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15

Cleaning and decontamination of the healthcare environment

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DOI: 10.1533/9780857096692.2.370

Abstract: Evidence is accumulating for the role of cleaning in controlling hospital infections. Hospital pathogens such as meticillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant enterococci (VRE), norovirus, multi-resistant Gram-negative bacilli and *Clostridium difficile* persist in the healthcare environment for considerable lengths of time. Cleaning with both detergent and disinfectant-based regimens help control these pathogens in both routine and outbreak situations. The most important transmission risk comes from organisms on frequently handled items because hand contact with a contaminated site could deliver a pathogen to a patient. Cleaning practices should be tailored to clinical risk, near-patient areas and hand-touch-sites and scientifically evaluated for all surfaces and equipment in today's hospitals.

Key words: cleaning, detergent, disinfectants, infection control, decontamination.

15.1 Introduction

There remains debate over clean hospitals when considering hospital-acquired infections (HAIs).[1,2] A visual experience of dirty hospitals is automatically linked with infection risk but this is difficult to prove for a number of reasons. Firstly, there are already several known risks for patients acquiring infection in hospital – antimicrobial consumption, insufficient isolation rooms and poor hand hygiene, for example. Secondly, since cleaning has never been investigated as a discrete scientific entity, it is impossible to determine just how important it might be towards overall infection control.[1] Finding the evidence to support cleaning as a significant intervention for preventing infection has been seriously disadvantaged because there are no accepted risk-based standards to verify whether a hospital is truly clean and safe.[3] Finally, there is confusion between nursing and domestic personnel over allocation of cleaning responsibilities. Even established cleaning regimens do not necessarily target high-risk reservoirs due to a lack of evidence and education.

Disclaimer: This chapter has not been funded by an individual or organisation. UNISON, the healthcare workers' union, kindly funded studies on hospital cleaning in the past.

Visual inspection of the hospital environment does not provide a reliable qualitative nor quantitative assessment of the infection risk for patients.[2,3] Microbes are invisible and they are not necessarily associated with visual dirt. The impression of cleanliness is confounded by clutter, excess equipment; cramped wards and fabric deficits. Visual assessment will inevitably be subject to bias under these circumstances, as well as subject to an individual's perception.[1] Despite this, there is general consensus that environmental cleanliness is important for controlling infection. This is largely due to historical influences as well as the large number of outbreak reports, which nearly always mention cleaning as an integral part of the control package.[4]

There has been much recent interest in the role of the environment in promoting transmission of pathogens as well as articles examining basic principles underlying the importance of cleaning.[5,6] Novel biocides, antimicrobial coatings and new types of cleaning equipment are constantly appearing, although few have been modelled against patient outcome. There is an increasing need to prioritise surface level cleaning in the prevention and control of hospital infection, particularly as pathogens are becoming more resistant to antimicrobial agents. Hospital cleaning in the 21st century deserves further investigation for both routine and outbreak practices.

15.2 Pathogen survival time in the hospital environment

If a microbial pathogen can retain viability on surfaces outside the human body, there is a risk that it could be picked up by hands or air currents and transmitted to a patient.[4] The longer it survives, the more likely it will ultimately reach a patient at a vulnerable site and cause infection. Robust pathogens will persist in an appropriate environmental niche for days unless removed through some cleaning process.[1,7] Organisms that are particularly good at resisting drying or desiccation are more likely to be associated with epidemic spread.[8–10]

Whilst the ability of bacterial spores to withstand intemperate environments is well known, survival patterns of vegetative bacteria and viruses in healthcare institutions are less predictable. It has been assumed that Gram-negative bacilli are more vulnerable to exposure on surfaces, and therefore pose less of a risk to patients.[1] This assumption has been challenged by studies that detail prolonged survival periods for some Gram-negative species.[7] For example, *Escherichia coli* and *Klebsiella* spp. have been shown to survive more than a year under certain conditions, and *Serratia marcescens* up to 2 months.[7] In contrast, methicillin-resistant *Staphylococcus aureus* (MRSA) has been shown to survive for a year in

hospital dust, the spores of *Clostridium difficile* for five months and epidemic vancomycin-resistant enterococci (VRE) for up to four years.[10–12] *Acinetobacter* can survive in surface dust for at least a month, with some strains reportedly surviving for up to 3 years.[8] *Pseudomonas aeruginosa* usually only survives for a couple of days but will persist for five weeks on a dry floor.[7,13] Along with *Stenotrophomonas maltophilia*, *Pseudomonas* spp. demonstrate long-term persistence within biofilm adherent to hospital plumbing components and other water-exposed sites.[14,15] Most respiratory viruses such as coronavirus, rhinovirus and influenza can survive on dry surfaces for a few days, with gastrointestinal viruses retaining viability for a couple of months. Norovirus is found in the hospital environment for days after an outbreak, demonstrating survivability despite terminal cleaning with bleach-based products.[16,17] Fungi such as *Candida* spp. may persist in hospitals for up to four months, although there are very few reports detailing the risk of cross-infection from an environmental source.[7,18,19]

Given the proven ability of these microorganisms to survive on surfaces for relatively long periods of time, it is obvious that the healthcare environment facilitates cross-transmission and outbreaks of many hospital pathogens. The risks of cross-transmission are exaggerated by heavy workload, understaffing, high bed occupancy rates and rapid bed turnover. Furthermore, in an era of cost cutting, those with cleaning responsibilities cannot hope to decontaminate all high-risk surfaces as often as required when a hospital is full to capacity and patients with attendant microorganisms are transferred between wards day and night.[4]

15.3 Identifying the main reservoirs of microorganisms

Pathogens can be recovered from the environment using a variety of microbiological techniques. Most organisms can be found in the air and ultimately on the floors, but almost any surface can host a range of microbes for differing lengths of time. These include general surfaces such as shelves and ledges; curtains, linen and clothes; furniture and computers, telephones, patients' beds and items of clinical equipment.[1,12,20–25]

Gram-negative organisms such as *Pseudomonas* spp. and *Stenotrophomonas* are associated with damp places such as taps, sinks, showers and baths.[1,13,15,26,27] Coliforms such as *Klebsiella* and *Serratia* have been identified from buckets, bowls, mops and liquids.[1,28] Thus, traditional sites for Gram-negative microbes have been sites constantly or intermittently exposed to water, but this is not always the case. Dry sites, e.g. patient charts, can also host a range of Gram-negative organisms.[23]

About 5% of near-patient sites demonstrate presence of Gram-negative bacilli indistinguishable to those from the patient.[22] Organisms identified

included *E.coli*, *Enterobacter*, *Serratia* and *Klebsiella*, and these organisms were recovered from a range of sites including linen and nightwear; bedside table, bed rail and chair; door handle; infusion pump and respirator; and expected bathroom sites. The most prevalent site for the patients' own isolate was the perineal region of the patients themselves, thus demonstrating the major reservoir for Gram-negative bacteria.[22] The perineum has already been highlighted as an important source of environmental contamination for hands of both patients and staff.[29]

Pathogens normally resident in the gastrointestinal system, such as norovirus, *C. difficile* and VRE, are predominantly recovered from bathrooms, toilets or commodes, although the propensity for survival of these particular organisms means that they can be found from many other sites in the healthcare environment.[12,17,30,31] Indeed, spores of *C. difficile* persist on hands and under fingernails, and could be carried between wards on the soles of shoes.[12,32,33] Spores may disseminate through the air, confounding attempts at controlling infection and invalidating terminal cleaning protocols.[34]

Norovirus easily spreads in air and on surfaces throughout an entire ward, although this usually reflects the situation during seasonal outbreaks.[17] Dust-loving MRSA and *Acinetobacter* contaminate rarely cleaned and/or inaccessible surfaces, such as shelves, tops of monitors, patient notes and computer keyboards.[25,35–38] The most frequently contaminated sites for MRSA on an acute ward are top of the bedside locker; overbed table and bed frame.[22,39] Airborne spread of MRSA and *Acinetobacter* has also been documented but remains poorly investigated.[40–43] Even *Pseudomonas* has been recovered from air, and similarly implicated in spread between patients.[13] The more traditional airborne pathogens, ubiquitous *Aspergillus* and *Bacillus* spp., are dispersed through the hospital particularly during hot dry weather, and often associated with construction or renovation.[1,44,45]

Coliforms and *Pseudomonas* may frequent 'wet' sites such as sinks and baths, with differences between the recovery rate from sinks on separate wards within the same hospital.[46] Few coliforms persisted in intensive care unit (ICU) sinks, as opposed to sinks on medical wards, with *Pseudomonas*-type bacteria more frequently isolated from ICU sinks than those on the medical wards. This was attributed to more frequent dispensing of alcohol and chlorhexidine for the purposes of hand disinfection in ICU. All environmental bacteria recovered from ICU were significantly more resistant to antibiotics than those from the medical wards. Antibiotic consumption appears to influence the resistance profiles of organisms on floors and other surfaces within a defined local environment such as a hospital ward.[46]

Prior room occupancy has been shown to be a risk for acquisition of both Gram-negative and Gram-positive organisms.[5,47–51] This suggests that

terminal cleaning and/or disinfection regimens for isolation rooms containing patients colonised and/or infected with MRSA, VRE, *C. difficile*, *Acinetobacter* and *Pseudomonas* fail to remove all microbial contamination, thus exposing a new admission to the remnants of a persistent environmental reservoir.[52] Given that this risk has been verified by many different authors, it strengthens the role of the environment in HAI.[53] A patient admitted into a room previously occupied by an infected patient remains at risk of acquiring the same organism, regardless of hand hygiene compliance rates by attendant clinical staff.[54]

Once a hospital pathogen reaches an appropriate environmental niche, it will persist, unless removed through some cleaning process. It then has the potential to contaminate hands or be uplifted by air currents and deposited upon a patient or onto surfaces beside the patient. [29,34,55,56] The greatest risk for infection for most patients emanates from surfaces beside or on beds, e.g. linen, bed frames, lockers and overbed tables.[3,24,39,57] Contamination of near-patient bedside sites provides an opportunity for everyone's hands, including those of the patient, to acquire pathogens and/or transfer them elsewhere.[29,58,59]

15.4 Transmission of contaminants by hands during healthcare

Items or surfaces that are frequently touched provide the largest risk of contamination by pathogens spread on hands.[3,25] These sites then act as reservoirs for subsequent dispersal. Seeding pieces of cauliflower mosaic virus onto a ward telephone allowed researchers to track the movement and spread of the viral marker around the unit, from hand-touch site to hand-touch site over the course of hours and days.[60] A similar community-based study placed viral components onto a door handle in a students' flat and charted the movement of the markers from site to site via hands.[61] These studies confirm the role of hands in mobilising microbial markers between hand-touch reservoirs, and the sites most likely to host pathogens. In addition, the community study showed how direct hand-to-hand contact, as occurs during handshaking, was able to spread marker virus to a succession of people following initial contamination of a door handle.[61]

Many previous studies have demonstrated transient and persistent carriage of hospital organisms on the hands of healthcare workers.[9,27,29,32,55,62–68] About 40% nurses' hands yield coliforms without prior disinfection, although rates depend upon the type of unit in which sampling takes place.[29,63] Another study showed that 17% ICU staff carried *Klebsiella* on their hands, and that these strains were probably related to those colonising or infecting patients resident on the unit.[55] Of clinical staff caring for patients with *C. difficile*, 59% had positive cultures for *C. difficile*

from their hands.[32] About 17% (9–25%) of contacts between a healthcare worker and an MRSA-colonised patient result in transmission of MRSA from a patient to the gloves of a healthcare worker.[66]

Staff also acquire organisms directly from the hospital environment.[29,55,65,69–72] Indeed, they are just as likely to acquire pathogens after touching environmental sites as they are after caring for patients.[65,70–72] Coliforms can be recovered from the hands of nurses after touching patients' washing materials and clothing, as well as after bed making, sluice room activities, handling bedlinen and curtains, and even after a drug round.[29] Once acquired, hands may then be responsible for contaminating additional environmental sites.[7,56,73]

Contamination of hands or gloves with hospital organisms provides a highly plausible route of transmission between patients on a ward.[7,55,63,64] Hand hygiene is an easy practical method of interrupting such transmission but compliance rarely reaches the levels required to remove the risk of HAI for many different reasons.[54,74] Even when staff know that a patient is isolated because they are colonised or infected with a hospital pathogen, hand hygiene compliance is still only about 50%.[74] It is also possible that hand hygiene is insufficient to stop pathogen transmission.[70,75] Neither chlorhexidine, alcohol, nor soap and water necessarily remove contamination from hands, and some hand cleansing products are ineffective against specific pathogens.[63,70,76–78]

15.5 The role of cleaning in reducing the infection risk for patients

Whilst there remains little evidence for the benefits of general surface cleaning alone, cleaning is often mentioned as an integral part of a multifaceted response to an outbreak lacking an identified common source.[79] Numerous reports detail cleaning as a major control component for outbreaks of MRSA; VRE; *C. difficile*; norovirus; and drug-resistant *Acinetobacter*. These pathogens thrive in dust and dirt in the temperate hospital environment and contaminate numerous sites on surfaces and equipment, particularly during an outbreak.

15.5.1 Cleaning and MRSA

There is some evidence that cleaning removes MRSA from the ward environment with benefit for patients.[35,59] MRSA was isolated from 13 patients on the dermatology ward over a 14-month period.[80] Extensive environmental culturing revealed that a blood pressure cuff and the patients' communal shower were positive for MRSA, with pulsed field gel electrophoresis (PFGE) demonstrating identical DNA typing patterns from

the majority of patient isolates and both environmental sources. Control was achieved after changing of blood pressure cuffs between patients and more stringent cleaning of communal areas.[80] Another MRSA outbreak on a urological ward resisted all the usual infection control interventions such as hand hygiene promotion and isolation of patients.[81] After the outbreak strain was isolated from the ward environment, the number of domestic cleaning hours was doubled from 60 to 120 hours per week and the number of patients affected immediately decreased. The cleaning intervention was thought to have played a significant role in the termination of the outbreak and saved at least £28 000.[81]

An outbreak of glycopeptide-intermediate *Staph. aureus* (GISA) in an intensive therapy unit (ITU) proved difficult to control until further control measures, including enhanced cleaning, were introduced.[82] Again, this probably helped to stop the outbreak, although it was not possible to determine the relative roles of barrier precautions and environmental decontamination. Outwith the outbreak situation, the effects of enhanced cleaning were monitored on two matched surgical wards in a prospective controlled cross-over trial for two 6-month periods.[59] There were nine ward-acquired MRSA infections during routine cleaning periods, but only four when the wards received extra cleaning, notably targeting hand-touch sites and clinical equipment. More MRSA patient-days during the enhanced cleaning periods predicted at least 13 new cases instead of the 4 that actually occurred. The study concluded that targeted cleaning using detergent wipes and water could be a cost-effective mechanism of reducing MRSA infections.[59]

15.5.2 Cleaning and VRE

Environmental cleaning might also be important for controlling VRE.[83,84] One study describes the impact of improved cleaning on the spread of VRE in a medical ICU, with and without promotion of hand hygiene compliance.[85] Enforcing cleaning measures along with improved hand hygiene was associated with less surface contamination with VRE, cleaner healthcare worker hands and a significant reduction in VRE cross-transmission among patients. The authors concluded that decreasing environmental contamination might help to control the spread of VRE in hospitals.[85] Introducing an educational programme, contact precautions and reinforcement of environmental cleaning was the response to escalating VRE cases in a Brazilian hospital.[86] Enhanced cleaning emphasised use of bleach for bathroom surfaces and 70% alcohol for furniture and patient equipment. The overall package helped prevent dissemination of VRE throughout the hospital, including intensive care, with a decrease in attack rate from 1.49 to 0.33 ($p < 0.001$).[86] Bleach-based terminal cleaning was used for an earlier

study to control VRE in a haemato-oncology unit, again as part of an intervention package.[84]

Another package of interventions, including extensive cleaning of environmental surfaces and environmental cultures, was implemented in three ICUs by a team in South Korea.[87] During the outbreak, a total of 50 patients with VRE were identified by clinical and surveillance cultures, and 46 had vancomycin-resistant *Enterococcus faecium* (VREF). PFGE analysis of VREF isolates during the initial two months disclosed six types and clusters of two major types. Environmental surfaces were rigorously cleaned three times a day using 5% sodium hypochlorite. The outbreak was terminated 5 months after implementation of the interventions, with the weekly prevalence rate reduced from 9.1/100 to 0.6/100 patient-days, and rectal acquisition rate down from 6.9/100 to 0/100 patient-days.[87]

15.5.3 Cleaning and *C. difficile*

The benefits of cleaning for control of *C. difficile* are well established.[88,89] Following a rise in *C. difficile* cases, one hospital introduced enhanced cleaning with hypochlorite into two ICUs.[90] One of the ICUs applied the extra cleaning to all areas, including rooms used solely by staff, and sensitive clinical equipment was wiped over twice daily using hypochlorite-impregnated cloths. The other unit introduced the intensive hypochlorite clean into isolation rooms housing patients already infected with *C. difficile*. Rates of infection decreased in both units over several months and appeared to be maintained at a lower rate for at least 2 years after the cleaning intervention, despite some relaxation of the initial regimen.[90]

Increased rates of *C. difficile* infection (CDI) in three American hospitals prompted terminal room cleaning of those affected with dilute bleach instead of the usual quaternary ammonium compound.[91] All surfaces, floor to ceiling, were wiped with dilute bleach applied with towels to thoroughly wet the surfaces. The prevalence density of *C. difficile* fell by 48%, with a sustained and significant reduction on the rate of nosocomial CDI. Another group implemented daily cleaning with 0.55% bleach wipes on two medical wards with a high incidence of *C. difficile*.[92] Pre-intervention, there was a total of 31 new cases of *C. difficile* on the wards. After the cleaning strategy, there were 4 cases on these wards over the following year, representing a 7-fold decrease in cases of *C. difficile*. There were no other interventions introduced other than targeted cleaning with bleach wipes.[92]

Use of chlorine-releasing disinfectants in rooms contaminated with *C. difficile* spores reduces the number of spores in the environment, with some evidence to suggest that this reduces the risk of recurrence and spread *C. difficile*-associated disease of (CDAD).[93] Evidence is strongest for products with higher concentrations of disinfecting agents (e.g. 5000 mg/L free

chlorine). The benefits of chlorine use might be greater in units where rates of CDAD are high (e.g. geriatric rehabilitation or assessment units) or in response to outbreaks. Additionally, effectiveness of cleaning agents used in the hospital environment on levels of spores and, more important, rates of CDAD, might be related to training and time-constraints of cleaning staff.[93,94]

15.5.4 Cleaning and *Acinetobacter*

The importance of cleaning in controlling outbreaks of *Acinetobacter* spp. has been emphasised in previous studies.[95–97] One of these describes an outbreak caused by multiply resistant strains of *A. baumannii* involving more than 30 patients in two ICUs.[96] Environmental contamination was recognised as an important reservoir of the epidemic strains and the outbreak ceased only after both ICUs were closed for terminal cleaning and disinfection.[96] Another study examined the levels of environmental contamination with *Acinetobacter* in a neurosurgical ICU during a prolonged outbreak.[98] Near-patient hand-touch sites frequently yielded the epidemic strain, and there was a significant association between the amount of environmental contamination and patient colonisation. The conclusion was that high standards of cleaning play an integral role in controlling outbreaks of *Acinetobacter* in the intensive care setting, although little is known about the best way to clean in non-outbreak settings.[98]

A further study describes what happened following the introduction of bedside computers in a paediatric burns ward.[37] There was a sudden increase in the number of patients acquiring *Acinetobacter* and environmental screening demonstrated the organism on various surfaces in the patients' rooms, especially the plastic covers on the computer keyboards. Targeted infection control measures that included the use of gloves before using the computer and thorough disinfection of the plastic covers effectively terminated the outbreak. Before the outbreak occurred, no one had thought to include the computers in a routine cleaning specification.[37]

A 3-year prospective study was conducted in intensive care and coronary care units to evaluate interventions including contact isolation precautions, hand hygiene, active surveillance, cohorting patients colonised or infected with pandrug-resistant *A. baumannii* and environmental cleaning with 1:100 sodium hypochlorite.[99] The rate of *A. baumannii* colonisation and/or infection was 3.6 cases per 1000 patient-days before the intervention. One year after the intervention, the rate of *A. baumannii* colonization and/or infection decreased by 66% to 1.2 cases per 1000 patient-days ($p < .001$) and two years later by 76% to 0.85 cases per 1000 patient-days ($p < .001$).[99]

15.5.5 Cleaning and multi-drug-resistant coliforms

The importance of cleaning in controlling outbreaks of Gram-negative microorganisms other than *Acinetobacter* is difficult to ascertain, given that enhanced cleaning usually comes as part of an overall package in response to cross-infection or outbreak. Despite this, there is general consensus that environmental cleanliness is important for controlling infection. Certainly, the literature is littered with reports of outbreaks of coliforms traced to discrete pieces of equipment, specific environmental site or particular product or practice.[1] This is probably because terminating an outbreak caused by single source contamination is a lot easier than implementing a routine cleaning regimen that prevents infection from a multitude of general surfaces. Identification of a single reservoir and eradicating it usually curtails the outbreak.[28,100–102]

Persistent reservoirs of resistant *Klebsiella pneumoniae* were traced to multiple contaminated sink components in an Aberdeen teaching hospital.[100] More recently, four patients in a neurosurgical ITU became infected or colonised with extended-spectrum β-lactamase-(ESBC)-producing *K. pneumoniae* over a period over 7 months.[102] An investigation revealed that the source of this outbreak was also a contaminated sink. By replacing the sink and its plumbing and improving routines regarding sink usage and cleaning, the outbreak was terminated.[102] Biofilm-forming *K. pneumoniae* strains, such as those demonstrating prolonged survival in plumbing components, are more likely to produce ESBLs.[103]

Another outbreak of resistant *K. pneumoniae* among neonates highlights the risks of reusing disposable equipment.[101] The investigation showed that most of the babies were infected a few days after birth or just after hospitalisation. The only common feature was that those presenting with respiratory distress received mucus aspiration a few days before becoming symptomatic. Although a new aspiration tube was used for each case, the tubes had been rinsed in tap water between each aspiration for the same baby. This tap water was not changed between babies and the bowl used was not properly cleaned either. The tap water was found to be contaminated with the same type of *K. pneumoniae*.[101]

The lack of evidence for benefits from general surface cleaning alone is well recognised, even as a response to an outbreak.[104] There is one recent report emphasising additional cleaning following the identification of a carbapenemase-producing *K. pneumoniae* in a ward in a UK hospital.[105] Chlorine-based cleaning was implemented throughout the ward, including patient-related items. Enhanced cleaning was only part of the overall infection control package, however, along with a urinary catheter care bundle; patient note tagging; hand hygiene emphasis; and contact precautions

for patient cases.[105] Another report describes an educational intervention to improve hand hygiene and environmental cleaning in an 11-bedded ICU.[106] The number of patients colonised with ESBL Enterobacteriaciae during a three month pre-intervention period decreased from 70% to 40% during a post-intervention period, although it is possible that the initial high proportion of colonised patients represented an underlying outbreak.[106]

15.5.6 Cleaning and *Pseudomonas*/*Stenotrophomonas*

Pseudomonas and *Stenotrophomonas* originating from water outlets have the potential to colonise and infect patients despite a lack of evidence for specific transmission pathways.[107] Only one previous report details transmission of *P. aeruginosa* from sinks to hands during handwashing.[27] Whilst survival on dry surfaces may be only transient, persistent reservoirs of these organisms can be traced to biofilm within sink components, water lines and hospital drains.[13,108] This complex living deposit on internal plumbing surfaces hosts and protects a multitude of water-loving organisms, some of which pose a threat to debilitated patients, particularly those in ITU. Bacteria within biofilm are more likely to be able to withstand chlorine and other types of disinfectants along with greater capacity for antimicrobial resistance.[109]

Various outbreak investigations have shown that recovery of pathogens from water sources, surrounding surfaces, and patient isolates demonstrate indistinguishable strains of *Pseudomonas* and *Stenotrophomonas*.[26,98,102,110,111] An outbreak of *Burkholderia cepacia* on a paediatric unit was attributed to sinks, possibly linked with the presence of aerator filters fitted to the taps.[112] Tap aerators have also been shown to be a source of patient colonisation with *Stenotrophomonas maltophilia*.[26] For this reason, aerators should be replaced with flow straighteners in healthcare premises. Disinfection using chlorinated products, without disruption of biofilm, only offers limited control; a comprehensive cleaning initiative is required to physically remove the biofilm lining the surfaces of affected plumbing components.[111,113] These are often difficult to access and require close collaboration between Estates and domestic staff. Complete eradication is almost impossible but regular cleaning and disinfection with chlorine products will hinder further cases if it is part of a long-term maintenance programme.[4,107]

15.5.7 Cleaning and norovirus

The importance of environmental cleaning in the control of outbreaks of norovirus is widely accepted.[114,115] All general cleaning, especially toilet and bathroom areas, should use a chlorine-containing disinfectant or bleach

at a specified concentration. Detergent-based cleaning often fails to eradicate the virus from the environment.[56] One study recently reported indistinguishable genotypes of norovirus from both patient and environmental sources, including detection of viable virus in the environment following terminal cleaning.[17] The authors found expected reservoirs near toilets in bathrooms but also on numerous types of clinical equipment, e.g. pulse and blood pressure machine; alcohol gel containers, and near-patient sites. Persistence of viral reservoirs means that new admissions will be exposed to norovirus, and with current pressures to reduce the length of stay, there is a higher throughput of increasing numbers of patients vulnerable to norovirus.[17] Without scrupulous cleaning attention, outbreaks will quickly resume.

Outside hospitals, norovirus outbreaks can be devastating in closed or semi-closed communities.[116] These include sudden and extensive outbreaks in hotels or prisons, but outbreaks can also occur in nursing and residential homes, cruise-ships and schools.[117,118] An outbreak reported recently in a primary school involved 79 pupils and 24 members of staff.[118] Subsequent investigation of the outbreak showed that person-to-person contact was a major factor in the transmission of the virus, but there was evidence that the environment was also implicated. A strain of norovirus, indistinguishable from patient strains, was isolated from a computer keyboard and mouse in one particular classroom despite cleaning with bleach the previous day. Public health officials recommended hand hygiene, exclusion of symptomatic persons and thorough environmental disinfection with a diluted (1:50 concentration) bleach solution, to include sites that were not commonly cleaned.[118]

15.6 Contaminated cleaning equipment and fluids

There is not much point in implementing comprehensive cleaning schedules if cleaning agents or equipment themselves are contaminated. Poor choice of cleaning methods or agents, or inadequate maintenance of equipment will result in environmental contamination of the very surfaces that need attention. There are numerous examples of different types of cleaning cloths, including microfibre products, that spread microbes across surfaces rather than removing them.[56,73,119–121] Cleaning equipment may also become contaminated with hospital pathogens and disperse these into the hospital environment.[1,28,122,123] Disinfectants are more effective at killing pathogens than in-use detergents but some hospital pathogens can resist bactericidal effect of a particular agent.[124] Both multi-drug resistant *S. marcescens* and extremely-drug-resistant strains of *K. pneumoniae* have demonstrated increasing tolerance to chlorhexidine.[125,126] Other cleaning fluids can become contaminated with Gram-negative bacilli during use; indeed, some

formulations may encourage acquisition of resistance elements by Gram-negative organisms.[127,128]

Microorganisms use an inadequately cleaned niche to exchange genetic material coding for antimicrobial resistance and other survival mechanisms, including resistance or tolerance to disinfectants.[129,130] Once established, these hardy strains will ultimately infect debilitated patients.[130] Hospital waste water has been shown to harbour KPC-2-producing *K. pneumoniae*, suggesting widespread contamination throughout the healthcare environment.[131]

15.7 Assessment of environmental cleanliness

Various scientific methods to measure environmental soil have been devised, since visual inspection cannot ascertain the infection risk for patients.[2] A validated and risk assessed technique is needed to determine cleanliness, rather than the subjective assessment currently provided by visual inspection and clipboards. Chemical (ATP bioluminescence) and microbiological methods have been utilised by the food industry for years, and have been tested in hospitals.[2,3] Measurements from these systems have provided a range of values to model against patient risk; from these, it might be possible to choose an appropriate benchmark for routine monitoring. Hospital staff need to know exactly which levels are acceptable for patient safety purposes.[2,3,4,132]

Currently, aerobic colony counts of <2.5–5 colony forming units (cfu) per cm^2 on hand-touch sites have been tested as microbiological benchmarks.[2,3,39,59,132–134] These levels have not been standardised for use in hospitals, but similar counts have been established in the food industry. Retail and food manufacturers, plus additional agencies, also use microbiological standards incorporating the presence of indicator organisms, identification of which depends upon risk to human health from the medium monitored.[135,136] Since coagulase-positive staphylococci provide a reliable indicator of environmental hygiene, studies examining the utility of microbiological standards in hospitals have chosen both *Staph. aureus* and MRSA to help monitor cleanliness.[3,39,132–134,137]

ATP systems have varying benchmarks depending upon the type of luminometer used. These range from 25 to 500 relative light units (RLUs) for 10–100 cm^2 on hospital surfaces, [133,134,138] but there is concern that some systems are not sufficiently sensitive to detect very low microbial counts (<10 cfu/cm^2).[139,140] One study found that benchmark categories of 100 RLUs and microbial growth <2.5 cfu/cm^2 were loosely associated, since there was approximately 60% agreement between them on whether a surface should pass or fail.[134] Clearly, more work needs to be done on finding the most appropriate method for detecting microbial soil.[141] ATP

measurements can be confounded by food and drink residues; disinfectants; microfibre products; and manufactured plastics found in the cleaning and laundering industries.[2,141,142] Chosen benchmarks should reflect patient risk; surfaces in outpatient clinics are not necessarily as critical for infection risk as sites beside a ventilated patient receiving intensive care. Once these benchmarks are established, routine monitoring should be able to indicate trends in hospital cleanliness and workload, and, most importantly, when enhanced cleaning activity is required before patients are exposed to serious risk of infection or even an outbreak.[132,133]

There are alternative methods of environmental assessment, notably cleaning inspections; education; monitoring; and feedback; all of which encourage enhanced performance by housekeepers. Placing invisible fluorescent markers at key sites for later inspection and feedback for domestic staff also improves overall cleaning compliance, along with reduction of key hospital pathogens.[143] Use of ATP monitoring demonstrates pronounced effect on cleaners when they received concomitant educational guidance.[138] Domestic staff react quickly to an environmental monitoring programme because they are concerned that their jobs may be at risk.[4,85] Further studies have demonstrated differing effects between direct observation, supervision and education of staff as they clean, again showing reduction of important hospital pathogens.[144–146] There is a concern that these interventions might lose impact over time, since cleaning is physically demanding, poorly paid and subject to inadequate staffing.[147] Hence training and continual evidence-based reassessment are required as part of staff development.

15.8 Current and future trends

New methods for environmental decontamination are constantly appearing on the market. Disinfectants tend to be expensive and environmentally unfriendly.[148] Some formulations persist in the water courses underlying towns and cities and exert long-term effects on other biological systems. This has encouraged 'greener' alternatives, particularly those that ultimately degrade into harmless components. Examples include ultra-heated steam; electrolysed water; ozone and hydrogen peroxide, amongst others.[149–152] Electrolysed water products have already shown potential for decontamination of the healthcare environment.[153,154]

In addition to these, are novel cleaning materials and equipment such as microfibre; scrubbing machines; microbicidal gases, vapours and anti-fogging or mist systems; ultraviolet (UV) light-emitting devices; air ionisers; and a range of high-pressure steam cleaners.[152,155–162] A recent paper describes the effect of a newly developed portable pulsed ultraviolet (UV) radiation device on bactericidal activity and its impact on the labour burden when

implemented in a hospital ward.[161] The use of pulsed UV in daily disinfection of housekeeping surfaces reduced the working hours by half in comparison with manual disinfection using ethanol wipes.[161]

There are new types of antimicrobial coatings available for linen, equipment, furniture and general surfaces such floors, walls and doors.[163,164] Practically anything that can be impregnated with chemicals, or coated with microbicidal paint, could potentially be marketed as 'antibacterial' for healthcare environments. Bioactive surfaces or coatings can contain heavy metals (or their derivatives) such as copper, zinc, silver or titanium, or antiseptics and biocides.[165–170] There is evidence that coating near-patient hand-touch sites with copper reduces organisms such as MRSA and consequently, the risk of HAI.[169,171]

There are also electrostatic and inhibitory surfaces that repel microbial adhesion and even coatings marketed as 'self-cleaning'.[163,172] Different variations on a theme appear at frequent intervals, using ever more innovative technology. One recent example is a coating of nano-silver particles combined with titanium dioxide to form highly reactive TiO_2 Ag particles.[173] This invisible protective nanocoating can be applied onto a range of surfaces under low temperatures, which means that virtually all environmental surfaces in a hospital could theoretically be treated.[173]

Numerous guidelines emphasise the importance of cleaning but offer little practical advice on how to achieve this, or how often sites should receive cleaning attention. Microbial reservoirs are likely to fluctuate at different sites throughout the day. However delivered, viable organisms will persist according to their capacity for survival, unless removed by an effective cleaning regimen. Even if cleaning occurs on a regular basis, pathogens may recontaminate surfaces or equipment immediately after the cleaning process.[174–176] Using agents or surfaces with residual microbiocidal activity to repel contamination would mean that hand hygiene might not be quite so critical, although staff should obviously not abandon their hand washing.[54,177,178] Provided such products could be shown to function as postulated, without significant toxicity, surface cleaning might also become less of an issue, although as with clinical staff and hand hygiene, routine cleaning practices should still be retained. Alternatively, a high-frequency cleaning regimen would theoretically discourage the accumulation of potential pathogens continually deposited on surfaces.[179]

Despite future promise from these products, traditional cleaning methods should not be relaxed or abandoned even if the whole hospital is treated to novel cleaning methods or coated with bioactive veneer.[30] No one single process will remove all relevant microbial soil from the hospital. There have already been problems reported with some of the methods mentioned, such as microfibre, steam cleaning, ozone, hydrogen peroxide and high-intensity light irradiation.[121,151,155,156,160, 174,180–184] Furthermore, concern remains over

activity of disinfectants in the field, since laboratory testing does not necessarily predict what happens on hospital surfaces.[185] There are always toxicity and cost issues to consider, and potential cross-resistance between disinfectants, antiseptics and antimicrobial agents.[148,186]

All novel cleaning methods require a comprehensive assessment in association with patient outcome before widespread adoption in healthcare systems. Cash-strapped hospitals should not invest in potentially toxic and/or expensive cleaning methods or agents without good reason. It goes without saying that traditional detergent-based cleaning should also receive a full and thorough appraisal.[79] It is possible that simply increasing the cleaning frequency of established high-risk sites with detergent could be a crucial factor in reducing infection risk, rather than an expensive and potentially toxic biocide. [79,179]

15.9 Conclusion

Microbiological screening has demonstrated numerous types of pathogen surviving throughout our hospitals. There is evidence to show that these resilient organisms pose a real and substantive infection risk for patients. The cleaning process could potentially have a huge impact on this risk, if it is aimed at the most frequently contaminated sites, physically removes or kills viable organisms; and takes place a sufficient number of times to inhibit the accumulation of pathogens delivered by air or hands. Whilst there are a flourishing number of novel disinfectants, antimicrobial surfaces and equipment now on the market, few have been properly assessed against patient infection risk and potential toxicity represents a long-term environmental threat. Establishing risk-based standards for all surfaces throughout the hospital would allow monitoring, measurement and scientific evaluation for the benefit of all patients and staff.[187] Frequent application of detergent-based cleaning requires urgent appraisal in order to be able to adequately and comprehensively compare future alternatives for cleaning our hospitals.

15.10 References

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