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REVIEW

Hospital cleaning in the 21st century

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Abstract More evidence is emerging on the importance of the clinical environment in encouraging hospital infection. This review considers the role of cleaning as an effective means to control infection. It describes the location of pathogen reservoirs and methods for evaluating hospitals' cleanliness. Novel biocides, antimicrobial coatings and equipment are available, many of which have not been assessed against patient outcome. Cleaning practices should be tailored to clinical risk, given the wide-ranging surfaces, equipment and building design. There is confusion between nursing and domestic personnel over the allocation of cleaning responsibilities and neither may receive sufficient training and/or time to complete their duties. Since less labourious practices for dirt removal are always attractive, there is a danger that traditional cleaning methods are forgotten or ignored. Few studies have examined detergent-based regimens or modelled these against infection risk for different patient categories. Fear of infection encourages the use of powerful disinfectants for the elimination of real or imagined pathogens in hospitals. Not only do these agents offer false assurance against contamination, their disinfection potential cannot be achieved without the prior removal of organic soil. Detergent-based cleaning is cheaper than using disinfectants and much less toxic. Hospital cleaning in the 21st century deserves further investigation for routine and outbreak practices.

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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 [3]. 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 factor in preventing infection has been seriously disadvantaged because there are no accepted risk-based standards to verify whether a hospital is truly clean and safe [4].

Visual inspection of the hospital environment does not provide a reliable qualitative nor quantitative assessment of the infection risk for patients [2, 4]. Microbes are invisible and they are not necessarily associated with visual dirt. Furthermore, the impression of cleanliness is confounded by clutter, excess equipment, cramped wards and fabric deficits [1]. Visual assessment will, inevitably, be subject to bias under these circumstances, as well as subject to an individual's perception. 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. Indeed, there has been a recent surge of articles supporting the importance of cleaning [5].

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Pathogens survive in the hospital environment

The microbes linked with HAI have two special properties. Not only do they cause disease, but they survive in the hospital environment for weeks [1, 6]. Examples include methicillin-resistant *Staphylococcus aureus* (MRSA), *Clostridium difficile*, *Acinetobacter* and vancomycin-resistant enterococci (VRE) [1, 6, 7]. Viruses such as norovirus and influenza, and fungi such as *Candida albicans*, may also persist in hospitals for long periods of time [6]. Gram-negative coliforms, e.g. *Escherichia coli* and *Klebsiella* spp., are less robust but survive on dry, as well as wet, surfaces, although this tends to be for shorter periods of time than hardy *Acinetobacter* and Gram-positive organisms already mentioned [6, 8]. A hospital pathogen will persist in an appropriate environmental niche unless removed through some cleaning process [1]. If abandoned, it may contaminate hands or be uplifted amongst dust by air currents and deposited onto a patient or surfaces beside the patient [9–13].

Location of pathogen reservoirs

Environmental screening can identify pathogens on a variety of hospital surfaces [8, 13–17]. Organisms attached to droplets, skin scales or dust particles may intermittently disperse through the atmosphere, ultimately settling on floors, but any surface can host a range of microbes for varying lengths of time [1, 6]. These include general surfaces such as shelves and ledges; curtains, linen and clothes; furniture; computers, telephones and all items of clinical equipment. Some pathogens, notably, *Pseudomonas* spp., persist in damp places such as sinks, showers and baths; others, e.g. *C. difficile* and VRE, contaminate toilet areas or commodes [14, 18–20]. Norovirus can be found virtually everywhere, although this usually reflects the situation during seasonal outbreaks [21]. Dust-associated microbes such as MRSA and *Acinetobacter* settle on rarely cleaned and/or inaccessible surfaces, such as shelves, highly placed equipment and computer keyboards; coliforms such as *Klebsiella* and *Serratia* inhabit buckets, bowls, mops and liquids; and ubiquitous *Aspergillus* and *Bacillus* spp. are spread through air currents, particularly during hot dry summers [1].

Some items, e.g. sheets, beds, lockers and overbed tables, tend to host pathogens more frequently than others [15, 22]. This may be due to patient shedding from colonised sites, inadequate cleaning and/or frequent handling, but it increases the risk of infection for all patients, particularly the immunocompromised and/or those receiving antibiotics, indwelling devices and/or surgery. The greatest infection risk for patients comes from surfaces beside or on beds [13, 15, 23, 24]. Contamination of these sites also provides an opportunity for hands to pick up pathogens and carry them elsewhere because they are touched so frequently. In addition, persistence between admissions means that future patients are put at risk, particularly those who are non-ambulant. There are several reports demonstrating increased risk of acquiring a specific pathogen if a patient is admitted into a room previously occupied by a patient colonised or infected with the same organism [5, 25–27].

Items or surfaces that are frequently touched present the largest risk of contamination by pathogens spread on hands [4, 13, 15]. These sites then act as reservoirs for subsequent dispersal. Seeding pieces of cauliflower mosaic virus onto a telephone in a paediatric unit allowed researchers to track the movement and spread of the virus marker around the unit, from hand-touch site to hand-touch site, over the course of hours and days [28]. Another community-based study placed virus marker onto a door handle in a students' flat and charted the movement of the viral pieces via hands [29]. These studies not only confirm the role of hands in mobilising microbial markers between hand-touch reservoirs, but they also highlight which sites are most frequently contaminated. Furthermore, the community study revealed how direct hand-to-hand contact, as which occurs during hand-shaking, was able to spread viral pieces to a succession of people following initial contamination from the door handle. Past and recent studies have shown how pathogens can be retained on hands or gloves following contact with the hospital environment [9, 10, 30, 31].

Cleaning reduces infection risk for patients

Many studies state that cleaning is a vital component of the intervention package required to reduce hospital-acquired infection [5]. Enhanced cleaning is nearly always incorporated into an infection control strategy in response to an outbreak. Numerous reports detail cleaning as a major control component for outbreaks of norovirus, MRSA, *C. difficile*, VRE and drug-resistant *Acinetobacter* [17, 21, 27, 32–36]. These pathogens thrive in dust and dirt in a warm hospital environment and easily contaminate surfaces and equipment, particularly during an outbreak. Extra cleaning following failed infection control measures finally terminated an outbreak of EMRSA-16 [32], with similar reports describing the need for enhanced cleaning for the termination of VRE and *Acinetobacter* outbreaks [27, 33, 35, 36]. Disinfectant-based cleaning is performed routinely for healthcare environments exposed to patients with *C. difficile*, whether it is part of the management of sporadic cases or during an outbreak [24, 34].

Enhanced cleaning and surface disinfection with bleach-containing products for wards containing norovirus patients is essential for the rapid resolution of an outbreak. Insufficient cleaning, or the mistiming of a cleaning intervention, encourages the re-emergence of cases [11]. One study recently reported indistinguishable genotypes of norovirus from both patient and environmental sources, including the detection of persistent virus in the environment following terminal cleaning [21]. The authors found expected reservoirs near toilets in bathrooms but also on clinical equipment and throughout the bedside environment. The persistence of viral reservoirs will expose new patient admissions to norovirus, which could regenerate an outbreak. This is further exacerbated by a higher throughput of more patients vulnerable to norovirus, due to shorter lengths of stay [21]. The persistence of bacterial pathogens also exposes new patients to enhanced infection risk, as aptly demonstrated by studies examining the residual contamination of rooms previously occupied by infected patients [5, 25–27].

Outbreaks of pseudomonas and stenotrophomonas have been traced to tap filters and aerators, sink traps and drains, where these water-associated bacteria hide within adherent biofilm [18, 37]. 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. These are often difficult to access and require close collaboration between estates and domestic staff. Complete eradication is almost impossible, but regular cleaning will hinder further cases if it is part of a long-term maintenance and disinfection programme [37].

Since cleaning is just one intervention within an overall control package, its importance as a stand-alone activity is often questioned. This does not encourage managerial support for hospital cleaning services outwith the outbreak situation, particularly if resources are limited [1]. Lack of evidence and continued cost-cutting discourage efforts to convince managers of the need for domestic review [1, 32]. It is worth considering the potential cost of a serious outbreak, since these costs invariably exceed prior infection control outlay [32, 38]. The clinical management of hospital-acquired infection involves extended length of stay as well as expensive, powerful drugs. Such avoidable costs are well worth considering when planning basic cleaning schedules [1, 23, 32].

Sites for targeted cleaning

Since contaminated near-patient hand-touch sites are thought to constitute the highest risk for patients, cleaning schedules should emphasise these sites [4]. There is little scientific support for this at present and virtually no evidence to inform on cleaning methods or frequency. One study introduced the disinfection of high-risk sites in intensive care units with a copper-based disinfectant and microfibre regimen without evidence for patient benefit; another targeted hand-touch sites on two surgical wards for a year with a high-frequency detergent-based regimen and halved the number of acute MRSA infections [23, 39]. A study in an Irish intensive care unit established how often MRSA was recovered from discrete sites beside non-infected and infected patients when screened at varying intervals. Level 2 cleaning (i.e. detergent-based cleaning of a room/bed space followed by 1% hypochlorite) was effective in eliminating MRSA initially, but sites soon became recontaminated [40]. It is possible that high-risk surfaces in areas such as intensive care units will require four-hourly cleaning attention in order to control recontamination by specific pathogens, notably, MRSA [39, 40]. Staff and patients (and relatives) habitually shed MRSA into the hospital environment, despite comprehensive attempts at removal [41].

Some environmental sites are forgotten or ignored for various reasons. If the bedside locker is covered with personal belongings, cleaning will be abandoned when staff are busy. Bed controls for electric beds and nurse call-buttons or consoles are in constant use but rarely get cleaned, probably because nobody thinks about it. The underside of the overbed table is touched everyday by the patient and staff, but it is usually only the upper surface which receives a wipe down before and after mealtimes [42]. An organism intent on accessing the gastrointestinal tract, e.g. *C. difficile*, would do well by contaminating this particular site. A recent audit on a surgical ward found high levels of organic soil on clinical items that did not appear to have anyone responsible for their cleaning [43].

Studies using fluorescent markers or kits for measuring organic soil have confirmed that many high-risk sites escape appropriate cleaning [5, 19, 44–47]. Wide and flat surfaces are much easier to clean than small fiddly areas, especially items such as buttons, switches and equipment controls [5, 44, 45]. Auditing surfaces and equipment on a ward can establish what is handled, how often it is handled and who has cleaning responsibility [43, 48]. The results of such an audit would provide basic information for the manipulation of cleaning schedules, although cleaning responsibilities and resources for any extra cleaning hours would require deliberation at managerial levels [49].

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]. Stating that a hospital is ‘clean’ means almost nothing unless a validated and risk-assessed technique has been used to determine cleanliness. Chemical (ATP bioluminescence) and microbiological methods have been utilised by the food industry for years, and have been tested in hospitals [2, 4]. Measurements from these systems have provided us with a range of values to model against patient risk; from these, it might be possible to choose an appropriate benchmark for routine monitoring. There would be real benefit in knowing exactly which levels are acceptable for patient safety purposes, from a validated scientific assessment of surface cleanliness [4, 50].

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, 4, 15, 23, 50–52]. These levels have not yet been standardised for hospital use, but similar counts have been established for the food industry. Additional agencies also use microbiological standards incorporating the presence of indicator organisms, the identification of which depends upon risk to human health from the medium monitored [53, 54]. Since coagulase-positive staphylococci provide a reliable indicator of environmental hygiene, several studies examining the utility of microbiological standards in hospitals have chosen coagulase-positive staphylococci for monitoring cleanliness [15, 23, 50–52, 55].

ATP systems have varying benchmarks, since it depends upon the type of luminometer used. These range from 25–500 RLUs for 10–100 cm^2 on hospital surfaces [47, 51, 52]. Values have been decreasing as equipment becomes more sophisticated [56]. One recent study found that benchmark categories of 100 RLUs and microbial growth <2.5 cfu/cm^2 were loosely associated, in that there was approximately 60% agreement between them on whether a surface should pass or fail [52]. Clearly, more work needs to be done on finding the best method for detecting microbial soil and choosing the most reliable benchmark for different sites and locations. ATP measurements can be confounded by food and drink residues, disinfectants, microfibre and manufactured plastics found in the cleaning and laundering industries [2, 57]. Different values should be chosen, depending upon patient risk; surfaces in outpatient clinics are not necessarily so critical for infection risk as sites beside a ventilated patient receiving intensive care. Once these benchmarks are established, routine monitoring could indicate trends in hospital cleanliness and workload, and, most importantly, when enhanced cleaning activity is required before patients are at risk of infection or even an outbreak [50–52].

Monitoring domestic effect

Assessment of surface-level cleanliness is not necessarily the same as assessment of cleaning effectiveness by domestic personnel. Individuals vary in their attitudes and abilities towards cleaning tasks, and these change from day to day due to any number of personal and professional factors [19]. Cleaning inspections, or perceived threat of these, will motivate staff to clean more thoroughly, as will competition between individuals or teams responsible for specific clinical areas. Education, monitoring and feedback have enhanced performance by housekeepers [5, 33, 45–47, 58]. Placing invisible fluorescent markers at key sites for later inspection and feedback for housekeeping staff has also succeeded at improving overall cleaning compliance, with concomitant reduction of hospital pathogens [5, 44, 45]. The use of ATP monitoring clearly showed the effect on domestic staff when they received educational guidance during the study [47]. Further studies have demonstrated differing effects between direct observation and supervision of staff as they clean, again with the reduction of key environmental organisms [59].

The trouble with motivating staff is that both short and longer term stimuli aimed at improving cleaning standards wear off over time. If cleaning fails, it is more likely to be a failure of personnel, rather than of product or procedure [58]. Domestic personnel have a tiring and repetitive physical job to do. Maintaining high levels of compliance deserves appropriate recognition, but since it is difficult to measure, extra effort usually goes unrewarded.

Cleaning staff requirements

General cleaning is performed by in-house staff or contracted out to a private company [60]. There are multiple arguments for and against each type of cleaning service but little real evidence of significant deficit for either in cleaning quality. It is generally agreed that speed of response and changing schedules is easier with in-house staff than contracted cleaners, since the latter must adhere to rigid contracts laid down after much negotiation [60]. The lack of urgent domestic response can present problems following cross-contamination incidents or during widespread outbreaks, especially out-of-hours. This then compounds bed turnover, since patients cannot be admitted into contaminated areas awaiting cleaning attention. Hospitals need flexible 24-h support services, with sufficient staff for immediate response following contamination incidents [60].

Domestic cleaners are not usually expected to clean specific patient items such as clinical notes, drip stands or commodes, nor clinical equipment, including electrical items [61]. These are nursing responsibilities, although there is no reason why suitably trained domestics could not absorb selected tasks. High-risk hand-touch sites beside the patient are not always cleaned by domestic staff either, since occupied beds, overbed tables and lockers are often cleaned by nurses [61]. Not only has this division of cleaning responsibilities caused confusion for managers charged with setting standards, but it has also meant that a whole range of objects have been missed from the cleaning schedule [5, 43–45, 48–50].

Doubtless, there are more forgotten items, depending on when and where cleaning audits are performed. Even if specific objects are assigned cleaning responsibility, they may not receive the requisite attention simply because staff do not have sufficient time. It is already well known that increasing workload will compromise infection control activities [62]. Nurses may be too busy to clean furniture and equipment properly, because patients' needs come first when the ward is hectic [50]. Activities such as delivering meals or washing patients would be seen as greater priority than wiping over the top of the locker or bed control. Since housekeeping duties do not necessarily fluctuate with the same intensity—or urgency—as nursing workload, it is possible that assigning more items to domestic staff might enhance the overall cleaning opportunities [43].

As with all professional activities, cleaning requires teaching and training, and never more so than in a hospital. Cleaning a crowded cluttered ward, with isolation rooms containing infected patients, is far more complex than cleaning offices or schools [60]. Unfortunately, the lowly status of dirt removal does not support extensive training and new recruits are often provided with nothing more than a perfunctory introduction to the cleaning process. Little knowledge of the microbiological principles underlying hygienic practice means that key microbial reservoirs in the clinical environment go unrecognised. In addition, cleaning equipment may be abused, poorly maintained and/or improperly stored; cleaning liquids may be incorrectly constituted and used inappropriately; and patients are placed at risk from exposure to contaminated equipment or materials, e.g. cloths applied to near-patient sites after use on toilets, rather than being discarded. Regular teaching of basic microbiological principles for all domestic staff, similar to that delivered to kitchen and catering staff, would be beneficial for cleaners [63].

Cleaning methods and materials

Detergent-based cleaning might remove microbes, but will not necessarily kill them. There are numerous examples of contaminated cleaning cloths and equipment actually spreading microbes across surfaces rather than removing them [11, 64–67]. Disinfectants are more effective at killing pathogens, particularly bacterial spores, but they tend to be expensive and environmentally unfriendly [3, 68]. Some formulations persist in the water courses underlying our 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 [69–72].

New methods to decontaminate the environment are constantly appearing: microfibre products; upgraded cleaning equipment; microbicidal gases, vapours and anti-fogging or mist systems; ultraviolet (UV) light-emitting devices; air ionisers; and a range of high-pressure steam cleaners [42, 72–78]. Innovative products are encouraged, sponsored and developed, thanks to collaboration between infection control professionals, academics and manufacturers [77, 79]. It is particularly important for such collaboration to start at an early stage of planning, so that any new technology can be targeted specifically for the healthcare environment. There are antimicrobial coatings available for items such as clothes (pyjamas) and linen (sheets and curtains); furniture (lockers and bedside tables); clinical equipment (computers and catheters); hand-touch sites (handles, pens and toilets); stationary; plastic items; and general surfaces such floors, walls and doors [80, 81]. Practically anything that can be impregnated or coated with microbicidal paint or chemicals could potentially be marketed as 'antibacterial' for healthcare purposes.

Bioactive surfaces or coatings can contain heavy metals (or their derivatives), such as copper, zinc, silver or titanium, or antiseptics and biocides [82–87]. There are electrostatic and inhibitory surfaces that repel microbial adhesion, and even products marketed as 'self-cleaning' coatings [78, 80, 88]. 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 Ti O^2 Ag particles [80]. 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 [89].

Triclosan deserves a special mention, since a variety of triclosan-impregnated materials have been available in supermarkets since 1997. Since then, the availability of products claiming antibacterial protection has increased rapidly in the UK. In the USA, a similar trend has been driven by increased public awareness and fear of microbial infections [90]. Many domestic products incorporate these agents, including dishcloths, lunch boxes, tooth brushes, washing-up liquid and hand-washing gels [80]. Manufacturers claim that these items give 'permanent protection against bacteria', although there is little independent scientific evidence of either efficacy or adverse effects [90–92].

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. Since frequently touched sites rapidly become recontaminated, disinfectants or coatings with prolonged biocidal activity might be useful for inhibiting further recontamination [40, 80, 93]. Using agents with residual activity to repel contamination by susceptible pathogens would mean that hand hygiene might not be quite so critical [94]. Provided that such products could be shown to function as postulated, without significant toxicity, surface cleaning would also become less of an issue.

Despite future promise, traditional cleaning methods should not be relaxed or abandoned, even if the whole hospital is treated to novel decontamination systems or coated with bioactive veneer [80]. No one single process will remove all relevant microbial soil from the hospital. There has already been concern raised over the efficacy of some of the methods mentioned, such as microfibre, steam cleaning, ozone, hydrogen peroxide and high-intensity light irradiation [41, 42, 66, 67, 71, 74, 95–99], and doubts remain over disinfectant activity in the field, since laboratory testing does not necessarily predict what actually happens on hospital surfaces [100]. In addition, there are always toxicity and cost issues to consider, and potential cross-resistance between biocides and antimicrobial agents [68, 101]. Regarding triclosan, there may be cross-resistance between this biocide and antimicrobial drugs. Given the widespread use of triclosan in various products, this should continue to be monitored [102, 103].

Coating constituents can wear off over time, degrade or simply fail due to the accumulation of organic soil [80]. They might also encourage unforeseen long-term health problems in exposed persons or additional toxic effects on the environment [80]. These futuristic surfaces might seem appropriate for a 21st century hospital, but they might offer false assurance if not properly tested over time. All require a comprehensive assessment in association with patient outcome before widespread adoption in healthcare systems. Cash-strapped hospitals and care homes should not invest in potentially toxic and/or expensive coatings without good reason. It goes without saying that traditional detergent-based cleaning should also receive a full and thorough appraisal [104]. Surprisingly, this has not yet happened. It is possible that simply increasing the cleaning frequency of established high-risk sites could be a crucial factor in reducing infection risk, rather than some toxic alternative [104]. Soap and water are also much less costly.

Conclusion

There is increasing evidence to support basic cleaning in hospitals. Targeted and comprehensive cleaning regimens reduce the risk of acquiring a hospital pathogen. Strengthening domestic schedules by highlighting high-risk sites beside the patient offers a cost-effective strategy independent of nursing pressures and escalating bed occupancy rates. Comprehensive cleaning is also easier to implement than persuading busy staff to wash their hands or by reducing empirical antimicrobial use. Microbes are becoming increasingly resistant to antibiotic agents, and there are fewer new drugs being developed by the pharmaceutical companies. There are a host of innovative new ideas in response to the burgeoning debate on decontamination. These varied surfaces, coatings, cleaning methods and products offer a 21st century response to labour-intensive cleaning, but all require robust evaluation in order to make the best decisions for our patients and future patients. The easy option may not necessarily be the best way forward. However, novel products offer some assurance that we will be able to control environmental dirt when it matters. A culture of hygiene pervading all healthcare facilities would influence and encourage the importance of cleaning and cleanliness for everyone. Global business and industry already play a central role in bringing novel methods onto the market; working together with doctors and scientists, government and cleaners themselves should continue to establish the importance of cleaning for everyone in the 21st century.

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