoirs of MROs exist in the environment as biofilms (bacteria embedded in exopolymeric substances, EPS). Biofilms are difficult to remove due to their increased resistance to detergents and disinfectants. These biofilms periodically release free-swimming planktonic bacteria back into the environment which then may act as an infection source. Following terminal cleaning, equipment and furnishings were removed aseptically from an intensive care unit (ICU) and subjected to culture and scanning electron microscopy (SEM). Samples were placed in 5 mL of tryptone soya broth, sonicated for 5 min before plate culture on horse blood agar, Brillance MRSA and Brilliance VRE agar plates. Samples for SEM (mattress, sterile supply reagent bucket, opaque plastic door, venetian blind cord, sink rubber, curtain) were fixed in 3% glutaraldehyde and hexamethyldisilizane (HMDS) prior to sputter-coating with gold and examination in an electron microscope. Biofilm was demonstrated visually on the sterile supply bucket, the opaque plastic door, the venetian blind cord, and the sink rubber, whereas EPS alone was seen on the curtain. Viable bacteria were grown from three samples, including MRSA from the venetian blind cord and the curtain. We have demonstrated the presence of biofilm and biofilm containing MROs on clinical surfaces from an ICU despite terminal cleaning, suggesting that current cleaning practices are inadequate to control biofilm development. The presence of MROs being protected within these biofilms may be the mechanism by which MROs persist within the hospital environment.

Introduction

Healthcare-associated infections (HAIs) are a widespread problem, affecting 5–10% of all patients.[1] In the intensive care unit (ICU), the presence of very sick, elderly and immunocompromised patients results in a disproportionate percentage (20%) of patients developing HAI.[2] This problem is compounded by the spread of multiresistant organisms (MROs), making treatment difficult or ineffective.[3] HAIs add considerable morbidity, increase hospital stay times, increase mortality, and add costs to patient care.[1,2,4]

Contamination of the inanimate environment around patients constitutes an important reservoir of MRO with the risk of HAI increased by an average of 73% if the patient previously occupying the room had MRSA, vancomycin-resistant enterococcus (VRE), acinetobacter, *Clostridium difficile* or other pathogens.[3,5,6] Numerous studies have shown persistence of these organisms in the environment even in the face of enhanced terminal cleaning.[7–9]

Biofilms are generally found in moist environments, causing infection on implantable medical devices such as catheters and breast implants or on instruments routinely immersed in fluid.[10–12] We hypothesize that, despite the decreased moisture availability on dry surfaces, bacteria within the ICU environment also reside in

* Corresponding author. Address: Australian School of Advanced Medicine, Macquarie University, North Ryde, NSW 2109, Australia. Tel.: +61 2 9812 3559; fax: +61 2 9812 3610.
E-mail address: Karen.vickery@mq.edu.au (K. Vickery).

0195-6701/$ – see front matter © 2011 The Healthcare Infection Society. Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.jhin.2011.07.007

biofilms, and that within these biofilms, MROs are protected from physical removal and chemical disinfection.

A biofilm is a structured community of organisms encased and attached to a surface by exopolymeric substances (EPS). The EPS makes up to 90% of the biofilm providing protection from environmental desiccation and this EPS is extremely difficult to remove using detergents.[13–15] Additionally, bacteria within biofilms are up to 1500 times (typically 100–250 times) more resistant to biocides than the same 'planktonic' bacteria growing in liquid culture.[13] These properties of biofilms result in decreased efficacy of cleaning and disinfection, thereby promoting the persistence of bacteria, including MROs, in the environment.

In this study we investigated whether biofilms can be found on furnishings in the ICU.

Methods

Following terminal cleaning in a 16-bed ICU, i.e initial cleaning with neutral detergent, followed by disinfection with 500 ppm chlorine (Diversol5000, Johnson Diversey, Smithfield, Australia), equipment and furnishings were aseptically removed from patient and common-use areas.

Sample collection

Items were destructively sampled using sterile gloves, forceps, pliers, scissors, or scalpel blades, depending on the material being sampled. Gloves and instruments were changed between each sample. Samples were then placed into sterile containers for transport to the laboratory. Small items, such as a sterile supply reagent box, were transported intact to the laboratory; larger items, such as the mattress and door, had sections removed (up to 8×10 cm in size) into sterile containers. Following transport to the laboratory, these large pieces were further sectioned into smaller pieces, using a sterile technique.

Scanning electron microscopy (SEM)

Samples up to 1 cm^2 were fixed in 3% glutaraldehyde, dehydrated through ethanol, immersed in hexamethyldisilizane (HMDS; Polysciences Inc., Warrington, PA, USA) for 3 min before sputter-coating with 20 nm gold film and examined in an SEM microscope as previously described.[12] An item was classified as being biofilm positive if bacteria attached to a surface and surrounded by EPS could be visualized.

Microbiology

Sections of equipment or furnishings up to 2 cm^2 were placed in 4 mL of tryptone soya broth, sonicated for 5 min and 100 μL spread over horse blood agar plates (HBA), Brilliance MRSA agar plates for the detection of multiresistant *Staphylococcus aureus* (MRSA) and Brillance VRE agar plates for the detection of vancomycin-resistant enterococcus (Oxoid, Adelaide, Australia). MRSA plates were incubated for 18–24 h and VRE and HBA plates up to 48 h.

Results

Six samples were examined by SEM (Table I). We failed to demonstrate biofilm on only one sample. Four samples had principally coccoid-shaped bacteria encased in large amounts of EPS and the sample from the curtain had 'strings' of dehydrated EPS evident. (Figure 1).

Bacteria grew on HBA from four of the six samples, demonstrating the presence of culturable organisms. The venetian blind cord and curtain, positive for biofilm by SEM, also grew MRSA. The mattress grew MRSA and *E. faecium* but we were unable to demonstrate biofilm visually on this sample (Table I). Two samples positive for biofilm were culture negative, using the procedure described above.

Table I
Scanning electron microscopy (SEM) and culture results for environmental surfaces

Sample	SEM	Culture plates		
		HBA	MRSA	VRE
Curtain	Positive EPS	Growth	Positive	Negative
Venetian blind cord	Positive biofilm	Growth	Positive	Negative
Mattress bay	Negative	Growth	Positive	*E. faecium*
See-through plastic door	Positive biofilm	Negative	Negative	Negative
Wash basin rubber	Positive biofilm	Negative	Negative	Negative
Sterile supply reagent bucket	Positive biofilm	Growth	Negative	Negative

HBA, horse blood agar; MRSA, multiresistant *Staphylococcus aureus*; VRE, vancomycin-resistant enterococcus.

Discussion

Many studies have shown that contamination of the environment makes an important contribution to HAI and that enhanced cleaning protocols reduce environmental contamination, which translates into decreased incidence of HAI.[5,6] In Dancer *et al.*'s study, the addition of one extra member of cleaning staff, five days a week, resulted in a 32.5% reduction in microbial contamination of hand-touch sites and a 26.6% reduction in new MRSA infections, saving the hospital an estimated £30,000 to £70,000.[7] Termination of the extra cleaner resulted in new clusters of MRSA infection within two to four weeks. However, even with enhanced cleaning, MROs can still be isolated from the environment.[7–9]

We hypothesize that surface condensation occurs, producing a thin film of water, or that the relative humidity in the ICU is high enough to allow biofilms to develop on ICU surfaces. Once formed, the EPS would protect the bacteria from desiccation and make them harder to remove.

We further hypothesize that MROs persist in the environment, in the face of enhanced cleaning, as biofilms. Although detergents are good at removing patient soil and planktonic bacteria, they are less effective at removing biofilm, rendering current cleaning protocols less efficient.[14,15] In industry, extreme measures including physical scraping and use of concentrated biocides are often required to remove biofilm, such as when removing legionella from water-cooling towers.

Of the six furnishings sampled bacteria were demonstrated to be embedded in EPS on four samples and residual EPS on one, whereas only the mattress sample was negative for biofilm by SEM. SEM of the non-porous covering of the hospital mattress shows that the surface is not completely level but has many microscopic dips. This is similar to the dips and imperfections that have been observed on new Teflon endoscope tubing.[12] With use, many of these dips or imperfections in endoscope tubing became contaminated with biofilm.[12] A similar situation may exist with the hospital mattresses and, if a larger area were to be inspected, biofilm may be found.

Using destructive sampling followed by sonication and broth culture, bacteria were grown from three of these biofilm-positive samples. Both the venetian blind curtain cord and the curtain grew MRSA. Even the mattress, the sole sample for which we failed to visually demonstrate biofilm, grew MRSA and VRE. It is worrying that we demonstrated biofilm on the reagent bucket that was used to contain sterile supplies, such as catheters and bandages. Although we did not detect MRSA or VRE, we were able to show

Please cite this article in press as: Vickery K, et al., Presence of biofilm containing viable multiresistant organisms despite terminal cleaning on clinical surfaces in an intensive care unit, Journal of Hospital Infection (2011), doi:10.1016/j.jhin.2011.07.007

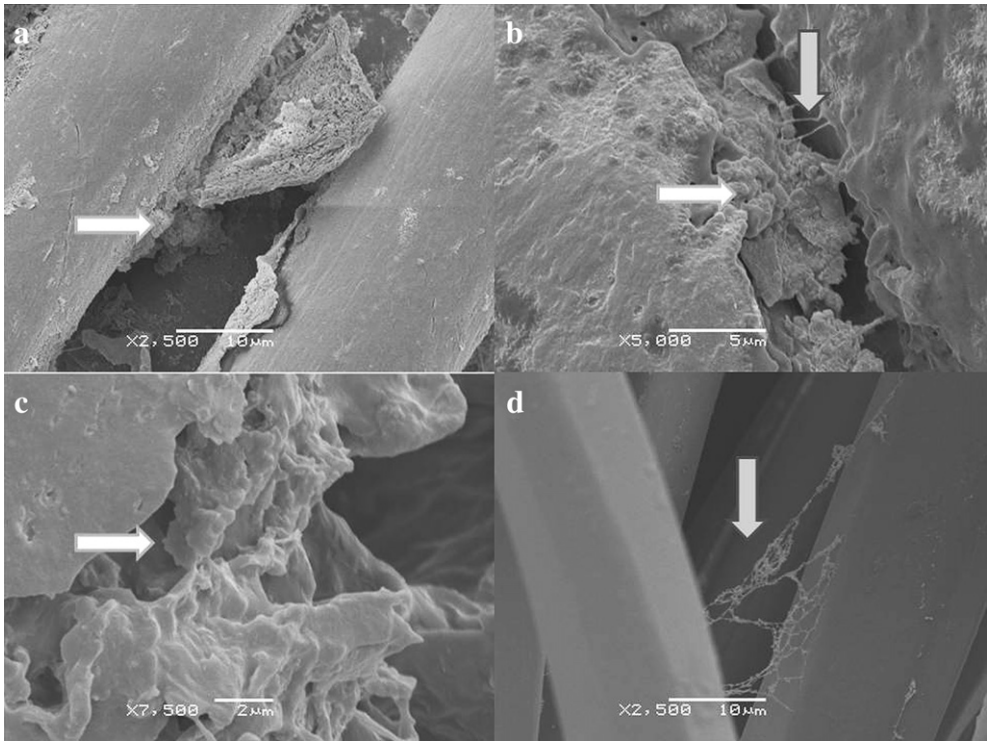

Figure 1. Scanning electron micrographs of: (a) blind cord (original magnification ×2500); (b) see-through ward door (original magnification ×5000); (c) red reagent box (original magnification ×7500); (d) curtain (original magnification ×2500). Horizontal arrows indicate coccoid bacteria embedded in exopolymeric substance (EPS). Vertical arrows indicate residual strings of EPS dehydrated during processing.

that viable bacteria were present in the biofilm. Additionally the rate of acquisition of new resistant determinants is increased in bacteria residing in biofilm.[16] A significant correlation has been shown to exist between class 1 integron resistance genes, biocide resistance and biofilm formation in clinical strains of *Acinetobacter baumannii*.[17] Whether this occurs when water is limited is unknown.

Despite visual confirmation of biofilm, neither the wash basin nor the plastic door grew bacteria when aerobic culture and HBA were used. These bacteria could have been dead, or not culturable using the conditions used, or unculturable due to their state of growth in the biofilm. Bacteria growing as biofilm are notoriously difficult to culture, although sonication of the sample in broth increases the rate of recovery.[13]

Dancer *et al.* found that antibiotic-resistant environmental bacteria were more prevalent in wards with a high level of antibiotic prescribing.[18] The combination of high antibiotic use and environmental biofilms in the ICU may be the mechanism whereby increased genetic exchange occurs between bacteria residing in biofilms, leading to persistence of antibiotic-resistant environmental bacteria, despite enhanced cleaning.

Using destructive sampling, followed by SEM and culture, we have demonstrated the presence of biofilm and biofilm containing MROs on clinical surfaces from an ICU despite terminal cleaning, suggesting that current cleaning practices are inadequate to control biofilm development. The presence of MROs being protected within these biofilms may be the mechanism by which MROs persist within the hospital environment.

Acknowledgements

The authors would like to acknowledge the scientific staff of Sydney South West Pathology Service – Liverpool, who supplied the chromogenic agar plates.

Conflict of interest statements
None declared.

Funding sources
None.

References

1. Sanchez-Velazquez LD, Ponce de Leon Rosales S, Rangel Frausto MS. The burden of nosocomial infection in the intensive care unit: effects on organ failure, mortality and costs. A nested case–control study. *Arch Med Res* 2006; **37**:370–375.
2. Rosenthal VD, Maki DG, Mehta A, *et al.* International Nosocomial Infection Control Consortium report, data summary for 2002–2007, issued January 2008. *Am J Infect Control* 2008;**36**:627–637.
3. Dancer SJ. Importance of the environment in meticillin-resistant *Staphylococcus aureus* acquisition: the case for hospital cleaning. *Lancet Infect Dis* 2008; **8**:101–113.
4. Shannon RP, Patel B, Cummins D, Shannon AH, Ganguli G, Lu Y. Economics of central line-associated bloodstream infections. *Am J Med Qual* 2006; **21**(6 Suppl.). 7S–16S.
5. Boyce JM. Environmental contamination makes an important contribution to hospital infection. *J Hosp Infect* 2007;**65**(Suppl. 2):50–54.
6. 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**(5 Suppl. 1). S41–50.
7. Dancer SJ, White LF, Lamb J, Girvan EK, Robertson C. Measuring the effect of enhanced cleaning in a UK hospital: a prospective cross-over study. *BMC Medicine* 2009;**7**:28.
8. Hota B, Blom DW, Lyle EA, Weinstein RA, Hayden MK. Interventional evaluation of environmental contamination by vancomycin-resistant enterococci: failure of personnel, product, or procedure? *J Hosp Infect* 2009;**71**:123–131.
9. Hayden MK, Bonten MJM, Blom DW, Lyle EA, van de Vijver DAMC, Weinstein RA. Reduction in acquisition of vancomycin-resistant enterococcus after enforcement of routine environmental cleaning measures. *Clin Infect Dis* 2006;**42**:1552–1560.
10. Bryers JD. Medical biofilms. *Biotechnol Bioengng* 2008;**100**:1–18.
11. Pajkos A, Deva AK, Vickery K, Cope C, Chang L, Cossart YE. Detection of subclinical infection in significant breast implant capsules. *Plast Reconstr Surg* 2003;**111**:1605–1611.

Please cite this article in press as: Vickery K, et al., Presence of biofilm containing viable multiresistant organisms despite terminal cleaning on clinical surfaces in an intensive care unit, Journal of Hospital Infection (2011), doi:10.1016/j.jhin.2011.07.007

12. Pajkos A, Vickery K, Cossart Y. Is biofilm accumulation on endoscope tubing a contributor to the failure of cleaning and decontamination? *J Hosp Infect* 2004;**58**:224–229.
13. Fux CA, Costerton JW, Stewart PS, Stoodley P. Survival strategies of infectious biofilms. *Trends Microbiol* 2005;**13**:34–40.
14. Vickery K, Pajkos A, Cossart Y. Removal of biofilm from endoscopes: evaluation of detergent efficiency. *Am J Infect Control* 2004;**32**:170–176.
15. Hadi R, Vickery K, Deva A, Charlton T. Biofilm removal by medical device cleaners: comparison of two bioreactor detection assays. *J Hosp Infect* 2010;**74**:160–167.
16. Gillings MR, Holley MP, Stokes HW. Evidence for dynamic exchange of qac gene cassettes between class 1 integrons and other integrons in freshwater biofilms. *FEMS Microbiol Lett* 2009;**296**:282–288.
17. Rajamohan G, Srinivasan VB, Gebreyes WA. Biocide-tolerant multidrug-resistant *Acinetobacter baumannii* clinical strains are associated with higher biofilm formation. *J Hosp Infect* 2009;**73**:287–289.
18. Dancer SJ, Coyne M, Robertson C, Thomson A, Guleri A, Alcock S. Antibiotic use is associated with resistance of environmental organisms in a teaching hospital. *J Hosp Infect* 2006;**62**:200–206.

Please cite this article in press as: Vickery K, et al., Presence of biofilm containing viable multiresistant organisms despite terminal cleaning on clinical surfaces in an intensive care unit, Journal of Hospital Infection (2011), doi:10.1016/j.jhin.2011.07.007