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Best practice in healthcare environment decontamination.

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Abstract

There is now strong evidence that surface contamination is linked to healthcare associated infections. Cleaning and disinfection should be sufficient to decrease microbial bioburden from surfaces in healthcare settings, and overall help in decreasing infections. It is however not necessarily the case. Evidence suggests there is a link between educational interventions and a reduction in infections. To improve the overall efficacy and appropriate usage of disinfectants, manufacturers need to engage with the end users in providing clear claim information and product usage instructions. This review provides a clear analysis of scientific evidence supporting the role of surfaces in healthcare associated infections, and the role of education in decreasing such infections. It is also looking at the debate opposing the use of cleaning *vs.* disinfection in healthcare settings.

Keywords: cleaning, disinfection, antibiotic resistance, surface, HCAI

Introduction

Healthcare-associated infections (HCAIs) are defined as infections associated with interventions, devices or procedures carried out in healthcare facilities occurring in patients at the time of hospital admission or within 48 hours of admission [1,2]. In 2011-2012 the European Centre for Disease Prevention and Control (ECDC) coordinated a Point Prevalence Survey (PPS) of HCAIs in acute care hospitals in Europe, the study revealed 6.0% of patients were infected with at least one HCAI, of which 54% were associated with a previous stay in the same hospital. It is estimated on any given day 81,089 patients have a HCAI in Europe, with the most common HCAI associated with respiratory tract infections [2]. Non-device related infections might account for a significant proportion of HCAIs [2]. The most frequently reported microorganisms in HCAIs are *Escherichia coli* (15.9%), followed by *Staphylococcus aureus* (12.3%), *Enterococcus* spp. (9.6%), *Pseudomonas aeruginosa* (8.9%), *Klebsiella* spp. (8.7%), coagulase-negative staphylococci (7.5%) (see [2] for more details). While *Clostridium difficile* accounts only for 5.4%, it is responsible for 48% of all gastrointestinal infections.

It is conservatively estimated that HCAIs cost the NHS £1 billion annually (£3,154 per patient) [1,3-5]. Significantly it is believed that 20-30% of HCAIs could be avoided with better application of existing knowledge and realistic infection control practices [4]. Enhanced cleaning practices are reported to save hospitals between £30,000–£70,000 [6]. With this in mind, infection prevention and control should be a priority at the forefront for all healthcare professionals and users, with a high standard of cleanliness being an intrinsic part of infection prevention. With HCAIs, such as methicillin-resistant *Staphylococcus aureus* (MRSA), *Clostridium difficile* and Norovirus, frequently reported in the media, infection control policies are subject to increased public scrutiny. Yet there appears to be a distinct lack of investment in the field of infection control, both from a research and product application perspective. This is also concurrent with a lack of understanding in disinfectant (biocidal product) efficacy and usage, which are often associated with, or lead to, poor practice. This review aims to analyse in more details the issues faced by infection control professionals and the industry.

The unjustified controversy of cleaning/disinfection failing to impact on HCAIs

Until relatively recently, there was a belief that the hospital environment was not a source of transmission for HCAIs. Indeed, early studies in the 1970s and 1980s indicated endemic transmission of pathogens via the hospital environment was negligible [7,8]. Since then a number of investigators have highlighted the importance of environmental contamination in the transmission of clinically relevant pathogens, such as *C. difficile* and MRSA [9-12] as well as the role of surface disinfection for controlling pathogenic microorganisms [13]. The importance of surface disinfection is further emphasised by its inclusion in several national and international infection control policies, including the epic3: national evidence-based guidelines for preventing healthcare-associated infections in NHS hospitals in England [14].

Hospital setting, environmental persistence and transmission

The most common source of microorganisms in a hospital setting are the patients themselves, infected and colonised patients (and hospital staff) shed bacteria, viruses and spores into the hospital environment. Whilst a direct link between HCAIs and the presence of a microorganism on a hospital surface has not been established

[10,15-19], studies have reported many organisms responsible for HCAIs, including MRSA, *C. difficile*, norovirus and vancomycin-resistant enterococci, survive and persist on hospital surfaces at concentrations sufficient for transmission and transference to the hands of healthcare workers. Given that the infectious dose for most potential pathogens appears to be low [20-22] coupled with the persistence of these organisms on hospital surfaces and medical equipment for prolonged periods (Table 1)[23], the presence of a pathogen on a surface does pose a transmission and/or infection risk (Table 2)[10-24].

In the hospital environment, areas near the patient and high-touch surfaces have been found to harbour microorganisms (Figure 1)[10,13,15,50,51]. A number of studies highlighted the transference of microorganisms from surfaces to hands (Table 3). Kampf and Kramer [61] reported the percentage of pathogens on healthcare workers hands as rhinovirus (65%), and rotavirus (19.5-78.6%), vancomycin-resistant *enterococci* (41%), *Clostridium difficile* (14-59%), *Klebsiella* spp. (17%), MRSA (16.9%), Serratia marcescens (15.4-24%), *Pseudomonas* spp (1.3-25%) and *Acinetobacter* spp. (3-15%). Adequate cleaning and/or disinfection of these surfaces (bedrails, commodes, doorknobs, light switches, patient call button, surfaces and equipment in close proximity to the patient) have been shown to be of particular importance [62-66]. It has been suggested that cleaning specifications do not adequately address high touch surfaces [10,50,67], with increased frequency and intensity of cleaning recommended for pathogens with an intestinal reservoir (*C. difficile* and norovirus)[68,69]. More recently, it has been suggested that cleaning and/or disinfection protocols should be ward specific and hence tailored to prevent ward-specific transmission routes. In addition to focusing on near patient surfaces, staff (medical chart, drug locker, staff toilet,) and patient (paper towel dispensers, bin lids) contact surfaces should also be considered as reservoirs of infection [70].

Evidence that surface decontamination eliminates transmission and lowers infection rates

There is an increasing body of knowledge which highlights improved infection control practices can help break the chain of transmission [20,71,72]. A review was undertaken by Rutala and Weber [72] who recommended routine cleaning and disinfection of surfaces following a comprehensive review of epidemiological and microbiological data following surface disinfection. Studies which show a positive impact of environmental cleaning have focussed predominantly on MRSA, *C. difficile* and norovirus, which is not surprising, given the infection rates and the ability of these organisms to persist in the environment (Table 4).

Roles, responsibilities and education of healthcare workers

The document compiled by the Comptroller and Auditor General on behalf of the National Audit Office [4] identified three staffing groups with cleaning responsibilities: a) dedicated cleaning staff, b) nursing, ambulance staff and departmental staff and c) estates staff. The division of cleaning responsibilities has often resulted in confusion, resulting in a number of objects (ward-based equipment) which 'fall through the gaps" in the cleaning schedule [106,107]. With this in mind it is apt to refer to the Matron's Charter which specifies that cleanliness is everyone's responsibility, not just the cleaner's [108]. Nonetheless it is evident that regular teaching of microbiological principles and infection control policies is beneficial [107,109].

Cleaning and disinfection form a fundamental part of infection control and prevention, integral to this is the appropriate education and training of all NHS personnel (medical and non-medical staff) and NHS users (patients and visitors). However, there appears to be a disparity in the provision of education and training provided to key healthcare personnel in the NHS. Nurses and healthcare assistants were provided with induction training on infection control in 90% of NHS Trusts, whilst only 16% of senior doctors received training [4]. The importance of education and training is reinforced by evidence that they can contribute to reductions in HCAIs (Table 5).

The education of healthcare workers may be hampered by the lack of general guidelines on cleaning standard and evaluation, and by conflicting information between the need for cleaning and/or disinfection and the evaluation of disinfectants/cleaning agents. There are no guidelines or standardised methods for monitoring of environmental cleaning. Visual assessment is the most generally accepted measure of cleanliness [115,116], despite being an unreliable indicator of microbial contamination. Currently the UK guidelines for surfaces in wards, is that they are "visually clean" [16]. A surface may be visibly free of soil however; this may not reflect that the surface is free of microbial load. Visual assessments are the cheapest and quickest means of assessing cleanliness, providing an indication of personal performance and cleaning efficiencies. However, subjective visual inspections have been reported to be poor indicators of cleanliness in comparison to fluorescent markers and adenosine triphosphate (ATP) assays [117].

UK guidelines do not currently advice on the routine sampling of floors, walls, surfaces and air [118]. Given that high touch surfaces are implicated in the transmission of HCAIs, validating and assessing the thoroughness of cleaning would be justified, serving as an additional training and educational tool. If sampling is to be undertaken the number of organisms per unit area or volume should be reported. Despite the time and resources required for microbial culturing, it represents the most accurate indication of the potential infection risk. The presence of indicator organisms, such as *S. aureus*, *C. difficile*, VRE or *Acinetobacter* spp., is indicative of a requirement for increased cleaning [119]. It has been proposed that aerobic colony counts on hand-touch sites should not exceed 2.5 CFU/cm^2 [55,119-121].

Cleaning or disinfection?

The choice of decontamination procedure will depend on the infection risk associated with the surface and the type of microorganism likely to have contaminated the surface [122,123]. An inherent consideration of all disinfection strategies is the elimination of the most resistant microbial sub-population. Yet there are disagreements about when and where a cleaning agent (removing of a bioburden from surfaces) or a disinfectant (killing microorganisms on surfaces) should be used (Table 6). This is further complicated by the fact that many disinfectant products will have a detergent (cleaning) ability too. In addition, there are many factors that will affect the efficacy of a disinfectants; these include factors related to the disinfectant such as concentration, pH and overall formulation, factors related to the target microorganisms and factors related to the product usage such as contact time, organic load, type of surface and temperature [124]. Failure to understand the effect of these factors on antimicrobial activity will result in the failure of the disinfectant. To assess the efficacy of a disinfectant a number of standard efficacy tests can be performed. These efficacy tests are key to product development and are the basis for regulatory clearance, labelling and use [125]. The type of test method employed and the requirements will depend on the type and intended purpose of the microbicide (disinfection, preservation, and antisepsis) and its application (medical, agricultural, industrial). Although data from standardised efficacy test methods (e.g. European Norm tests) are required for a product to be commercialised and for a producer to make a product claim, the parameters used in these standard tests may not reflect realistic in-use conditions. For example, disinfectants used in the healthcare settings generally have a contact time of 10 minutes, i.e. the surface must stay wet after cleaning for 10 minutes to achieve a 3 log reduction [13], however such a long exposure time is not practical and will require re-application of the product. Generally the contact time specified on the label of a product is too long to reflect realistic in-use conditions, thus the efficacy of some products maybe grossly overestimated [125,126]. The Centres for Disease Control and Prevention (CDC) specifies a contact time of 3-5 minutes based on the evaporation of the product, however a 1 minute contact time is more realistic of in-use conditions, indeed contact times of 30 – 60 seconds have been reported for a number of disinfectants [127-129]. For antimicrobial wipes, there is no international or national guidance on wipe selection and use [130,131]. Without an accepted standard test for wipes, information on the effectiveness of a product can only be gleaned from laboratory tests. This can lead to the use of wipes that might not be appropriate for applications in the health care environment [132,133].

The choice of disinfectant will depend on its intended use, thus the manufacturer's instructions should be followed to ensure correct application [124]. Incorrect selection and use of a formulated disinfectant can results in transference of microorganisms to clean surfaces [65,132,134-138]. In laboratory simulated conditions, studies have demonstrated the transference of microorganisms from contaminated cleaning cloths (commercial wipes and microfiber cloths) to clean surfaces [132,139,140]. Nine of the ten commercially available wipes tested demonstrated the repeated transfer of *C. difficile* spores [132]. The changing and/or cleaning of cloths and the wiping of surfaces from clean to dirty is crucial to limiting microbial transference [133].

Conclusions

A valid infection control intervention will reduce the microbial burden in the environment and hence the persistence of the organism, which can only be achieved with appropriate cleaning and disinfection programmes. As such surface disinfection

should be included in local, national and international infection control policies. The current debate as to whether or not cleaning only (i.e. without a disinfection step) is sufficient to eliminate microbial pathogens from surfaces in the healthcare environment needs to be addressed and supported by practical evidence.
It is clear that better education together with better compliance [141] of end users is needed. A number of considerations can easily be taken into account prior to choosing a disinfectant (Table 7). A product label will state the name of the test method used to assess the efficacy of the product. Information relating to the test, the laboratory in which it was undertaken and the test results should be available from the manufacturer.

Concurrently, manufacturers need to have clear instructions about standard efficacy tests that need to be performed not only to make a product claim but also to represent better the usage of a product in practice. If no standard test is available, manufacturers should be encouraged to provide evidence of the activity of their products under in use conditions. Unfortunately, it is increasingly clear that a product that passes a standard efficacy test (such as European Norm tests) will meet its label claim but it might not necessarily mean that the product will be efficacious in practice; two of the most documented examples are the use of antimicrobial wipes[130-133] or the testing of products against *Clostridium difficile* [142-144]. Manufacturers need also to provide clear product use instructions. Decreasing microbial bioburden on surfaces through cleaning and disinfection should be easily achievable with most of the disinfectant formulations available at present. More efforts need to be done to educate and motivate the end users to use the purposefully designed disinfectant appropriately. Decreasing HCAIs remain a multifactorial approach [145] in which surface decontamination is central [14].

Conflict of interest

None to declare

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Table 1 Persistence of microorganisms on dry surfaces (based on [23])

Organism	**Persistence (range)**
Acinetobacter spp	3 days to 5 months
Clostridium difficile (spores)	5 months
Enterococcus spp. including Vancomycin Resistant enterococci	5 days – 4 months
Escherichia coli	1.5 hours – 16 months
Klebsiella spp.	2 hours to > 30 months
Mycobacterium tuberculosis	1 day – 4 months
Pseudomonas aeruginosa	6 hours – 16 months
Salmonella Typhimurium	10 days – 4.2 years
Shigella spp.	2 days – 5 months
Staphylococcus aureus, including MRSA	7 days – 7 months
Haemophilus influenzae	12 days
Adenovirus	7 days – 3 months
Influenza virus	1 – 2 days
Norovirus and feline calici virus (FCV)	8 hours – 7 days

Table 2 Evidence of persistence of microorganisms on surfaces and/or acquisition of infection from contaminated environment

Evidence	**Organisms**	**Reference**
Plastic cover of medical charts are frequently contaminated with pathogens and may serve as source of infection	Coagulase-negative staphylococci, MRSA, *E. coli K. pneumoniae* and *A. baumannii*	[25]
24% of HCWs hands contaminated with *C. difficile* spores after routine care of CDI patient. 44% of the HCWs with contaminated hands provided at least one episode of direct patient care without use of gloves.	*C. difficile*	[12]
79% of sampled surfaces were positive for MDROs. Molecular typing identified related strains from patients, the environment and hands of healthcare workers	MRSA, VRE, *E. coli* and *K. pneumoniae* resistant to extended-spectrum cephalosporins,	[26]

	and carbapenem-resistant (CR) *A. baumannii.*	
14% of clinical and emergency department rooms had ≥1 surface contaminated with *C. difficile.* Outpatient clinics maybe an important source of community-associated *Clostridium difficile* Infection (CDI)	*C. difficile.*	[27]
15% of iPads sampled were positive for *S. aureus*	*S. aureus*	[28]
3% and 6% of hospital surfaces were contaminated with MRSA or *C. difficile*, respectively	MRSA, *C. difficile*	[29]
The persistence of potentially pathogenic staphylococci on hospital surfaces represents an infection threat	*Staphylococci* spp.	[30]
Unrecognized colonization and/or the aerosolization of Enterococci together with inadequate cleaning can lead to widespread persistence in environmental contamination	*Enterococci* spp.	[31]
Environmental contamination due to *C. difficile* aerosolisation can occur when a lidless toilet is flushed	*C. difficile*	[32]
A prior room occupant with CDI is a significant risk factor for CDI acquisition. Of the patients who acquired CDI after admission 11% had a prior occupant with CDI	*C. difficile*	[33]
60% of surfaces (gowns, bed rail/cranks, table and infusion pumps) in close proximity to patient were positive for MRSA and may serve as reservoirs for infection	MRSA	[34]
Bacterial contamination of stethoscopes ranges between 66-90% depending on site sampled (bells, earpieces and diaphragms). The presence of pathogenic and non-pathogenic bacteria on stethoscopes may pose a potential transmission risk	*Micrococcus* spp., Coagulase negative staph, MRSA, MSSA, *Pseudomonas* spp, *Enterobacter* spp., *E. coli*, Streptococcus viridans Group	[35]

Toxin-producing *C. difficile* present in non-isolation rooms (16%), physician work areas (31%), nurses work station (10%) and portable equipment (21%)	*C. difficile*	[36]
Acquisition of VRE from prior environmental contamination of ICU	VRE	[37]
Environmental contamination responsible for outbreak of *A. baumannii*	*A. baumannii*	[38]
Increased risk of acquiring MRSA and VRE from rooms previously occupied by MRSA-positive and VRE-positive patients	MRSA, VRE	[39]
Enforced environmental cleaning reduces surface contamination with VRE	VRE	[40]
Epidemiological link found between outbreak strains of *Enterobacter cloacae* and strains isolated from therapeutic beds	*Enterobacter cloacae*	[41]
Widespread VRE contamination of surfaces and hands	VRE	[42]
Epidemiological link between hospital dust and transmission of MRSA	MRSA	[43]
Presence of two toxigenic *C. difficile* in the environment accounted for 45.3% of CDAD cases	*C. difficile*	[44]
Outbreak strains survive longer than in the environment than non-outbreak strains	MRSA	[45]
Survival and persistence of *A. baumanii* on dry surfaces	*A. baumanii*	[46]
Survival and persistence of non-sporulating bacteria on dry surfaces	*M. bovis, S. aureus, E. faecalis, S. thyphi, Ps. aeruginosa*	[47]
Outbreak strains survive longer than in the environment than non-outbreak strains	MRSA	[48]
Patient, HCW and environment implicated as source of *C. difficile* contamination	*C. difficile*	[49]

Table 3 Evidence of transference of microorganisms onto hands of healthcare workers

Comments	**Organisms**	**Reference**
24% of HCWs hands contaminated with *C. difficile* spores after routine care of CDI patient	*C. difficile*	[12]
39% of patients hands were contaminated with at least 1 pathogenic organism. Pathogenic organisms can be frequently detected on hands of acute care patients.	*Acinetobacter* spp., MRSA, *C. difficile,* VRE	[52]
Molecular typing identified related strains from patients, the environment and hands of HCWs	MRSA, VRE, *E. coli* and *K. pneumoniae* resistant to extended-spectrum cephalosporins, and carbapenem-resistant (CR) *A. baumannii.*	[26]
Acquisition of *C. difficile* spores on gloved hand following contact with contaminated surfaces	*C. difficile*	[24]
Daily disinfection of high-touch surfaces was associated with a significant reduction on pathogen acquisition on hands	MRSA *C. difficile*	[53]
A 10% risk of acquiring VRE is associated with each contact with VRE colonised patient and environment	VRE	[54]
23% of samples analysed did not meet hygiene standards, with hand touch sites found to display significantly more failures than non-hand touch sites	*S. aureus* Aerobic colony counts	[55]
Transfer of VRE from inanimate objects and patient skin via hands of HCWs	VRE	[56]
Environmental contamination is an important source of MDRO transmission	MRSA, *P. aeruginosa*, Enterobacteriaceae, and *A. baumannii*	[57]
Evidence of transmission of influenza virus from objects to hands of healthcare workers	Influenza virus	[58]
Transfer of VRE onto gloved hands after contact with contaminated surfaces.	VRE	[59]
Surfaces in close proximity to patients are frequently contaminated with MRSA. The contaminated surfaces may serve as a reservoir	MRSA	[60]

of MRSA		
Patient, HCW and environment implicated as source of *C. difficile* contamination	*C. difficile*	[49]

Table 4 Evidence that cleaning and disinfection eliminates transmission and lowers colonisation/infection rates

Comments	**Organisms**	**Reference**
Surface disinfection reduced environmental contamination with VRE by 9%	VRE	[73]
Cleaning and disinfection of respiratory equipment with 70% ethanol wipe reduced fungal and bacterial contamination by 60% and 75%, respectively	*Pseudomonas spp. Acinetobacter spp*., *Klebseilla pneumoniae, E.coli* and *Stenotrophomonas maltophila. Candida* spp, Streptomyces spp, Aspergillus	[74]
Daily disinfection of high touch surfaces and a dedicated housekeeping team resulted in a 60% reduction in the number of *C. difficile* positive cultures	*C. difficile*	[75]
Disinfection of portable ultrasound machines with isopropanol reduced contamination by 85%	Coagulase negative *staphylococcus* spp., *Neisseria* spp., *Streptococcus* spp.	[76]
Cleaning with a hydrogen peroxide disinfectant wipe yielded <2.5 CFU/cm^2 on 99% of surfaces	Aerobic colony count	[77]
37% reduction in CDAD rate was observed following HPV decontamination	*C. difficile*	[78]
Hydrogen peroxide vapour (VHP) decontamination of rooms reduced the likelihood of MDROs and VRE acquisition by 64% and 80% respectively	VRE, multidrug resistant Gram-negatives	[79]
Environmental cleaning, education, hand hygiene and VHP decontamination successfully controlled MRAB in an intensive therapy unit	*A. baumannii*	[80]
Antibacterial wipes reduce the numbers of bacteria	*S. aureus*	[81]

near to the patient		
Early intensification of infection control practices (disinfection, hand hygiene and education) interrupts the transmission of carbapenemase-producing *Klebsiella pneumoniae* outbreak	*K. pneumoniae*	[82]
Disinfection of bed rails reduced the intrinsic bacterial burden by up to 99%	*Staphylococci* spp. VRE	[83]
Active surveillance and adherence to infection control procedures required to prevent transmission of VRE	VRE	[84]
Patients with MDR-AB, frequently contaminate the environment. Surfaces often touched by health care workers are commonly contaminated and may facilitate transmission	*A. baumannii*	[85]
Daily disinfection with a germicidal bleach wipe reduced hospital acquired-CDAD by 85%	*C. difficile*	[86]
Use of disinfectant wipes on supports used in hip arthroplasty may reduce infection rates	Coagulase negative staphylococci, coryforms, *Bacilli* spp.	[87]
Enhanced ICU cleaning may reduce VRE and MRSA transmission and acquisition	VRE, MRSA	[88]
Environmental decontamination using VHP halted the transmission of MDR *A. baumannii* in a long term acute care hospital	MDR *A. baumanii*	[89]
Enhanced cleaning reduced microbial contamination of high-risk hand-touch sites by 32.5% and MRSA infections by 26.6%	MRSA	[10]
39% reduction in CDAD rate was observed following HPV decontamination. When adjusted for presence of epidemic NAP1 strain a 53% reduction in CDAD rate.	*C. difficile*	[90]
Changes to cleaning protocols reduced environmental contamination with gastroenteric viruses	Norovirus, astrovirus, rotavirus	[91]
Patient and staff decolonisation combined with HPV decontamination terminated MRSA outbreak on surgical ward	MRSA	[92]
Cleaning with water and detergent followed by cleaning with hypochlorite helps to achieve a greater reduction in	Aerobic count, MRSA	[93]

the total bacterial bio-burden on hand touch sites in isolation rooms		
Environmental cleaning with sodium hypochlorite solution reduced rate of CDAD	*C. difficile*	[94]
Implementation of appropriate control measures controlled *C. difficile* outbreak	*C. difficile*	[95]
Epidemiological link found between outbreak strains of *Enterobacter cloacae* and strains isolated from therapeutic beds	*Enterobacter cloacae*	[41]
Increased cleaning reduced environmental contamination of VRE	VRE	[40]
Thorough cleaning and HPV disinfection eradicated *Serratia marcescens* from a neonatal intensive care unit (NICU)	*Serratia marcescens*	[96]
Transfer of VRE from inanimate objects and patient skin via hands of HCWs	VRE	[56]
Environmental contamination is an important source of transmission of nosocomial pathogens	MRSA, *P. aeruginosa*, Enterobacteriaceae, and *A. baumannii*	[57]
Significant correlation between environmental contamination and patient colonisation/infection with A. baumanii	*A. baumannii*	[97]
Thorough environmental cleaning and education can reduce transmission of A. baumanii	*A. baumannii*	[98]
Cleaning with hypochlorite significantly reduced incidence of CDI on one ward	*C. difficile*	[99]
Environmental decontamination with 0.5% sodium hypochlorite attributed to control of VRE outbreak	VRE	[100]
Routine and thorough cleaning contributed to the control of MRSA outbreak	MRSA	[43]
Hand washing, environmental cleaning and disinfecting may help reduce infection rate in long-term care facilities	-	[101]
Barrier precautions and environmental decontamination	VRE	[102]

eradicated VRE outbreak		
Environmental disinfection with sodium hypochlorite reduced rates of CDAD	*C. difficile*	[103]
Environmental contamination by MRSA can be controlled by supervised cleaning and education	MRSA	[104]
Aggressive infection control measures (included environmental disinfection, hand washing, education) resulted in sustained decrease in CDI over 7 year period	*C. difficile*	[105]

Table 5 Evidence that education and training reduces environmental contamination

Comments	**References**
The use of fluorescent markers resulted in a 10% reduction in the number of positive CDI cultures after disinfection	[76]
Daily disinfection of iPads with isopropanol wipes following app based instructions reduced microbial load	[110]
Gram staining of environmental cultures and use of UV markers was successful at improving cleaning in operating rooms	[111]
Improved cleaning practices, staff education, and monitoring cleanliness reduced environmental prevalence of MRSA and VRE in ICU rooms.	[112]
Educational interventions directed at housekeeping staff reduced *C. difficile* and VRE contamination of surfaces	[113]
Implementation of appropriate control measures controlled CDI outbreak	[95]
Educating health-care workers and families of patients, and all head nurses contributed to controlling outbreak of *C. difficile*	[114]

Table 6 Summary for and against the use of detergents and disinfectants (modified from Rutala and Weber [72]

Justification for detergent use	**Justification for disinfection use**
Surfaces contribute minimally to endemic nosocomial infections	Surfaces may contribute to the transmission of epidemiologically important microbes (e.g., VRE, MRSA, *C. difficile*, viruses)
There is no difference in infection rates of floors cleaned with detergent versus disinfectant	Disinfectants are needed for surfaces contaminated by blood and other potentially infective material
No environmental impact associated with disposal of detergents	Disinfectants are more effective than detergents in reducing microbial load on floors
Lower costs	Detergents become contaminated and result in seeding the patient's environment with bacteria
No occupational health exposure issues	Some newer disinfectants have persistent antimicrobial activity
Use of antiseptics/disinfectants may select for antibiotic-resistant bacteria, especially where a residual activity is present	Advantage of using a single product for decontamination of floors and equipment
More aesthetically pleasing floor	Formulations can achieve a combination of cleaning and disinfection, while resulting in aesthetically pleasing floor
	Disinfectants may reduce the risk of emerging bacterial resistance

Table 7 Evaluating efficacy testing data for surface disinfection

Questions	Comments
What standardised test was used?	Test used appropriate to make a claim for healthcare application? A phase 2 step 2 test should be used[#] (i.e. surface test)
Does it support the application claim?	Bactericidal, sporicidal, fungicidal For sporicidal claim: what bacterial species was used?
Was the exposure time realistic?	A contact time of 5, 10 and >10 min for surface disinfection is not realistic (see text)
Was the test conducted in clean (0.3 g/L bovine serum albumin) or dirty conditions (3.0 g/L bovine serum albumen[#])?	Absence of test with organic load limits the practicability of the test.
Was a neutralisation step used?	Absence of neutralisation increases the apparent activity of a disinfectant[*]
Was *C. difficile* used?	Need to have information on spore production method and purity level of the preparation (>90% spores). Need to have assurance test laboratory has access to anaerobic facility.
Were controls performed?	For specific activity, for example sporicidal activity, a hypochlorite control can be used to validate the appropriateness of the test method.

[#] for European Norm test

[*] European Norm test include neutraliser, and controls of neutraliser toxicity and efficacy.

Figure 1: Examples of high touch surfaces found to harbour microorganisms in the healthcare setting. (1) bed frame and cot sides, (2) bed controls, (3) light switch, (4) patient chair, (5) mattress, (6) tray table, (7) bedside table, (8) IV pole, (9) IV pump, (10) patient entertainment system and nurse call button