An environmental cleaning bundle and health-care-associated infections in hospitals (REACH): a multicentre, randomised trial

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Summary

Background The hospital environment is a reservoir for the transmission of microorganisms. The effect of improved cleaning on patient-centred outcomes remains unclear. We aimed to evaluate the effectiveness of an environmental cleaning bundle to reduce health care-associated infections in hospitals.

Methods The REACH study was a pragmatic, multicentre, randomised trial done in 11 acute care hospitals in Australia. Eligible hospitals had an intensive care unit, were classified by the National Health Performance Authority as a major hospital (public hospitals) or having more than 200 inpatient beds (private hospitals), and had a health-care-associated infection surveillance programme. The stepped-wedge design meant intervention periods varied from 20 weeks to 50 weeks. We introduced the REACH cleaning bundle, a multimodal intervention, focusing on optimising product use, technique, staff training, auditing with feedback, and communication, for routine cleaning. The primary outcomes were incidences of health-care-associated *Staphylococcus aureus* bacteraemia, *Clostridium difficile* infection, and vancomycin-resistant enterococci infection. The secondary outcome was the thoroughness of cleaning of frequent touch points, assessed by a fluorescent marking gel. This study is registered with the Australian and New Zealand Clinical Trial Registry, number ACTRN12615000325505.

Findings Between May 9, 2016, and July 30, 2017, we implemented the cleaning bundle in 11 hospitals. In the pre-intervention phase, there were 230 cases of vancomycin-resistant enterococci infection, 362 of *S aureus* bacteraemia, and 968 *C difficile* infections, for 3 534 439 occupied bed-days. During intervention, there were 50 cases of vancomycin-resistant enterococci infection, 109 of *S aureus* bacteraemia, and 278 *C difficile* infections, for 1 267 134 occupied bed-days. After the intervention, vancomycin-resistant enterococci infections reduced from 0·35 to 0·22 per 10 000 occupied bed-days (relative risk 0·63, 95% CI 0·41–0·97, p=0·0340). The incidences of *S aureus* bacteraemia (0·97 to 0·80 per 10 000 occupied bed-days; 0·82, 0·60–1·12, p=0·2180) and *C difficile* infections (2·34 to 2·52 per 10 000 occupied bed-days; 1·07, 0·88–1·30, p=0·4655) did not change significantly. The intervention increased the percentage of frequent touch points cleaned in bathrooms from 55% to 76% (odds ratio 2·07, 1·83–2·34, p<0·0001) and bedrooms from 64% to 86% (1·87, 1·68–2·09, p<0·0001).

Interpretation The REACH cleaning bundle was successful at improving cleaning thoroughness and showed great promise in reducing vancomycin-resistant enterococci infections. Our work will inform hospital cleaning policy and practice, highlighting the value of investment in both routine and discharge cleaning practice.

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Introduction

Health-care-associated infections prolong length of stay in hospital, increase risk of mortality, and are a substantial burden on health-care services and populations.[1] Antimicrobial resistance is intensifying this problem and effective evidence-based prevention programmes are needed to reduce the risk of health-care-associated infections.[2]

The hospital environment is a reservoir for the transmission of microorganisms that can lead to infection.[3] Some microorganisms can survive in hospital for several months, posing an ongoing transmission risk unless removed by cleaning.[3] Hospital surfaces that are frequently touched, such as bed rails and call bells, act as reservoirs and present the largest risk of contamination because pathogens can be spread via hands.[4] Previous studies[5] have focused on improving the cleaning of frequent touch points. Evidence also suggests that patients admitted to a room that was previously occupied by another patient with a multidrug-resistant organism are at increased risk of subsequent colonisation and infection with that organism.[6] This finding suggests that current cleaning practices fail to reduce the risk of acquisition and highlights the critical role of hospital cleaning, also known as environmental hygiene, in infection prevention and control.

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Research in context

Evidence before this study

The hospital environment is a reservoir for the transmission of microorganisms, some of which can survive in hospitals for several months posing an ongoing transmission risk. We searched MEDLINE, Cochrane, and CINAHL for English language peer-reviewed articles published between Jan 1, 1984, and Dec 1, 2014. We selected studies that examined exposure or acquisition in a hospitalised population where the previous occupant of the room was colonised or infected with a specific organism. Our systematic review identified evidence that admission to a room previously occupied by a carrier of bacteria is a risk factor for subsequent acquisition. The findings suggest that existing environmental cleaning practices in hospitals do not reduce the risk of acquisition. Han and colleagues have also done a systematic review to explore existing methods of cleaning, disinfecting, and monitoring cleanliness of patient rooms, and contextual factors that might affect implementation and effectiveness. They found there were no randomised multicentred trials exploring the efficacy of improved routine and discharge cleaning on infection. The authors concluded that future studies should be real-world interventions for reducing the risk of health-care-associated infections, and should assess the role of frequently touched objects and the effect of cleaning on patient-centred outcomes. A randomised control study by Anderson and colleagues showed the value of ultraviolet light, with a focus on discharged cleaning only.

Added value of this study

To our knowledge, this is the first randomised, multicentre clinical trial to evaluate the effect on the incidence of health-care-associated infections of a cleaning bundle that focuses on routine and discharge hospital cleaning. The intervention does not require new technology, but prioritises evidence from previous studies on the basis of feasibility and cost of implementation, using an implementation science framework to guide application. This bundle has the potential to be implemented into various hospital settings.

Implications of all the available evidence

The findings from our real-world, pragmatic study suggest that improving hospital cleaning requires a multimodal, tailored approach that considers the local setting. By using a bundle approach to improve routine and discharge cleaning, improved cleaning performance and a reduction in the number of vancomycin-resistant enterococci infections is possible. Since vancomycin-resistant enterococcus is a useful surrogate for other bacteria, there are potential benefits of a tailored cleaning bundle for other pathogens that survive in the environment. However, we found no effect of the cleaning bundle on *Staphylococcus aureus* bacteraemia and *Clostridium difficile*.

To date, studies to evaluate hospital cleaning and infection transmission have been largely quasi-experimental or single-centre,[7] with the exception of one trial[8] that showed a decrease in patients' acquisition of vancomycin-resistant enterococci after enhanced terminal room cleaning and disinfection. More studies on the effect of improved routine cleaning are needed. The Researching Effective Approaches to Cleaning in Hospitals (REACH) study aimed to use a rigorous and pragmatic approach[9,10] to evaluate the effectiveness of an environmental cleaning bundle in reducing health-care-associated infections in hospitals.[11]

Methods

Study design and participants

The REACH study was a multicentre, stepped-wedge, randomised trial of an environmental cleaning bundle implemented in 11 Australian hospitals. Our pragmatic study design was assessed against the PRagmatic-Explanatory Continuum Indicator tool (appendix).[9] Inclusion criteria were having an accredited intensive care unit, classification by the National Health Performance Authority as a major hospital (public hospital) or having more than 200 inpatient beds (private hospital), and having an established health-care-associated infection surveillance programme. We approached eligible hospitals to optimise the feasibility and practicality of completing the trial, and to ensure our findings were generalisable by including a sample of publicly funded and privately funded hospitals from at least four of the eight Australian states and territories. Full details of recruitment are given in the appendix.

See Online for appendix

This project received human research ethics approval from the Uniting Care Health Human Research Ethics Committee and the Queensland University of Technology Human Research Ethics Committee. Local ethics and site-specific governance approvals were obtained for all participating hospitals. Individual consent was not required for this study. The study protocol has been published.[11]

Randomisation and masking

The stepped-wedge design minimises bias by randomly allocating the timing of the intervention, which means that hospitals also received varying intervention durations (20–50 weeks). Once all 11 hospitals were enrolled, the study statistician (AGB) used Microsoft Excel to randomly allocate hospitals to a starting time, corresponding to codes A to K. The cleaning bundle was a hospital-wide intervention that included training, audit, and feedback to staff. Therefore, environmental cleaning staff could not be masked to the intervention. The statisticians were aware of the timing of the intervention to enable analysis. Patients were not aware of the intervention.

Procedures

The intervention, the introduction of the REACH environmental cleaning bundle, was created via a review of peer-reviewed publications and guidelines, prioritisation of evidence by an expert panel (with a focus on interventions that were easy to implement and low cost), and successful pilot-testing at a large Australian hospital.[11,12]

The REACH bundle makes recommendations on optimal types of cleaning agents, frequency of cleaning, cleaning techniques, auditing strategies, environmental cleaning staff training, and creating a hospital-wide commitment to improved cleaning (appendix). The cleaning bundle was used for routine cleaning of all wards in participating hospitals, but was not used for outbreak situations or periodical maintenance cleaning.

Hospitals were informed of their start date and intervention timings 8 weeks before the control phase. After site preparation and scheduling, context assessments started during the 4-week establishment period. The REACH training facilitator delivered training activities to environmental services staff with a role in ward cleaning in week 1 to 2 of the intervention phase. Core training content included cleaning roles and responsibilities, components of the cleaning bundle, and effect of environmental cleaning on health-care-associated infections. The cleaning technique included a defined and consistent cleaning sequence, daily cleaning of the high-risk frequent touch points, use of sufficient pressure and movement, and adherence to manufacturers' instructions for product use (ie, dilutions and contact time). Tailored training activities and content reflected the context of the respective hospitals, including existing cleaning products and schedules. Further details on the extent of training and changes in knowledge have been published.[13]

Communication was a key strategy to sustaining a hospital-wide commitment to improved cleaning and bundle components. Hospital-wide promotional activities were used to raise the profile and importance of cleaning in reducing infections and to support a culture shift in environmental services staff. Daily contact between cleaning staff and ward leaders or managers was encouraged, with cleaning staff representation on relevant clinical governance committees.

Trained site team members audited cleaning using DAZO UV (Ecolab, St Paul, MN, USA) fluorescent marker technology, which involves gel dots applied to surfaces. The dots are invisible to the naked eye, resist dry abrasion, and are removed completely by routine cleaning.[5] In each hospital, at least 50% of the wards and the intensive care unit were selected for data collection. Wards that presented the highest risk for transmission of infection and had existing auditing processes (such as hand hygiene compliance) were selected for auditing by the hospital in collaboration with the study team. One participating hospital had more than one intensive care unit. In this instance, one unit was chosen at random for auditing. The study team trained a local site team in the gel dot sampling method and provided a hard copy randomised monthly schedule, generated using Microsoft Excel, of nominated patient cubicles or bathrooms in selected wards that were to be audited. Frequent touch points represent the largest risk of contamination by pathogens and thus potential transmission.[14] Dots were applied by the site team to various nominated frequent touch points (range, nine to 16 points) in two bedrooms and bathrooms, as per the schedule, consistent with the US Centers for Disease Prevention and Control Environmental Cleaning Checklist and previous literature.[5] Cleaning staff were not aware of the exact placement of the dots. Touch points that were typically cleaned only by clinical staff—predominantly equipment—were excluded, because clinical staff were not the focus of the cleaning bundle. After cleaning was completed or 24 h after the gel dots were applied, the sites were checked by the site team using an ultraviolet light torch to determine whether the dot had been completely removed. Audit results were reported to individual staff at the time of audit; hospital-level results were reported monthly to cleaning staff, with additional reports provided to clinical governance committees.

We used several strategies to monitor cleaning bundle implementation, infection prevention, and control programme changes and outbreaks or other issues at each hospital during the trial period. A key strategy was regular email and telephone contact, at least monthly, between the study and site team. The study team also requested that a monitoring document be completed by the site team every 2 months to systematically capture changes in any aspect of the infection prevention programme, including screening and staffing changes, outbreaks, and the fidelity of the bundle implementation.

Outcomes

The primary outcomes were incidence rates of health-care-associated infections: *Staphylococcus aureus* bacteraemia (meticillin-resistant and meticillin-sensitive), *Clostridium difficile* infection, and vancomycin-resistant enterococci infections (sterile sites only), at each hospital, per 10 000 occupied bed-days, and the cost-effectiveness of a decision to adopt the environmental cleaning bundle. The cost-effectiveness outcome will be reported separately. For the calculation of health-care-associated infections, pre-intervention data refers to combined data from the historical, establishment, and control phases and first 4 weeks of implementation. Post-intervention data were collected from 4 weeks after the start of intervention to allow for a delay in the intervention effect. Standardised infection definitions were applied.[11]

Colonisation with these organisms was not assessed; all outcomes were clinical infections. Subsequent infections in the same patient were excluded, consistent with national and international definitions.[15,16] Infections with multiple-resistant Gram-negative bacilli were not

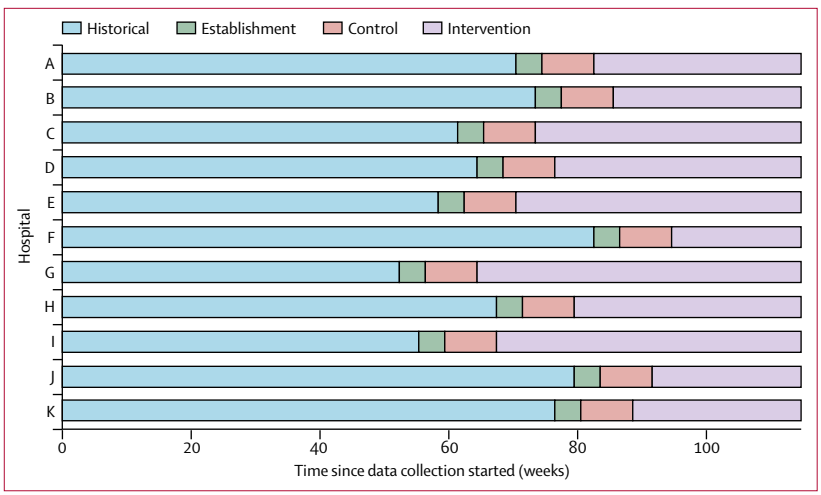

Figure 1: **Trial design**
There was a 4-week establishment period and an 8-week control period for baseline data collection of cleaning audits, context assessment, and staff surveys.

included in the primary outcomes; these organisms are not endemic in any Australian hospital.

The secondary outcome was thoroughness of hospital cleaning, measured by the DAZO Fluorescent Marking Gel and Ultraviolet Light System. Data collection of cleaning audits occurred during the control and intervention period. The outcome was the probability that a dot was completely removed.

Other prespecified outcomes were the bio-burden of frequent touch points after cleaning, changes in staff knowledge and attitudes around environmental cleaning, changes in rates of screening and clinical isolates, and changes in patients' perception of hospital cleanliness. These will be reported in future studies, with the exception of changes in staff knowledge and attitude, which has already been reported.[13]

Statistical analysis

To calculate power, we used the stepped-wedge sample size formula from Hussey and Hughes,[17] informed by a dataset of more than 2 million admissions to hospital and infection data from nine Australian hospitals.[18] Owing to conflicting evidence on the size of the effect expected from improving cleaning on different infection types, we decided to use a combined infection rate, rather than three separate power calculations for each infection type. 11 hospitals with a pre-intervention infection rate (a combination of *S aureus* bacteraemia, *C difficile* infection, and vancomycin-resistant enterococci infection) of five per 10 000 patient days gave 86% power to detect a 20% post-intervention reduction in infection risk. This power was based on a 5% two-sided significance level, a within-hospital correlation in infection rates of 0·3, and pre-determined intervention timings.

We analysed data in R (version 3.4.3), using package lme4. Further details are provided in the appendix. For both primary and secondary outcomes, model comparison was done using Akaike's information criterion.

For the primary outcome, Poisson generalised linear mixed models were fitted to weekly confirmed cases of *S aureus* bacteraemia, *C difficile* infection, and vancomycin-resistant enterococcus infection. To standardise rates, weekly numbers of occupied bed-days by hospital divided by 10 000 were included as a model offset. There is a standard method for the collection of bed-day data in Australian hospitals. Models had a random intercept for each hospital to control for baseline differences between hospitals, a linear fixed effect to control for unrelated changes over time, and a binary independent variable for the intervention that switched from "no" to "yes" 4 weeks after the intervention started to allow for a delay in the intervention effect. To summarise overall effectiveness of the cleaning bundle, intervention effects on the three infections were combined, using meta-analysis to produce a combined estimate and corresponding 95% CI.[11] We summarised uncertainty in model-based predictions over time using 95% prediction intervals (PIs) obtained from bootstrapping.

We did sensitivity analyses to determine the possibility of a delayed intervention effect of longer than 4 weeks, the influence of each individual hospital, and the effect of the intervention on *S aureus* bacteraemia classes (meticillin-resistant and meticillin-susceptible strains of *S aureus*). The delayed intervention effect modelled was 8 weeks after each hospital's intervention start date. The influences of each hospital were examined using a leave-one-hospital-out analysis examining changes to the intervention effect and Cook's distances. We also examined models fitted separately to meticillin-resistant and meticillin-susceptible *S aureus* bacteraemia.

For the secondary outcome, we analysed data from monthly cleaning audits using a binomial generalised linear mixed model with a logit link function on the proportion of frequent touch points that were deemed cleaned. A random intercept was included for each hospital and the room (bathroom or bedroom) was included as an independent variable. Three specifications of the intervention effect were tested: a binary intervention effect, to model an instant improvement in cleaning; a linear intervention effect, defined as weeks after each hospital's intervention start date, to model a more gradual improvement over time; and a combined binary–linear intervention effect. For each model specification, we tested whether the change in cleaning performance was the same for bathroom versus bedroom frequent touch points. This was modelled by including two-way interaction terms between room and the binary or linear intervention effects.

Consistent with recent debate when discussing outcomes, we focused on the effect of the intervention, plausibility of mechanism, study design, data quality, and real-world benefits, rather than p values in isolation.[19]

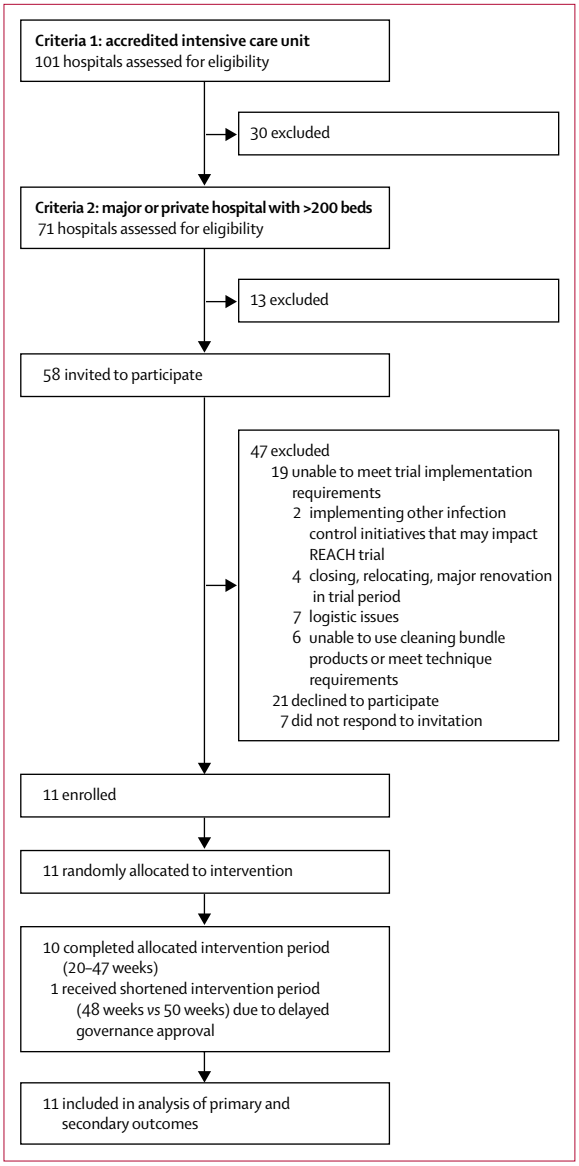

Figure 2: **Trial profile**

	Pre-intervention	Post-intervention
Infection		
Clostridium difficile infections		
n	968	278
Unadjusted rate per 10 000 OBDs	2·74	2·19
Variance (SE)	0·008 (0·088)	0·017 (0·132)
Staphylococcus aureus bacteraemia		
n	362	109
Unadjusted rate per 10 000 OBDs	1·02	0·86
Variance (SE)	0·003 (0·054)	0·007 (0·082)
Meticillin-susceptible *S aureus* bacteraemia		
n	296	87
Unadjusted rate per 10 000 OBDs	0·84	0·69
Variance (SE)	0·002 (0·049)	0·005 (0·074)
Meticillin-resistant *S aureus* bacteraemia		
n	66	22
Unadjusted rate per 10 000 OBDs	0·19	0·17
Variance (SE)	0·001 (0·023)	0·001 (0·037)
Vancomycin-resistant enterococcus clinical isolates		
n	230	50
Unadjusted rate per 10 000 OBDs	0·65	0·39
Variance (SE)	0·002 (0·043)	0·003 (0·056)
Total OBDs	3 534 439	1 267 134

Unadjusted rates do not account for baseline variation between hospitals or time trends. Pre-intervention includes historical, establishment, and control phases and the first 4 weeks of the intervention phase. Intervention includes from week 5 of the intervention phase until the end of the trial. OBDs=occupied bed-days.

Table 1: **Crude rates of health care-associated infections**

This study is registered with the Australian and New Zealand Clinical Trial Registry, number ACTRN12615000325505.

Role of the funding source

The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

Between May 9, 2016, and July 30, 2017, we implemented the cleaning bundle in 11 hospitals, covering six of the eight states and territories in Australia (figure 1). Nine hospitals were public and two were private (figure 2). The median number of overnight beds was 500 (IQR 351–804). In the pre-intervention phase there were 230 cases of vancomycin-resistant enterococci infection, 362 of *S aureus* bacteraemia, and 968 *C difficile* infections, for 3 534 439 occupied bed-days (table 1). Higher adjusted baseline rates were seen for *C difficile* infection (2·34 per 10 000 occupied bed-days, 95% CI 1·55–3·55) than for *S aureus* bacteraemia (0·97, 0·76–1·24) and vancomycin-resistant enterococcus infection (0·35, 0·14–0·87). 1729 different staff members cleaned 190 wards across the 11 hospitals. Further analysis of variation of cleaning practices, governance, and staff at baseline have been published.[20] Of the hospitals that were invited to participate but did not take part, the reasons for exclusion are provided in figure 2. For excluded hospitals, we examined *S aureus* bacteraemia rates, from eight hospitals for which data were publicly available for 2015–16. No difference in *S aureus* bacteraemia was found between these hospitals and the pre-intervention *S aureus* bacteraemia rates for hospitals included in our study (appendix).

	Estimate (95% CI)	p value
No intervention		
Clostridium difficile infections	−28·8 (−45·9 to −6·4)	0·0163
Staphylococcus aureus bacteraemia*	5·1 (−33·0 to 65·0)	0·8280
Vancomycin-resistant enterococcus clinical isolates	−15·6 (−53·1 to 51·9)	0·5653
With intervention		
Clostridium difficile infections	7·3 (−11·8 to 30·5)	0·4655
S aureus bacteraemia*	−18·1 (−40·2 to 12·0)	0·2180
Vancomycin-resistant enterococcus	−36·9 (−59·0 to −2·8)	0·0340
All infections	−5·8 (−19·8 to 9·4)	0·4246

Per-protocol adjusted results, calculated using a linear trend and a binary switch with a 4-week intervention lag.
*Includes both meticillin-resistant and meticillin-sensitive *S aureus*.

Table 2: **Percentage changes in infection rates, by intervention**

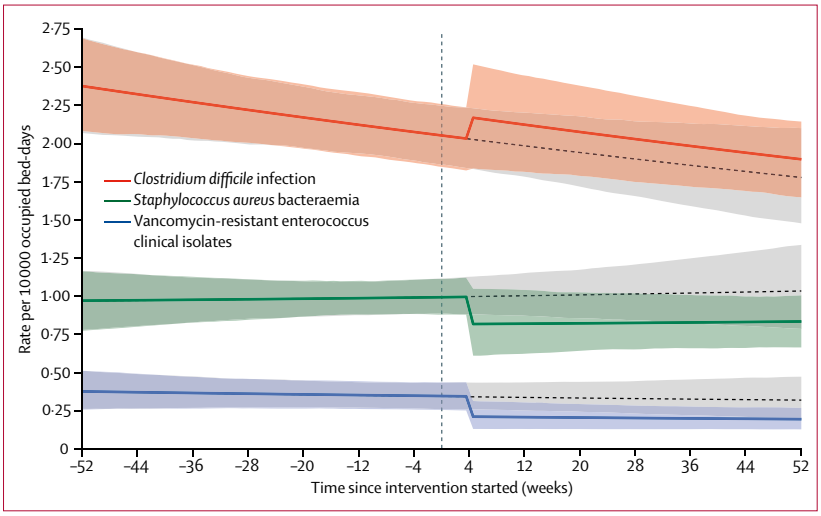

Figure 3: **Estimated changes in health care-associated infection rates before and after the intervention**
Ribbons are 95% prediction intervals. Grey shading shows expected infection rates with no intervention.

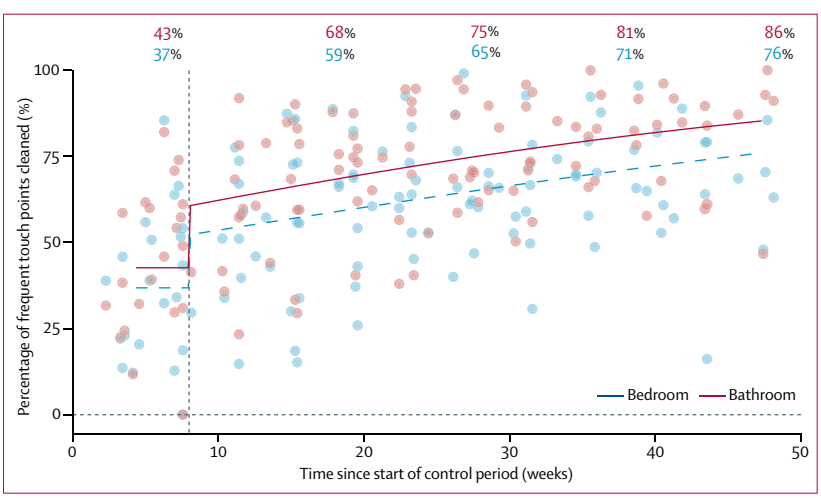

Figure 4: **Percentage of frequent touch points cleaned in patient bathrooms and bedrooms**
Percentages are model-based predictions of the outcome. Dotted line shows the start of intervention.

For all infection types, unadjusted prevalence rates per 10 000 occupied bed-days reduced during the intervention, compared with the pre-intervention phase (table 1, appendix). There were 50 cases of vancomycin-resistant enterococci infection, 109 of *S aureus* bacteraemia, and 278 *C difficile* infections, for 1 267 134 occupied bed-days during the intervention phase. Using the model with the best Akaike's information criterion, which was a binary switch with a 4-week intervention lag, we modelled the trend over time expected (based on pre-intervention data). *S aureus* bacteraemia and vancomycin-resistant enterococcus infection showed no pre-existing linear trend; however, *C difficile* infections were already de-creasing before the intervention. The additional effect of the intervention caused a reduction in vancomycin-resistant enterococcus infections from 0·35 to 0·22 per 10 000 occupied bed-days (relative risk [RR] 0·63, 95% CI 0·41–0·97, p=0·0340). Infection rates for *S aureus* bacteraemia decreased from 0·97 to 0·80 (0·82, 0·60–1·12, p=0·2180) and *C difficile* infections increased from 2·34 to 2·52 (1·07, 0·88–1·30, p=0·4655; table 2), but these changes were not statistically significant (figure 3).

Our sensitivity analysis showed a decrease in meticillin-susceptible *S aureus* bacteraemia from 0·23 to 0·17 infections per 10 000 occupied bed-days, but the difference was not significant (0·74, 0·53–1·05, p=0·0828). For meticillin-resistant *S aureus* bacteraemia, incidence rates increased from 0·07 to 0·09 per 10 000 occupied bed-days, but again, the difference was not significant (1·28, 0·62–2·67, p=0·5250; appendix). The other sensitivity analyses are reported in the appendix. A prespecified estimate of the effect of the intervention on the combined incidence of all three infections showed no significant difference (0·94, 0·81–1·11, p=0·4246; figure 3, appendix). Post-hoc sensitivity analyses are reported in the appendix.

Our secondary outcome was the thoroughness of cleaning. During the study, 25 443 individual frequent touch points (5134 control, 20 309 intervention) were audited (appendix). 690 (11%) of available beds were audited every quarter (range, six to 16 between hospitals). The proportion of frequent touch points cleaned increased in both the bathroom (odds ratio 2·07, 1·83–2·34, p<0·0001) and bedroom (1·87, 1·68–2·09, p<0·0001; appendix). The percentages of frequent touch points cleaned before and after the intervention increased from 55% (95% PI 53–57) to 76% (75–78) for the bedroom, and from 64% (62–66) to 86% (84–87) for the bathroom (figure 4). No changes in hand hygiene compliance or antimicrobial use were seen over the course of the trial; however, there is large variation in antimicrobial use between difference classes (appendix). No adverse effects or events associated with this study were reported. No site reported programme changes or outbreaks that could have affected the primary outcomes.

Screening policies at hospitals did not change during the study (appendix). Several strategies were used to identify outbreaks or policy changes that could affect the trial outcomes (appendix). No such changes were reported by the participating hospitals.

Discussion

This pragmatic, multicentre trial showed that the REACH bundle, a multifaceted hospital cleaning bundle, improved thoroughness of cleaning and reduced vancomycin-resistant enterococcus infections. We found no significant change in the incidence of *S aureus* bacteraemia or *C difficile*. A small, non-significant reduction was seen in the combined infection rate. These findings suggest that a clean hospital environment is important for the safety of admitted patients.

A reduction in the incidence of vancomycin-resistant enterococci has been reported in other research after the introduction of the bundle; however, our study used clinical infections as the primary outcome measure, rather than colonisation.[21] The role of cleaning in reducing incidence of vancomycin-resistant enterococci is important when considering the increasing incidence of this health-care-associated infection and the wider challenges of antimicrobial resistance. Reduction in vancomycin-resistant enterococci infection is important not only for patients, but also for health systems, by potentially decreasing length of stay and costs of antimicrobial resistance.[22,23] Vancomycin-resistant enterococcus is also a useful surrogate for other bacteria (such as *Acinetobacter* species), given similarities in their survival in the hospital environment and transmission pathways.[24] Therefore, these reductions could extend to other pathogens that survive in the environment.

Non-significant reductions in the incidence of *S aureus* bacteraemia were associated with introduction of the cleaning bundle. To our knowledge, this study is the first to assess the effect of hospital cleaning on *S aureus* bacteraemia, previous research has predominantly focused on reducing environmental contamination. It is important to consider this finding in the context of *S aureus* bacteraemia in Australia. National surveillance of, and targets for, *S aureus* bacteraemia, and national hand hygiene initiatives, were started long before our study.[25] Further, major reductions in *S aureus* bacteraemia have already occurred.[26] It is possible that the transmitted proportion of *S aureus* has already been reduced by previous measures, with residual transmission now affected by the cleaning bundle. Therefore, the reduction we identified could be clinically important in the context of already declining and relatively low incidences of these infections.

The incidence of *C difficile* infection did not change significantly after the intervention, after accounting for the already declining incidence. The incidence of *C difficile* infection increased when the intervention was started, then decreased towards pre-intervention levels as the study progressed. It is unclear why this occurred, but there are several possible explanations for why a significant decrease in infection rates was not seen. First, Australia has major reservoirs of *C difficile* outside the hospital environment.[27] Second, genetically diverse strains of *C difficile* from these reservoirs are being transmitted into hospitals and infecting patients.[28,29] In addition, not all hospitals used a sporicidal disinfectant for cleaning and hospitals could choose which disinfectant they wished to used.[20] In six hospitals, for patients who were not under contact precautions, room cleaning involved the use of a detergent. Given these factors and improved understanding of *C difficile* epidemiology and transmission pathways since the commencement of this study, it is not surprising that our cleaning bundle alone did not reduce the incidence of *C difficile* in a hospital setting. All hospitals had an antimicrobial stewardship programme in place throughout the study. Variation in antibiotic usage was consistent with national trends in published data from the Australian National Antimicrobial Utilisation Surveillance Program.[30]

The implementation of the REACH cleaning bundle resulted in improved thoroughness of cleaning that continued to improve over the intervention period. The thoroughness of cleaning at baseline (control) was low. We have previously shown variation in cleaning practices in the participating hospitals.[20] We would expect variation in cleaning practices to also be present in hospitals excluded from our study. Our results are similar to previous findings demonstrating the benefit of using a fluorescent gel to assess cleaning with provision of feedback to staff.[5] However, our intervention included other elements, such as a focus on cleaning technique, training, communication, and correct product use. Using this bundled intervention, we previously reported[13] changes in knowledge, practice, and attitudes in environmental services staff, improvement in the thoroughness of cleaning, and an overall reduction in health-care-associated infections.

Our robust, yet pragmatic, study design, assessed against the PRagmatic-Explanatory Continuum Indicator tool,[9] was implemented in hospitals with varied practices and staff knowledge at baseline.[20] We will report separately the degree of alignment with the five bundle components and the homogeneity of the intervention in the context of primary and secondary outcomes observed. Previous studies[31] of hospital cleaning have used a before and after design, or have been done within outbreak settings, not controlling for pre-existing trends and erroneously claiming causality. We modelled the effect of the intervention separately to infection trends over a long period and accounted for trends in our analysis. We collected data on potential confounders and no noticeable changes in hand hygiene compliance or antimicrobial use were identified during the trial period.

Screening programmes varied between hospitals for meticillin-resistant *S aureus* and vancomycin-resistant enterococcus at baseline. However, monitoring confirmed that screening policies at hospitals did not change during the study. Clinical staffing levels and individual patient

characteristics were not included in the statistical analysis because it was assumed that randomisation and the stepped-wedge design (where hospitals act as their own controls) controlled for these factors.

Our study has several limitations. Owing to the pragmatic approach used, we did not examine patient colonisation. We did not use microbiological testing of the environment or whole genome sequencing to prove transmission pathways, because of financial constraints. Microbial testing of the environment also has limitations.[32] Gel dot auditing staff were trained and regular monitoring and feedback was given by the REACH study team if anomalies were seen in data provided. However, given the size of the study, we did not have capacity to independently validate this data.

By contrast with previous research, our bundle development process prioritised evidence-based strategies that were easier to implement and lower cost than newer expensive technologies.[33] An economic evaluation of the REACH trial will assess cost-effectiveness to inform whether the REACH bundle should be adopted under conditions of scarce resources; the results will be published elsewhere.

In summary, the REACH cleaning bundle was successful at improving cleaning thoroughness and showed great promise in reducing vancomycin-resistant enterococci infections, although we noted no significant change in *S aureus* bacteraemia or *C difficile*. The intervention is broadly applicable to cleaning in any hospital, throughout the continuum of care, because it does not solely focus on discharge cleaning. We have shown the benefits using a bundle that accommodates the complexity of hospital environments and allows for better consideration of culture and context, and hopefully greater ownership by hospitals. As a result, the findings of this study are relevant to hospitals internationally. We recommend that health services and policy-makers that are interested in reducing vancomycin-resistant enterococci infections by improving hospital cleaning should consider both this bundle and our implementation approach.

Contributors

BGM and LH developed the concept and drafted the manuscript. AF collected data, along with the study team. NW analysed the data, with input from AGB. AF, AG, KH, KP, DLP, TVR, CAG, AGB, and NG critically reviewed the manuscript. NG was the chief investigator. All authors contributed to the design of the study and approved the final version of the article.

Declaration of interests

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