Importance of the environment in meticillin-resistant *Staphylococcus aureus* acquisition: the case for hospital cleaning

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In the UK, we continue to debate the importance of hospital cleaning in relation to increasing numbers of patients acquiring meticillin-resistant *Staphylococcus aureus* (MRSA). However, there is little direct evidence for the effectiveness of cleaning because it has never been afforded scientific status. Hospital hygiene is usually assessed visually, but this does not necessarily correlate with microbiological risk. A more robust case for hospital cleaning can be presented by considering the evidence for all the stages of the staphylococcal transmission cycle between human beings and their environment. Cleaning has already been accepted as an important factor in the control of other hardy environmental pathogens, such as *Clostridium difficile*, vancomycin-resistant enterococci, norovirus, and *Acinetobacter* spp. This Review will show why the removal of dirt might have more impact on the control of MRSA than previously thought. Introduction of additional cleaning services is easier than improvements in hand-hygiene compliance.

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Introduction

There is much concern over the state of hygiene in hospitals.[1–3] The UK general public seem to associate visibly dirty wards with increasing rates of meticillin-resistant *Staphylococcus aureus* (MRSA) acquisition,[4] but historically there has been little evidence that the environment is important in endemic hospital-acquired infection.[5–9] This premise has been challenged since the increase in MRSA in hospitals in the past decade.[1,10] Because a clean environment is usually taken for granted, it is not surprising that there is little evidence to show that cleanliness could be an important control factor in the spread of MRSA.[11] Furthermore, the measurement of how clean a hospital is other than by visual assessment, which is both subjective and inaccurate, is difficult because such an assessment does not necessarily correlate with microbiological risk.[12–14]

Various audits and standards have been published for the express purpose of improving the appearance of the hospital environment and thus helping to alleviate public concern.[15,16] There have also been cleaning manuals, model cleaning contracts, infection-control guidance, and monitoring strategies.[17–20] These government-sponsored documents may address the aesthetic demands from patients and their relatives about the superficial appearance of hospitals, but they are based on visual assessment and fail to recognise that microorganisms, including human pathogens, are invisible to the naked eye.

The issue of hospital-acquired infections is compounded by the current politically generated drive to reduce waiting lists. Hospitals are crowded with sick people in close proximity to one another, even though years of work in infection control have shown us that patients pass their microorganisms to those nearby. This was first recognised by Florence Nightingale in the 19th century, at least 10 years before the advent of bacteriology.[21] She concluded that the use of small separate rooms could have prevented the high rate of mortality in maternity cases after an outbreak of erysipelas at a midwife training school.[22] However, lack of isolation facilities and continued pressure on the availability of beds provide a serious challenge to standard principles of infection control. A recent study has confirmed an association between MRSA bacteraemia rates, bed occupancies, and even bed turnover times.[23] Despite this finding, a UK House of Lords debate on MRSA included a response that stated that there is no conflict between good cross-infection control and good bed management.[24] Therefore, not only do governmental faculties not understand the link between visible dirt and the presence of pathogenic microorganisms, but they also do not support the premise that crowded hospitals facilitate the spread of infection.[23,24] This attitude reminds us of the situation 150 years ago in the hospital at Scutari, and then on return to the UK, when Florence Nightingale tried to convince the authorities of the need for basic hygiene and ventilation in health-care institutions, poorhouses, and army barracks.[22]

Only a few studies provide evidence that cleaning reduces the risk of acquiring MRSA in health-care institutions.[10,25–27] There is another way, however, of justifying cleaning as a useful control strategy for MRSA. We already have evidence to support each of the individual components of the staphylococcal transmission cycle between patients, staff, and the inanimate environment.[28–30] Much of the work on coagulase-positive staphylococcus, originally done 50 years ago, is as relevant for MRSA as it is for its susceptible predecessor. The epidemiological properties of *S aureus*, whether meticillin resistant or not, remain the same. One difference between the hospital staphylococcus of the 1960s and current MRSA strains is that isoxazolyl penicillins (eg, flucloxacillin) quickly cured patients with *S aureus* infections before it had a chance to spread to other patients or into the environment. Additionally, the hospitals received more cleaning at that time, since they had not been exposed to today's

Panel 1: The debate on hospital-acquired infection and hospital cleaning

- There is no evidence; cleaning has never been regarded as an evidence-based science
- Aesthetic considerations make cleaning difficult to assess
- No way to measure the cleaning process or its impact on the environment
- Confounded by fabric and maintenance deficits
- We cannot see the microorganisms
- It costs money
- Cleaning has always been taken for granted

emphasis on cost cutting. Now, of course, we do not have a quick cure for MRSA—currently available drugs are either toxic or expensive, or relatively inefficient, and most have to be given parenterally.[31] Resistance has already been shown for newly released agents.[32,33] This condemns colonised or mildly infected patients to conservative management only, thus enhancing their risk for future sepsis as well as providing the organism with an opportunity for dispersal throughout the environment and to others.

Even if the epidemiology of the staphylococcus has not changed over the years, there are, however, differences in the type of patients that we see nowadays and the clinical environments in which they are nursed. Patients are older, immunologically weaker, and are subjected to far more invasive procedures and devices than the patients of 50 years ago. Furthermore, there has been a huge influx of electronic equipment into the near-patient vicinity, providing more hand-touch sites that require a greater degree of sophisticated cleaning attention. Certain liquid cleaning agents would damage many items of medical and nursing equipment. All of these differences could have contributed towards an increase in MRSA acquisition in modern hospitals.

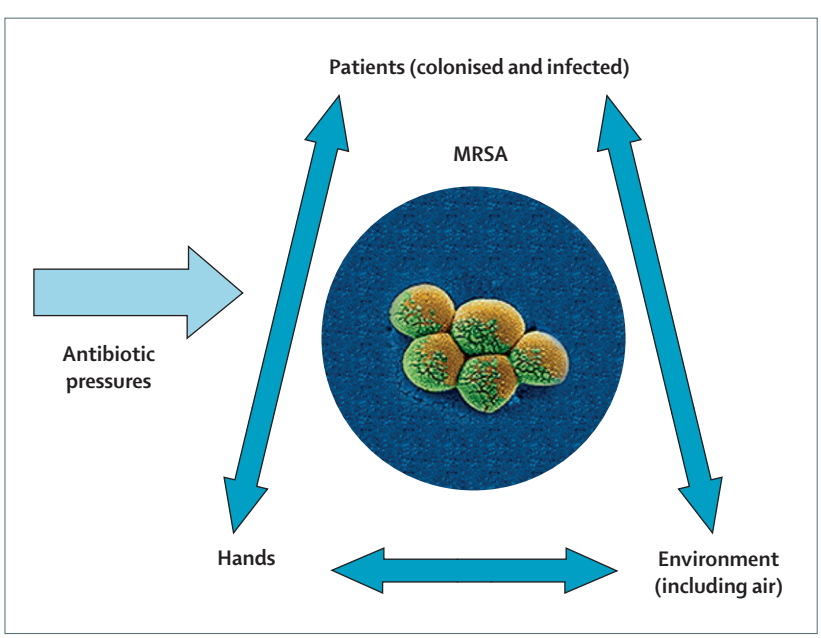

Figure 1: Dynamic transmission cycle of MRSA

Panel 2: Component statements within the staphylococcal transmission cycle

- People carry staphylococci
- People shed staphylococci into the general environment
- Staphylococci contaminate specific items in hospitals
- Staphylococci survive in the hospital environment
- People transmit their staphylococci to other people
- Staphylococci spread between people and the environment
- Small numbers of staphylococci can initiate infection
- Various cleaning methods reduce MRSA in the environment
- Cleaning reduces staphylococcal infection rates
- Cleaning is important in the control of other pathogens

This Review will present the evidence that supports the epidemiological and transmission characteristics of coagulase-positive staphylococci. Each component of the transmission cycle can be considered independently in order to assess the potential impact of cleaning.

The transmission cycle

The staphylococcal transmission cycle can be broken down into several stages, each of which is supported by studies. Additionally, there is direct evidence for the benefits of cleaning, both for control of staphylococci and for other hardy hospital pathogens in the clinical environment (panel 1). The propagation of this generally human commensal bacterium is perpetuated by a dynamic staphylococcal transmission cycle between human beings and their environment (figure 1). The coagulase-positive staphylococcus is the most common bacterial pathogen worldwide, and this fact alone generates concern over the insidious loss of antimicrobial agents with which to treat it.[34] The possibility that cleaning could truly have an impact on staphylococcal transmission justifies a closer look at its properties (panel 2).

People carry staphylococci

S aureus colonises many sites on the human body (figure 2), of which the anterior nares is the most common carriage site.[28–30,35,36] About 30% of the population are found to carry *S aureus* at any one time; this includes 20% who always seem to be colonised, and a further 10% who are transient carriers.[30,35] Some people have an inherent tendency to always carry *S aureus* and they recolonise very quickly after eradication attempts. They

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may carry the same strain for months, or even years, unless it is replaced by another strain that displays greater adherent properties. Screening among the general population rarely identifies more than one strain colonising a habitual carrier.[30,37,38]

There seems to be a link between *S aureus* nasal carriage and staphylococcal infection.[36] A causal relation between carriage and an infecting strain is shown by the fact that the nasal strain of *S aureus* and the infecting strain share the same genotype.[39] Given the propensity for people to pick, touch, or blow their noses, it is not surprising that carriers will often harbour their own strain of *S aureus* on their fingers, which they will then transfer to any site accessible to their hands.[36,40] Application of a topical antibiotic into the nose temporarily eliminates carriage and reduces the risk of infection.[41]

People shed staphylococci into the general environment

The extent to which a carrier sheds his or her strain into the environment is very variable.[36] Some individuals are surrounded by minute skin particles, each associated with a few colony-forming units (CFUs) of staphylococci, but in such great quantities that the individual is referred to as a "cloud adult".[42] This is seen in people with an upper respiratory tract infection or those with exfoliative skin conditions. Some individuals shed after antibiotic treatment, some shed depending on which sites are colonised, and other people seem never to shed at all.[42,43] Thus, coagulase-positive staphylococci may be found normally colonising people, in the surrounding air, or in the environment in which they live or through which they have just passed.

Staphylococci can be detected in the general environment by use of air sampling, settle plates, and environmental microbiological screening.[29] Skin particles with adherent staphylococci fall to the floor under gravity, or indeed onto any horizontal surface that interrupts their flight. Air sampling shows the dynamic nature of staphylococcal dispersal, but the organisms' final destination is usually the floor. Air currents or draughts, such as those created when a door or window is opened, will encourage skin particles to remain airborne; equally, a sudden blast of air will elevate resting particles to become airborne. Smaller and generally more mobile particles will take longer to sink to the ground and are therefore more susceptible to air turbulence.[44,45]

Studies that have shown *S aureus* to be present in the environment are often done in response to a hospital outbreak or as a general fact-finding investigation.[44,46–54] All such studies have shown the presence of coagulase-positive staphylococcus wherever they have looked. Furthermore, some studies have established that environmental strains may be genotypically indistinguishable from strains obtained from patients within the same environment.[47,48,50,51,53,54]

Other studies have specifically looked for MRSA in the air in hospitals.[51,55] One such study did sequential air sampling before and after bed making and showed that MRSA counts remained elevated for up to 15 min after the bed was made.[56] If airborne transmission of MRSA is

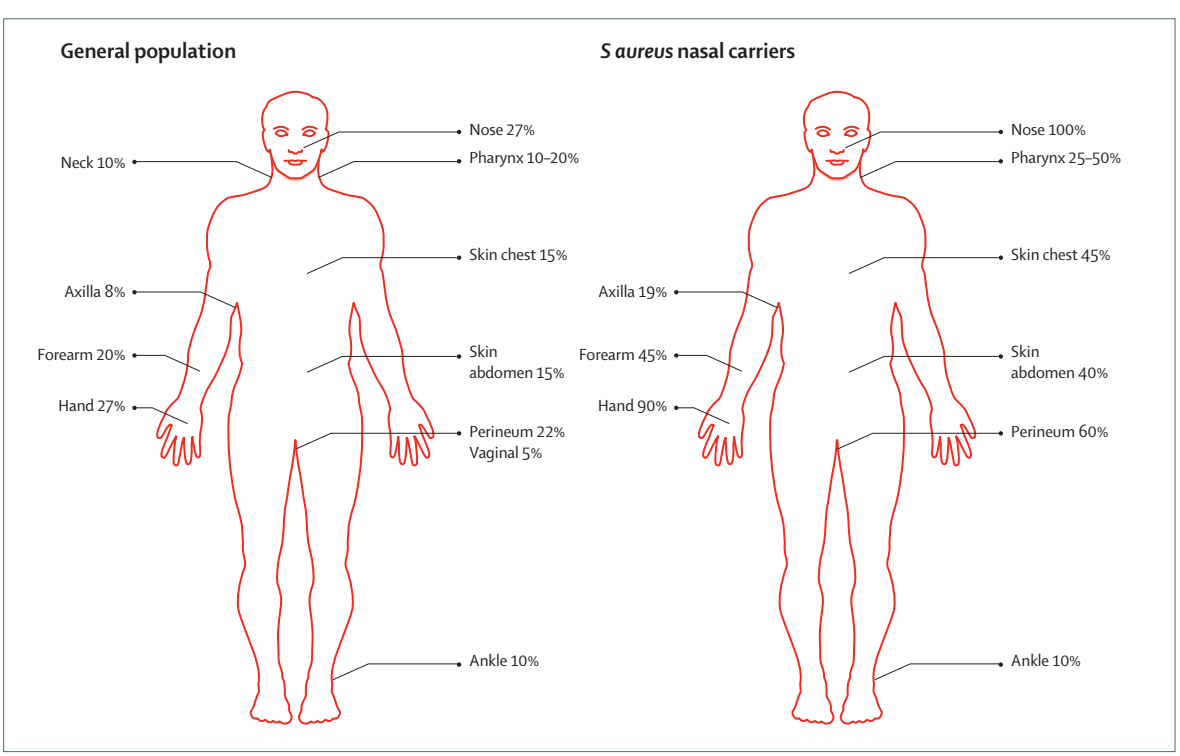

Figure 2: Distribution of *S aureus* on body sites of the general population and of nasal carriers[30]

a significant risk for acquisition, then the more patients there are in a small confined space, the more likely it is that a patient will be at risk of initial colonisation. There is certainly a correlation between increased bed numbers and an increased risk of MRSA colonisation.[57] However, the debate over the importance of airborne MRSA continues, since most microbiologists would argue that patients are more likely to acquire the organism from the hands of health-care workers rather than directly from the air.[58] The contribution of airborne MRSA to the spread of infection cannot be discounted, because some infections arising from contact transmission may have involved the airborne transportation of MRSA onto inanimate surfaces.[59]

Survival of staphylococci in the hospital environment

Although MRSA seems to contaminate the air and general environment throughout the hospital, this would not matter if the organism were unable to survive outside the human host. However, all members of the staphylococcal family (coagulase negative and positive) show an avid ability to survive in the environment, over a wide range of temperatures, humidity, and exposure to sunlight.[60,61] Staphylococci's resistance to desiccation is also long established.[62] Persistence has been shown by DNA typing results from outbreaks in hospitals lasting from 3 months to 5 years, with no obvious role attributed to colonised staff.[27,47,63] A recent prospective controlled trial also supports the persistence of MRSA in the clinical environment.[64] When mixed with hospital dust, MRSA can still be revived more than 1 year after inoculation.[65] This increases the chance that someone else will acquire viable staphylococci from the environment, since the organism awaits its opportunity to be picked up and transferred to a new host.[60]

There is little difference between the survival properties of *S aureus* and its meticillin-resistant variant, although one study has drawn attention to differences in survival times between sporadic and epidemic meticillin-resistant strains.[65] These survival properties could even determine why any one particular strain seems to spread more successfully between people than another.[65] Otherwise, there are plenty of reports describing survival of MRSA on items ranging from paper to mops, to more laboratory-based studies examining persistence on Formica, hospital fabrics, and plastics.[66–69] Even deep cleaning of a ward with detergent and a steam cleaner, followed by use of 1000 parts per million chlorine disinfectant for all hard surfaces, does not completely eradicate MRSA from the clinical environment.[64,70] Such persistence is likely to create a reservoir in hospitals, thus representing a significant risk of infection to patients.[10,70]

Staphylococci contaminate specific items in hospitals

Since there is plenty of evidence to show that MRSA can be found throughout the general environment, it is hardly surprising that it is also found on more tangible objects within clinical areas (table). The evidence for *S aureus* and MRSA contamination of a huge variety of items in hospitals is overwhelming. Objects such as computer keyboards, door handles, tourniquets, pens, television sets, stethoscopes, telephones, beds and bedside tables, equipment packaging, paper and patient's notes, and toys are just a few examples.[66,67,71–83] Near-patient items such as bed linen, patients' gowns, and the overbed table provided the highest degree of contamination. Overall, about one-third of surfaces on average seem to harbour MRSA when sampled in both endemic and outbreak situations.

The fact that most of these items can be touched by hands is important when considering the origin of MRSA contamination (figure 3).[67,83,84] If staphylococcal carriers are likely to carry their own strain on their fingers, it follows that anything that depends on hands for functionality is at risk of contamination from a carrier's strain. An habitual carrier is not necessarily required for the transfer of MRSA to hand-touch objects, since anyone who has just touched a contaminated site would be able to do the same.[48,78]

Laundered items and soft furnishings are also at risk for contamination. There are plenty of reports detailing MRSA from bedclothes, pillows, mattresses, and cushions.[56,85–87] Nurses' uniforms and doctors' ties have also been implicated, with predictable media response generated by the latter.[88,89] Ward curtains have long been suspected as capable of harbouring staphylococci, although published

	Outbreak	Endemic				Site estimated mean§
	Rampling et al[27]*	Boyce et al[48]*	Sexton et al[51]†	Lemmen et al[50]*‡	French et al[64]*	
Floor	9%	50–55%	44–60%	24%	..	34·5%
Bed linen	..	38–54%	44%	34%	..	41%
Patient gown	..	40–53%	..	34%	..	40·5%
Overbed table	..	18–42%	64–67%	24%	..	40%
Blood pressure cuff	13%	25–33%	..	..	..	21%
Bed or siderails	5%	1–30%	44–60%	21%	43%	27%
Bathroom door handle	..	8–24%	..	12%¶	..	14%
Infusion pump button	13%	7–18%	..	30%	..	19%
Room door handle	11%	4–8%	..	23%	59%	21·5%‖
Furniture	11%	..	44–59%	19%	..	27%
Flat surfaces	7%	..	32–38%	..	..	21·5%
Sink taps or basin fitting	..	..	..	14%	33%	23·5%
Average quoted**	11%	27%	49%	25%	74%	37%

..=not reported. *Broth enrichment incorporated into sampling method. †Data includes vancomycin-resistant enterococcus (VRE) isolates from the environment of four VRE patients and 50 meticillin-resistant *S aureus* (MRSA) patients. ‡First 2 weeks of 4 weeks' data. §Mid-range value taken for estimated mean. ¶Described as "bathroom door". ‖Additional study by Oie et al[71] reports overall 9% MRSA contamination on room door handles. **Mean proportion of environmental sites quoted from original studies and not calculated from the data above, since these data were incomplete.

Table: **Proportions of environmental sites positive for MRSA in endemic and outbreak situations**

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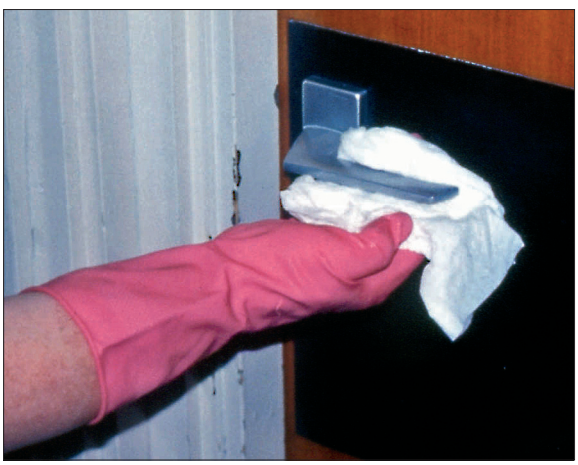

Figure 3: **A common hand-contact surface**

evidence for MRSA on curtains is hard to find. Susceptible *S aureus* was isolated from ward curtains beside a patient with a staphylococcal infection in a study done in the 1960s, and both isolates were of the same phage type.[90] The important point about curtains is that they are often the first object touched after examining a patient on the ward round, even before the examining clinician has had a chance to wash his or her hands. Furthermore, the difficulties entailed by removing them for cleaning will condemn them to remain in place for much longer than is desirable. In today's hospitals, off-site laundries, bed pressures, and shortage of spare curtains and the space to put them, all compound current management of ward curtains. Replacing them with vertical blinds, where possible, will not alleviate these problems.[91]

People transmit staphylococci to other people

There are reports detailing staphylococcal transmission between people in hospitals and people at home. These cases may relate to outbreak situations involving health-care workers or patients newly transferred from elsewhere.[92,93] Other reports document transmission from health-care workers to family members,[94–96] spread between patients in the community,[97] and transmission between ambulant patients.[98] Such evidence for person-to-person transmission of MRSA effectively negates the importance of MRSA in the environment and its removal through cleaning. However, whereas there is little doubt that carriers can transmit their strain to others, none of the studies mentioned are able to specify the exact mechanism of transfer. Perhaps indirect transmission via an environment frequented by both donor and recipient should be assumed to be as likely as direct person-to-person transmission.

A recent report describes the transmission of a particular phage type of MRSA from a dermatology patient to his attendant physician.[79] Contamination of the physician's office was thought to be responsible for the subsequent colonisation, after apparently successful topical clearance.[79] Boyce and co-workers[48] showed that just fewer than half of the nurses entering the rooms of MRSA patients acquired the patient's strain of MRSA on gloved hands and aprons. The nature of these contacts was indirect, in that the nurses did not actually administer hands-on care to the patients. However, nearly two-thirds of nurses acquired the organism if they were involved in direct contact with the patient.[48] Another study showed that about 12 (17%) of 70 contacts between a health-care worker and an MRSA-colonised patient resulted in transmission of MRSA from the patient to the gloves of the health-care worker.[99]

Staphylococci spread between people and the environment

People who are not habitual staphylococcal carriers are able to acquire *S aureus* from hand-touch sites or from the air, and transmit it to others or to other environmental sites.[30] They may carry certain strains for various lengths of time at various sites but do not seem to do so long term. Staphylococcal carriage has been associated with contamination of the home environment and refractory carriage has been linked with the continued presence of MRSA at home.[100,101] In hospital, one study examined the frequency of acquisition of various pathogens, including MRSA, on an investigator's hands after touching environmental surfaces near hospitalised patients.[78] About 20 (31%) of 64 hand-imprint cultures yielded coagulase-positive staphylococci from the bed rail and bedside table in occupied rooms, although only half of the patients were known to have previous colonisation or infection with *S aureus* or MRSA.[78]

Assessment of the presence and persistence of MRSA in the hospital is important, but the nature of the staphylococcal cycle between people and their environment requires evidence for dynamic transmission of the organism. A study in an intensive-care unit (ICU) examined coagulase-negative staphylococci from the hands of staff, the ICU environment, and the patients' blood, and found that indistinguishable strains could be identified from all three sources.[14] Although coagulase-negative staphylococci do not usually show the same pathogenic potential as *S aureus* and MRSA, they do share similar epidemiology and could be said to match the spread of their more pathogenic counterparts.

Indistinguishable strains of MRSA have been found from patients and their environments.[47,48,50,51,53] A recent study described an outbreak of glycopeptide intermediate-resistant *S aureus*, in which the outbreak strain was found on various surfaces both inside and outside the rooms containing colonised or infected patients.[54] Only one study has shown related strains from staff, patients, and the environment.[48] Whereas all these studies confirmed that there is an indisputable dynamic relation between people and their environments regarding staphylococcal transmission, few were able to indicate the origin of strains or in which direction they travelled.[14] The exception is a study by Hardy and

colleagues,[53] which showed the presence of unique MRSA strains in the ICU environment before retrieving indistinguishable strains from patients. No other patient in the ICU was infected or colonised with the same strain before acquisition. Additionally, a recent conference poster presented similar data showing chronological relations between staphylococci gathered from the environment and from patients with ICU-acquired staphylococcal infections.[102] The timescales of finding indistinguishable organisms from clinical and environmental sources supported dynamic transmission in both directions.[102]

Numbers of staphylococci required to initiate infection

What size of staphylococcal inoculum is required to initiate an infection? The answer to this question is only relevant if contamination on clinical surfaces is thought to represent a risk for transmission. If fingertips pick up only a few CFUs of MRSA from the environment to deliver to a patient, are these enough to cause infection?

Experimental induction causes infection within 24–48 h in human skin samples, but the inoculum required is four to eight million staphylococci.[103] Experimental lesions made by scraping the epidermis from the human forearm can be infected with as little as 15 staphylococci if the lesions are then sealed with a cover slip and adhesive tape.[104] Perhaps this experimental state could be compared with the insertion site of a vascular catheter or other device that breaches the epidermis. Skin abscesses in mice may be produced by use of as few as ten CFUs of staphylococci when introduced on suture material or cotton dust.[105] If this technique is applied to human beings, severe stitch abscesses can be produced after inoculation of 100 CFUs.[103] Thus, an inoculum of anything from ten to several million CFUs could potentially cause an infection in a patient.[28,61]

The incubation period for a staphylococcal infection can be reasonably assumed to be inversely proportional to the original inoculum, but patients are unlikely to receive a dose of several million CFUs of staphylococci at first acquisition.[61] A few viable units picked up from the environment may be delivered to a vulnerable patient, at a vulnerable site, and it is possible that these patient-related factors are the chief determinants of whether a patient succumbs to infection. The size of the original inoculum may not be crucial in initiating an infection, although it might determine how quickly that infection becomes obvious to attendant physicians. If this is the case, then the generally small numbers of MRSA recovered from environmental sites represent a genuine risk for potential infection.

Studies on the contamination of health-care workers' hands provide further support for this bacterial transmission hypothesis in the clinical environment.[106] In one study, 15% of nurses working in an isolation unit carried a median of 10 000 CFUs of *S aureus* on their hands.[107] In another study, *S aureus* was recovered from the hands of 20% (67 of 328) ICU staff, and 21% of doctors (69 of 328) and 5% of nurse carriers (16 of 328) had more than three CFUs of the organism on their hands.[108] Studies showing that hands (or gloves) of health-care workers become contaminated with MRSA after touching inanimate objects in patients' rooms have already been mentioned.[48,78] The median number of CFUs that were acquired on hands tended to be low (median 3 CFUs; range 1–300 CFUs).[78]

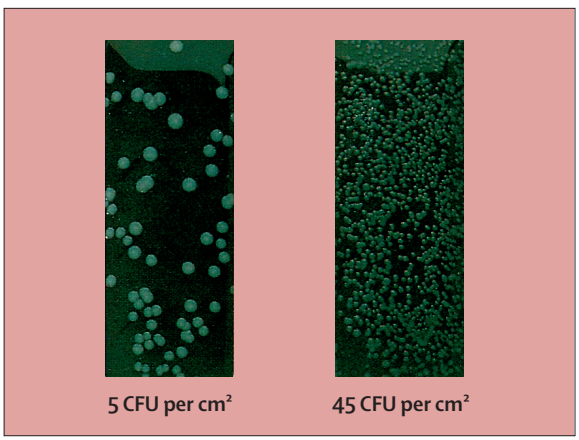

Figure 4: **Colony-forming units on dip slides coated with agar**
Colony-forming units consist of several different vegetative organisms, including staphylococci. Photo courtesy of Professor Chris Griffith (University of Wales Institute, Cardiff, UK).

There are only a few studies that have actually measured the number of CFUs of staphylococci from clinical environmental sites, but this area is attracting increasing interest, particularly regarding the possibility of introducing quantitative standards for surface-level hygiene (figure 4).[12,84,109,110] Standards such as these could be used to assess the infection risk to patients from the clinical environment, given that just a few CFUs delivered to a compromised patient could initiate infection.[29]

Importance of cleaning

Various cleaning methods reduce MRSA in the environment

Several studies detailing the effects of various methods to reduce environmental MRSA have recently been published, including a study examining the effect of portable high-efficiency particulate air filtration on airborne MRSA in isolation rooms.[111] The cleaning methods included routine vacuuming and detergent-based cleaning, deep cleaning with disinfectants, and gaseous decontamination using hydrogen peroxide vapour.[27,64,70] All of these methods seemed to reduce MRSA in the hospital environment, although standardised measurement of bacterial counts was not used. The move towards quantification of bacterial load in the hospital environment will provide a baseline for further work on the effectiveness of cleaning.[84] Microbiological assessment of different

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hospital cleaning methods has already suggested a relation between high microbial growth and the presence of coagulase-positive staphylococci.[109,110]

Although we may assume that there is a difference in bacterial growth between visibly dirty areas and those that seem clean, only one study has specifically examined concurrent visual assessment against chemical (bioluminescence detection) and microbiological methods of measuring organic and microbial soil.[12] Most wards seemed visibly clean (range 82–91%), but less than half were microbiologically clean (range 30–45%), and only a quarter were free from organic soil (range 10–24%).[12] Despite these findings, all of the current standards for assessing hospital hygiene recommend the use of visible cleanliness as a performance criterion.[2,15–20] A recent study attempted to link UK National Health Service patient environment action scores, which include a visual measurement of cleanliness, with MRSA bacteraemia rates in English hospitals.[112] As expected, there was no correlation, prompting some discussion on the merits of even attempting such an analysis.[113,114]

Effect of cleaning on staphylococcal infection rates

Evidence for the effect of basic cleaning on reducing the acquisition rate of MRSA in hospital is scant. A concerted effort in the early 1970s to rid a UK district general hospital of MRSA was successful when a programme of ward closure, cleaning, increased screening, and other infection-control interventions was used.[25,26] The overall rate of susceptible *S aureus* infections also decreased substantially, prompting editorial comment in *The Lancet* that hospital infection can be controlled.[115]

More recently, there has been a report describing an MRSA epidemic among male surgical patients.[27] Application of the usual infection-control activities had no effect on the outbreak until the time allocated for basic cleaning of the ward was doubled. There was an emphasis on removal of dust by vacuum cleaning and allocation of responsibility for the routine cleaning of shared medical equipment. Before the cleaning intervention, 69 patients acquired the outbreak strain E-MRSA-16, and the strain was found to be widespread in the ward environment. After the cleaning intervention, the outbreak strain was eliminated from the ward environment and there were no more infections with this strain among the patients. The investigators stressed that thorough and continuous attention towards ward hygiene and removal of dust was needed to terminate a prolonged outbreak of MRSA on this general surgical ward. The extra cleaning was in addition to standard infection-control measures. The study also calculated the cost-benefit of the cleaning intervention, which was estimated as nearly £28000 for the 6 months when the extra cleaning took place. The investigators concluded that, in the long term, cost cutting on cleaning services is neither cost-effective nor made sense.[27]

An additional study that reported an outbreak of vancomycin-resistant enterococci (VRE), which involved nearly 50 patients, described how infection-control interventions for VRE patients resulted in a significant increase in MRSA infections throughout the hospital ($p=0\cdot013$).[116] Annual environmental audits showed that only 43% of the minimum cleaning requirements had been completed in the month before the sudden increase in MRSA acquisitions, compared with 80% from an audit completed the year before. The investigators concluded that contamination of the ward environment was an important factor in facilitating transmission of the epidemic VRE strain, but they did not include the increase in MRSA in this hypothesis. They felt that the lack of isolation rooms, prioritised for VRE patients, which meant that newly colonised MRSA patients were nursed in the open wards, provided the opportunity for MRSA to spread.[116] This study shows how difficult it is to tease out the effects of different infection-control practices, particularly in an outbreak situation.

Similarly, an outbreak of glycopeptide intermediate-resistant *S aureus* in an ICU proved difficult to control until a wave of further control measures, including enhanced cleaning, was introduced.[54] The outbreak encompassed two clusters of infection in patients, although genotyping showed that all cases were caused by the same strain. The second cluster occurred despite the introduction of maximum contact-isolation procedures. This directed attention towards the inanimate environment as a major source of cross-contamination, since it was thought that re-emergence of the strain could be explained by a marked ability to survive on inert surfaces. The meticulous cleaning procedures finally implemented probably helped to stop the outbreak, although again it was not possible to determine the relative roles of barrier precautions and environmental decontamination in eradicating the strain.[54]

In a recent report of the impact of hypochlorite disinfection on MRSA rates, the monthly percentage of non-duplicate MRSA isolation from routine clinical specimens was collated over a 9-year period, along with the timing of different infection-control interventions.[117] Environmental sampling, bleach for cleaning, availability of hand gel, and screening on admission were all implemented together in response to a peak percentage of MRSA in clinical specimens. This resulted in an overall decrease in the number of routine isolations of MRSA, but removal of bleach for cleaning precipitated a significant increase once more in positive MRSA specimens ($p=0\cdot03$). This study did not necessarily provide evidence for the cleaning process itself, but it does suggest that the environment is important in the spread of MRSA.[117]

Effect of cleaning on control of other pathogens

MRSA is not the only pathogen capable of withstanding the inanimate environment. There are others, all hardy survivors, that capitalise on their ability to persist in the environment in the hope that they will be transferred

back into a living host. They include *Clostridium difficile*, VRE, *Acinetobacter* spp, and norovirus.[10] The properties that these particular organisms share with MRSA make them potentially vulnerable to the cleaning process, and any evidence supporting the role of cleaning in controlling their spread supplies additional scientific support for the benefits of cleaning on MRSA.

C difficile is a spore-forming anaerobic bacillus that has been recovered in abundance from the environment of symptomatic patients.[118,119] Such contamination is now well accepted as a risk factor for the acquisition of *C difficile*.[10] Furthermore, as the level of environmental contamination increases, so does the amount of *C difficile* on the hands of health-care workers, and near-patient hand-touch sites are regarded as a particular risk.[118,120] Having established that there is a dynamic transmission cycle for *C difficile* similar to that for MRSA, there is additional evidence to support the value of cleaning in the control of *C difficile*.[121,122] Infection-control teams do not question the importance of thorough environmental cleaning, although whether cleaners should use disinfectants or detergents for the cleaning process continues to be hotly debated.[118,119,123]

VRE are also known to contaminate and survive in the hospital environment.[124,125] These bacteria are particularly resistant to the cleaning process and require powerful disinfectants to eradicate problem strains.[126] The additional use of aprons or gowns with gloves when caring for VRE carriers is thought to help reduce VRE acquisition, perhaps because their use protects staff from environmental contamination.[125,127,128] However, contact with contaminated surfaces in the rooms of colonised patients results in transfer of VRE to gloved hands, despite cleaning with disinfectants.[78,129]

Environmental cleaning has already been suggested as important in the control of VRE, and a recent study describes the impact of improved environmental cleaning on the spread of VRE in a medical ICU, with and without promotion of hand-hygiene compliance.[130–132] The study found that enforcing cleaning measures was associated with less surface contamination with VRE, cleaner health-care workers' hands, and a substantial reduction in VRE cross-transmission among patients. The investigators concluded that decreasing environmental contamination might help to control the spread of VRE in hospitals.[132]

Another recent study examined the risk of acquiring MRSA or VRE from a room previously accommodating a patient positive for either of these infections.[133] The investigators found that there was a small but significant increase in the risk of acquiring MRSA or VRE if a patient was admitted into a room previously occupied by a carrier patient ($p=0\cdot04$). This particular route of transmission was not thought to be a major contributor towards overall transmission, but the effect of current cleaning practices in reducing the excess risk and the potential for further reduction were unknown.[133] An Australian study found that when patients with VRE were isolated, as one of several control measures implemented during an outbreak, the rate of MRSA acquisition increased because the isolation facilities were full of VRE patients.[116]

Yet another hardy hospital survivor, acinetobacter, can also be recovered from the hospital environment with ease.[66] Although the importance of cleaning in controlling outbreaks of *Acinetobacter baumanii* has been emphasised in previous studies, little is known about the best approach to environmental cleanliness in an endemic situation.[134] One study examined the levels of environmental contamination with *A baumanii* in a neurosurgical ICU after introducing new cleaning protocols, as well as showing an association between environmental contamination and colonisation of patients.[135] The study concluded that high standards of cleaning play an integral part in controlling outbreaks of *A baumanii* in the ICU setting.[135]

Finally, the importance of environmental cleaning in the control of outbreaks of norovirus is now widely accepted.[10,136–138] Without scrupulous attention to the environment, outbreaks not only continue, but will resume within a short space of time.[10,139,140] The virus can be found on many types of surfaces both in hospitals and in the community.[136,137,141,142] Several studies cite the association of norovirus with hand-touch sites, such as toilet taps, door handles, hospital equipment, elevator and microwave buttons, and telephones.[136,137,141,143] When fingers come into contact with virus-contaminated material, norovirus is consistently transferred to typical hand-touch sites.[143] Cleaning policies should include the use of specified disinfectants, because detergent-based cleaning often fails to eradicate the virus.[137,142,143]

Discussion

Cleaning has two main functions. The first is non-microbiological—to improve or restore appearance, maintain function, and prevent deterioration. The second is microbiological—to reduce the numbers of microbes present and any substances that support their growth or interfere with subsequent disinfection or sterilisation.[7] Reduction of the numbers of microbes on an object or in the general environment should not only reduce the risk of there being a pathogen present, but should reduce the risk of infection for people in contact with that object or environment. The importance of microbial surface contamination in the epidemiology of infectious diseases has been recognised.[12] Public-health activists throughout history have used basic hygiene in the continued fight against pathogens; these interventions are held in high esteem and are practised all over the world today.[144] Unfortunately, even this recognition is unable to justify additional managerial spending on domestic services, unless there is clear evidence of benefit. All we have are single observations, anecdotal reports, or quasi-experimental studies without concurrent control groups or with short follow-up.

Given the preoccupation with hospital budgets, we need another strategy for tackling the presence of MRSA

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in our hospitals other than campaigning for more cleaning hours. Visual appearance is an unreliable guide to the presence of pathogenic microbes and, indeed, rates of infection.[12,14,112] Perhaps targeting the areas in a hospital that constitute the highest risk for the presence of MRSA would be a feasible option in the short term. Buffing the floors in outpatient departments might improve the appearance of the waiting areas, but patients do not generally acquire MRSA from floors. The greatest risk for patients is contaminated near-patient hand-touch sites in clinical areas (figure 5).[14,48,64,145,146] This is borne out by studies that have seeded viral or other molecular fragments onto a door handle or a telephone, and then charted their movements over the course of a few days.[143,147–149] Such studies show the importance of sites that human hands touch more frequently, and can be used as an indicator for what might happen regarding the spread of MRSA.

The role of near-patient hand-touch sites in MRSA transmission and, indeed, other hospital pathogens, has not been given the priority that it deserves. In the UK, ward cleaners work to a set specification that encompasses and gives great emphasis to the cleaning of floors and toilets.[17] These are not near-patient hand-touch sites. Examples of the latter include bed rails, bedside lockers, infusion pumps, door handles, and various switches, including the nurse-call button, which rarely feature in the domestic cleaning specification.[84] These hand-touch sites, which might harbour and transmit microbial pathogens, are only poorly cleaned.[150] The responsibility for cleaning many hand-touch sites usually rests with the ward nurses, who are often very busy and almost permanently understaffed in many hospitals. Two recent studies in ICUs have shown an increased risk of infection after periods of inadequate nurse staffing or excessive workload.[151,152] Concentration of available cleaning resources on high-risk hand-touch sites may be the most cost-effective cleaning strategy.[84]

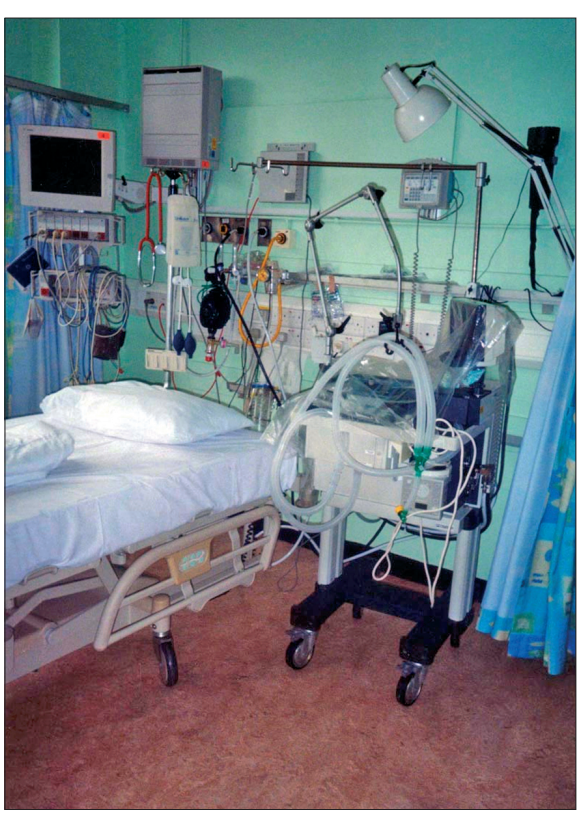

Figure 5: **A critical care patient is surrounded by many hand-touch sites**

Why do we not simply advocate more attention towards hand hygiene, to interrupt the final common pathway in the acquisition of MRSA? Contaminated hands are the chief mode of transmission for most patients who acquire a hospital infection. There can be no doubt that prioritising hand hygiene is the single most beneficial intervention in the control of MRSA and many other pathogens.[153] However, the problem with the cleaning of hands is that it is impossible to get everyone to do it at the most appropriate time.[154] One study has already contrasted the success and relative ease of instituting and maintaining an environmental cleaning programme with the failure of a hand-hygiene initiative.[132] And even if everyone does wash their hands properly, the effects of exemplary hand hygiene are eroded if the environment is heavily contaminated with MRSA.[52,155]

Cleaners should be included as an integral part of the infection-control team. They should be allocated more cleaning hours from the hospital budget, particularly when there is evidence for substantial savings.[156] Cost of drugs alone to treat MRSA, without even considering the costs of extended bed-stay for infected patients, justifies targeting domestic resources in clinical areas.[157] Furthermore, the increasing prevalence of MRSA and other multiple-drug-resistant bacteria in UK hospitals support the prioritisation of cleaning and other control measures before definitive validation.[158] We should have faith that we are doing the right thing.[159]

If cleaner hospitals ultimately reduced the number of patients acquiring health-care-associated MRSA, there would be a concomitant reduction of MRSA in the community, because acquisition in hospital invariably leads to patients taking the infection home. A cleaner culture adopted by hospitals might impinge on the community in other ways. The general public should consider their own attitude to hygiene when cleaning themselves and their homes, and when preparing food. Any societal erosion of hygiene might be caused by complacency emanating from the discovery of antimicrobial agents.[160] This issue requires urgent appraisal, since the increasing numbers of community strains of MRSA have been associated with hygiene issues and more frequent antibiotic consumption.[161] These community strains are more virulent than established hospital strains and have already shown their potential to start hospital outbreaks.[162]

Search strategy and selection criteria

Data for this Review were identified by searches of Medline, PubMed, and references from relevant articles. Many articles were identified through searches of the author's own personal collection of papers relating to hospital cleaning. Search terms used were "hospital cleaning", "met(h)icillin-resistant *Staphylococcus aureus*", "MRSA", "staphylococci", "epidemiology", "hospital", "cloud adult", "transmission", "environment", "healthcare", and "contamination". Only English language papers published during the past 50 years were reviewed.

People look towards hospitals to treat the sick and set appropriate standards of hygiene. But modern hospitals in the UK are often cluttered, overcrowded, and visibly dirty. Cleaning staff and hours have been drastically reduced over the past decade. Even if scientific validation is obtained, regenerating interest in the removal of dirt in the 21st century will require monumental effort. Aside from its low status, cleaning costs money and it is hard work. It is difficult to measure the process of cleaning, its impact, or assess it against the risk of acquiring MRSA. There has been enough debate and too many recent documents, guidelines, and audits. We should take the half-century's worth of data that we have and try to change things while we still can.[163] We do not yet know exactly what impact cleaning could have on control, but this ignorance should not be used as an excuse for doing nothing.[164]

Conflicts of interest

I declare that I have no conflicts of interest.

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References

1 Thomson M, Hempshall P. Dirt alert. *Nursing Times* 1998; **94:** 63–64.
2 Infection Control Nurses Association, Association of Domestic Management. Standards for environmental cleanliness in hospitals. Bathgate, West Lothian, UK: Infection Control Nurses Association, April, 1999.
3 UK Department of Health. The NHS Plan. July, 2000. http://www.nhsia.nhs.uk/nhsplan/contentspdf.htm (accessed Sept 17, 2007).
4 BBC Frontline Scotland. Dirty wards blamed for superbugs. June 3, 2003. http://news.bbc.co.uk/1/hi/scotland/2958362.stm (accessed Sept 18, 2007).
5 Washer P, Joffe H. The "hospital superbug": social representations of MRSA. *Soc Sci Med* 2006; **63:** 2141–52.
6 Maki DG, Alvarado CJ, Hassemer CA, Zilz MA. Relation of the inanimate hospital environment to endemic nosocomial infection. *N Engl J Med* 1982; **307:** 1562–66.
7 Collins BJ. The hospital environment: how clean should a hospital be? *J Hosp Infect* 1988; **11** (suppl A)**:** 53–56.
8 Weber DJ, Rutala WA. Environmental reservoirs of infectious agents. In: Wenzel RP, ed. Prevention and control of nosocomial infections, 3rd edn. Baltimore: Williams and Wilkins, 1997: 491–514.
9 McGowan JE Jr. Environmental factors in nosocomial infection—a selective focus. *Rev Infect Dis* 1981; **3:** 760–69.
10 Dancer SJ. Mopping up hospital infection. *J Hosp Infect* 1999; **43:** 85–100.
11 Dancer SJ. Hospital-acquired infection: is cleaning the answer? *CPD Infect* 2002; **3:** 40–46.
12 Griffith CJ, Cooper RA, Gilmore J, Davies C, Lewis M. An evaluation of hospital cleaning regimes and standards. *J Hosp Infect* 2000; **45:** 19–28.
13 Malik RE, Cooper RA, Griffith CJ. Use of audit tools to evaluate the efficacy of cleaning systems in hospitals. *Am J Infect Control* 2003; **31:** 181–87.
14 Dancer SJ, Coyne M, Robertson C, Thomson A, Guleri A, Alcock S. Antibiotic use is associated with resistance of environmental organisms in a teaching hospital. *J Hosp Infect* 2006; **62:** 200–06.
15 Auditor General, Audit Scotland. A clean bill of health? A review of domestic services in Scottish hospitals. April, 2000. http://www.audit-scotland.gov.uk/docs/health/2000/nr_000407_domestic_services_hospitals.pdf (accessed Sept 17, 2007).
16 NHS Estates. National standards of cleanliness for the NHS. London: Stationery Office, 2001.
17 NHS Estates, UK Department of Health. NHS healthcare cleaning manual. April, 2004. http://patientexperience.nhsestates.gov.uk/clean_hospitals/ch_content/cleaning_manual/introduction.asp (accessed Sept 17, 2007).
18 Department of Health. Revised guidance on contracting for cleaning. December, 2004. http://patientexperience.nhsestates.gov.uk/clean_hospitals/ch_downloads/contracting_for_cleaning.pdf (accessed Oct 10, 2007).
19 Healthcare Associated Infection Taskforce, Scottish Executive Health Department. Monitoring framework for NHSScotland national cleaning services specification. http://www.hfs.scot.nhs.uk/guest/HaiInitiatives/monitoringFramework.pdf (accessed Oct 10, 2007).
20 Siegel JD, Rhinehart E, Jackson M, Chiarello L, Healthcare Infection Control Practices Advisory Committee. Management of multidrug-resistant organisms in healthcare settings, 2006. Atlanta, GA: Centers for Disease Control and Prevention. http://www.cdc.gov/ncidod/dhqp/pdf/ar/mdroGuideline2006.pdf (accessed Sept 17, 2007).
21 Nightingale F. Notes on nursing (revised edn). London: Gerald Duckworth & Co, 1952.
22 Woodham-Smith C. Florence Nightingale. London: Constable & Co Ltd, 1950: 473–74.
23 Cunningham JB, Kernohan WG, Rush T. Bed occupancy, turnover intervals and MRSA rates in English hospitals. *Br J Nursing* 2006; **15:** 656–60.
24 UK House of Lords. Daily Hansard text for 7 Feb 2005—MRSA. http://www.publications.parliament.uk/pa/ld200405/ldhansrd/vo050207/text/50207-01.htm (accessed Sept 17, 2007).
25 Noone P, Griffiths RJ. The effect of sepsis rates of closing and cleaning hospital wards. *J Clin Pathol* 1971; **24:** 721–25.
26 Noone P, Shafi MS. Controlling infection in a district general hospital. *J Clin Pathol* 1973; **26:** 140–45.
27 Rampling A, Wiseman S, Davis L, et al. Evidence that hospital hygiene is important in the control of methicillin-resistant *Staphylococcus aureus*. *J Hosp Infect* 2001; **49:** 109–16.
28 Noble WC. Microbiology of human skin, 2nd edn. London: Lloyd-Luke, 1981.
29 Lidwell OM. Some aspects of transfer and acquisition of *Staphylococcus aureus* in hospitals. In: Macdonald A, Smith G, eds. The staphylococci. Proceedings of the Alexander Ogston Centennial Conference. Aberdeen: Aberdeen University Press, 1981: 175–202.
30 Wertheim HFL, Melles DC, Vos MC, et al. The role of nasal carriage in *Staphylococcus aureus* infections. *Lancet Infect Dis* 2005; **5:** 751–62.
31 Dancer SJ. Glycopeptide resistance in *Staphylococcus aureus*. *J Antimicrob Chemother* 2003; **51:** 1309–11.
32 Hayden MK, Rezai K, Hayes RA, Lolans K, Quinn JP, Weinstein RA. Development of resistance in vivo in methicillin-resistant *Staphylococcus aureus*. *J Clin Microbiol* 2005; **43:** 5285–87.
33 Tsiodras S, Gold HS, Sakoulas G, et al. Linezolid resistance in a clinical isolate of *Staphylococcus aureus*. *Lancet* 2001; **358:** 207–08.
34 Lowy F. *Staphylococcus aureus* infections. *N Engl J Med* 1998; **339:** 520–32.
35 Williams RE. Healthy carriage of *Staphylococcus aureus*: its prevalence and importance. *Bacteriol Rev* 1963; **27:** 56–71.
36 Solberg CO. A study of carriers of *Staphylococcus aureus* with special regard to quantitative bacterial estimations. *Acta Med Scand Suppl* 1965; **436:** 1–96.

37 Dancer SJ, Noble WC. Nasal, axillary and perineal carriage of *Staphylococcus aureus* among women: identification of strains producing epidermolytic toxins. *J Clin Pathol* 1991; **44:** 681–84.

38 Bibel DJ, Aly R, Bayles C, Strauss WG, Shinefield HR, Maibach HI. Competitive adherence as a mechanism of bacterial interference. *Can J Microbiol* 1983; **29:** 700–03.

39 von Eiff C, Becker K, Machka K, Stammer H, Peters G. Nasal carriage as a source of *Staphylococcus aureus* bacteraemia. *N Engl J Med* 2001; **344:** 11–16.

40 Wertheim HF, Vos MC, Ott A, et al. Risk and outcome of nosocomial *Staphylococcus aureus* bacteraemia in nasal carriers versus non-carriers. *Lancet* 2004; **364:** 703–05.

41 Perl TM, Cullen JJ, Wenzel RP, et al. Intranasal mupirocin to prevent postoperative *Staphylococcus aureus* infections. *N Engl J Med* 2002; **346:** 1871–77.

42 Sherertz RJ, Bassetti S, Bassetti-Wyss B. 'Cloud' health-care workers. *Emerg Infect Dis* 2001; **7:** 241–44.

43 Berntsen C, McDermott W. Increased transmissibility of staphylococci to patients receiving an antimicrobial drug. *N Engl J Med* 1960; **262:** 637–42.

44 Williams RE, Blowers R, Garrod LP, Shooter RA. Hospital infection: causes and prevention. London: Lloyd-Luke, 1960.

45 Hambraeus A, Bengtsson S, Laurell G. Bacterial contamination in a modern operating suite. 3. Importance of floor contamination as a source of airborne bacteria. *J Hyg (Lond)* 1978; **80:** 169–74.

46 Rutala WA, Katz EB, Sherertz RJ, Sarubbi FA Jr. Environmental study of a methicillin-resistant *Staphylococcus aureus* epidemic in a burns unit. *J Clin Microbiol* 1983; **18:** 683–88.

47 Layton MC, Perez M, Heald P, Patterson JE. An outbreak of mupirocin-resistant *Staphylococcus aureus* on a dermatology ward associated with an environmental reservoir. *Infect Control Hosp Epidemiol* 1993; **14:** 369–75.

48 Boyce JM, Potter-Bynoe G, Chenevert C, King T. Environmental contamination due to methicillin-resistant *Staphylococcus aureus*: possible infection control implications. *Infect Control Hosp Epidemiol* 1997; **18:** 622–27.

49 Blythe D, Keenlyside D, Dawson SJ, Galloway A. Environmental contamination due to methicillin-resistant *Staphylococcus aureus* (MRSA). *J Hosp Infect* 1998; **38:** 67–70.

50 Lemmen SW, Hafner H, Zolldan D, Stanzel S, Lutticken R. Distribution of multi-resistant gram-negative versus gram-positive bacteria in the hospital inanimate environment. *J Hosp Infect* 2004; **56:** 191–97.

51 Sexton T, Clarke P, O'Neill E, Dillane T, Humphreys H. Environmental reservoirs of methicillin-resistant *Staphylococcus aureus* in isolation rooms: correlation with patient isolates and implications for hospital hygiene. *J Hosp Infect* 2006; **62:** 187–94.

52 Fitzpatrick F, Murphy OM, Brady A, Prout S, Fenelon LE. A purpose built MRSA cohort. *J Hosp Infect* 2000; **46:** 271–79.

53 Hardy KJ, Oppenheim BA, Gossain S, Gao F, Hawkey PM. A study of the relationship between environmental contamination with methicillin-resistant *Staphylococcus aureus* (MRSA) and patients' acquisition of MRSA. *Infect Control Hosp Epidemiol* 2006; **27:** 127–32.

54 de Lassence A, Hidri N, Timsit JF, et al. Control and outcome of a large outbreak of colonization and infection with glycopeptide-intermediate *Staphylococcus aureus* in an intensive care unit. *Clin Infect Dis* 2006; **42:** 170–78.

55 Shiomori T, Miyamoto H, Makishima K. Significance of airborne transmission of methicillin-resistant *Staphylococcus aureus* in an otolaryngology-head and neck surgery unit. *Arch Otolaryngol Head Neck Surg* 2001; **127:** 644–48.

56 Shiomori T, Miyamoto H, Makishima K, et al. Evaluation of bedmaking-related airborne and surface methicillin-resistant *Staphylococcus aureus* contamination. *J Hosp Infect* 2002; **50:** 30–35.

57 Kibbler C, Quick A, O'Neill A-M. The effect of increased bed numbers on transmission in acute medical wards. *J Hosp Infect* 1998; **39:** 213–19.

58 Bauer TM, Ofner E, Just HM, Daschner FD. An epidemiological study assessing the relative importance of airborne and direct contact transmission of microorganisms in a medical intensive care unit. *J Hosp Infect* 1990; **15:** 301–09.

59 Beggs CB. The airborne transmission of infection in hospital buildings: fact or fiction? *Indoor Built Environ* 2003; **12:** 9–18.

60 Crossley KB, Archer GL. The staphylococci in human disease. First edn. New York: Churchill Livingstone, 1997.

61 Colbeck JC. Environmental aspects of staphylococcal infections acquired in hospitals. *Am J Public Health* 1960; **50:** 468–73.

62 Rountree PM. The effect of dessication on the viability of *Staphylococcus aureus*. *J Hyg* 1963; **61:** 265–72.

63 Dominguez M, Lencastre H, Linares J, Tomasz T. Spread and maintenance of a dominant methicillin-resistant *Staphylococcus aureus* (MRSA) clone during an outbreak of MRSA disease in a Spanish hospital. *J Clin Microbiol* 1994; **32:** 2081–87.

64 French GL, Otter JA, Shannon KP, Adams NMT, Watling D, Parks MJ. Tackling contamination of the hospital environment by methicillin-resistant *Staphylococcus aureus* (MRSA): a comparison between conventional terminal cleaning and hydrogen peroxide vapour decontamination. *J Hosp Infect* 2004; **57:** 31–37.

65 Wagenvoort JH, Sluijsmans W, Penders RJ. Better environmental survival of outbreak *vs* sporadic MRSA isolates. *J Hosp Infect* 2000; **45:** 231–34.

66 Dietze B, Rath A, Wendt C, Martiny H. Survival of MRSA on sterile goods packaging. *J Hosp Infect* 2001; **49:** 255–61.

67 Getchell-White SI, Donowitz LJ, Groschel DH. The inanimate environment of an intensive care unit as a potential source of nosocomial bacteria: evidence for long survival of *Acinetobacter calcoaceticus*. *Infect Control Hosp Epidemiol* 1989; **10:** 402–07.

68 Oie S, Kamiya A. Survival of methicillin-resistant *Staphylococcus aureus* (MRSA) on naturally contaminated dry mops. *J Hosp Infect* 1996; **34:** 145–49.

69 Neely AN, Maley MP. Survival of enterococci and staphylococci on hospital fabrics and plastic. *J Clin Microbiol* 2000; **38:** 724–26.

70 Jeanes A, Rao G, Osman M, Merrick P. Eradication of persistent environmental MRSA. *J Hosp Infect* 2005; **61:** 85–86.

71 Oie S, Hosokawa I, Kamiya A. Contamination of room door handles by methicillin-sensitive/methicillin-resistant *Staphylococcus aureus*. *J Hosp Infect* 2002; **51:** 140–43.

72 Berman DS, Schaefler S, Simberkoff MS, Rahal JJ. Tourniquets and nosocomial methicillin-resistant *Staphylococcus aureus* infections. *N Engl J Med* 1986; **315:** 514–15.

73 Banerjee D, Fraise A, Chana K. Writing pens are an unlikely vector of cross-infection with methicillin-resistant *Staphylococcus aureus* (MRSA). *J Hosp Infect* 1999; **43:** 73–75.

74 Bures S, Fishbain JT, Uyehara CF, Parker JM, Berg BW. Computer keyboards and faucet handles as reservoirs of nosocomial pathogens in the intensive care unit. *Am J Infect Control* 2002; **28:** 465–71.

75 Stacey A, Burden P, Croton C, Jones E. Contamination of television sets by methicillin-resistant *Staphylococcus aureus* (MRSA). *J Hosp Infect* 1998; **39:** 243–44.

76 Cohen HA, Amir J, Matalon A, Mayan R, Beni S, Barzilai A. Stethoscopes and otoscopes—a potential vector of infection? *Fam Pract* 1997; **14:** 446–48.

77 Ciragil P, Gul M, Aral M. Bacterial contamination of computers and telephones in a university hospital in Turkey. *J Hosp Infect* 2006; **62:** 247–48.

78 Bhalla A, Pultz NJ, Gries DM, et al. Acquisition of nosocomial pathogens on hands after contact with environmental surfaces near hospitalised patients. *Infect Control Hosp Epidemiol* 2004; **25:** 164–67.

79 Wagenvoort JH, de Brauwer EI, Sijstermans ML. MRSA decontamination of paper-containing objects. *J Hosp Infect* 2002; **51:** 74.

80 Panhotra BR, Saxena AK, Al-Mulhim AS. Contamination of patients' files in intensive care units: an indication of strict handwashing after entering case nores. *Am J Infect Control* 2005; **33:** 398–401.

81 Davies MW, Mehr S, Garland ST, Morley CJ. Bacterial colonization of toys in neonatal intensive care cots. *Pediatrics* 2000; **106:** E18.

82 Barnett J, Thomlinson D, Perry C, Marshall R, MacGowan AP. An audit of the use of manual handling equipment and their microbiological flora—implications for infection control. *J Hosp Infect* 1999; **43:** 309–13.

83 Cua A, Lutwick LI. The environment as a significant cofactor for multiply resistant nosocomial infections. *Semin Respir Infect* 2002; **17:** 246–49.

84 Dancer SJ. How do we assess hospital cleaning? A proposal for microbiological standards for surface hygiene in hospitals. *J Hosp Infect* 2004; **56:** 10–15.

85 Reiss-Levy E, McAllister E. Pillows spread methicillin-resistant staphylococci. *Med J Aust* 1979; **1:** 92.

86 Ndawula EM, Brown L. Mattresses as reservoirs of epidemic methicillin-resistant *Staphylococcus aureus*. *Lancet* 1991; **337:** 488.

87 Balslev U, Bremmelgaard A, Svejgaard E, Havstreym J, Westh H. An outbreak of borderline oxacillin-resistant *Staphylococcus aureus* (BORSA) in a dermatological unit. *Microb Drug Resist* 2005; **11:** 78–81.

88 Perry C, Marshall R, Jones E. Bacterial contamination of uniforms. *J Hosp Infect* 2001; **48:** 238–41.

89 Bhattacharya S. Doctors' ties harbour disease-causing germs. NewScientist.com news service, May 24, 2004. http://www.newscientist.com/article/dn5029.html (accessed Sept 17, 2007).

90 Rountree PM, Beard MA, Loewenthal J, May J, Renwick SB. Staphylococcal sepsis in a new surgical ward. *Br Med J* 1967; **1:** 132–37.

91 Karas JA, Barker C, Hawtin L, Hoadley M. Turning a 'blind eye' to vertical blinds in hospital wards. *J Hosp Infect* 2002; **51:** 75.

92 Blok HE, Troelstra A, Kamp-Hopmans TE, et al. Role of healthcare workers in outbreaks of methicillin-resistant *Staphylococcus aureus*: a 10-year evaluation from a Dutch university hospital. *Infect Control Hosp Epidemiol* 2003; **24:** 679–85.

93 Tansel O, Kuloglu F, Mutlu B, et al. A methicillin-resistant *Staphylococcus aureus* outbreak in a new university hospital due to a strain transferred with an infected patient from another city six months previously. *N Microbiol* 2003; **26:** 175–80.

94 Eveillard M, Martin Y, Hidri N, Boussougant Y, Joly-Guillou ML. Carriage of methicillin-resistant *Staphylococcus aureus* among hospital employees: prevalence, duration and transmission to households. *Infect Control Hosp Epidemiol* 2004; **25:** 114–20.

95 Calfee DP, Durbin LJ, Germanson TP, Toney DM, Smith EB, Farr B. Spread of methicillin-resistant *Staphylococcus aureus* (MRSA) among household contacts of individuals with nosocomially-acquired MRSA. *Infect Control Hosp Epidemiol* 2003; **24:** 422–26.

96 Mitsuda T, Arai K, Ibe M, Imagawa T, Tomono M, Yokoto S. The influence of methicillin-resistant *Staphylococcus aureus* (MRSA) carriers in a nursery and transmission of MRSA to their households. *J Hosp Infect* 1999; **42:** 45–51.

97 Borer A, Gilad J, Yagupsky P, et al. Community-acquired methicillin-resistant *Staphylococcus aureus* institutionalised adults with developmental disabilities. *Emerg Infect Dis* 2002; **8:** 966–70.

98 Herwaldt LA, Boyken LD, Coffman S, Hochstetler L, Flanigan MJ. Sources of *Staphylococcus aureus* for patients on continuous ambulatory peritoneal dialysis. *Perit Dial Int* 2003; **23:** 237–41.

99 McBryde ES, Bradley LC, Whitby M, McElwain DL. An investigation of contact transmission of methicillin-resistant *Staphylococcus aureus*. *J Hosp Infect* 2004; **58:** 104–08.

100 Masterton RG, Coia JE, Notman AW, Kempton-Smith L, Cookson B. Refractory methicillin-resistant *Staphylococcus aureus* carriage is associated with contamination of the home environment. *J Hosp Infect* 1995; **29:** 170–72.

101 Allen KD, Anson JJ, Parsons LA, Frost NG. Staff carriage of methicillin-resistant *Staphylococcus aureus* (EMRSA-15) and the home environment: a case report. *J Hosp Infect* 1997; **35:** 307–11.

102 White L, Dancer SJ, Robertson C. Where is MRSA in an intensive care unit and does it matter? Proceedings of the 17th European Congress of Clinical Microbiology and Infectious Diseases; Munich, Germany; March 31–April 3, 2007. Abstract 131.

103 Elek SD, Conen PE. The virulence of *Staphylococcus pyogenes* for man; a study of the problems of wound infection. *Br J Exp Pathol* 1957; **38:** 573–86.

104 Foster WD, Hutt MS. Experimental staphylococcal infections in man. *Lancet* 1960; **2:** 1373–76.

105 Noble WC. The production of subcutaneous staphylococcal skin lesions in mice. *Br J Exp Pathol* 1965; **46:** 254–62.

106 Pittet D, Allegranzi B, Sax H, et al. Evidence-based model for hand transmission during patient care and the role of improved practices. *Lancet Infect Dis* 2006; **6:** 641–52.

107 Ayliffe GA, Babb JR, Davies JG, Lilly HA. Hand disinfection: a comparison of various agents in laboratory and ward studies. *J Hosp Infect* 1988; **11:** 226–43.

108 Daschner FD. How cost-effective is the present use of antiseptics? *J Hosp Infect* 1988; **11** (suppl A)**:** 227–35.

109 White LF, Dancer SJ, Robertson C. A microbiological evaluation of cleaning methods. *Int J Environ Health Res* 2007; **17:** 1–11.

110 Griffith CJ, Obee P, Cooper RA, Burton NF, Lewis M. The effectiveness of existing and modified cleaning regimens in a Welsh hospital. *J Hosp Infect* 2007; **66:** 352–59.

111 Boswell T, Fox PC. Reduction in MRSA environmental contamination with a portable HEPA-filtration unit. *J Hosp Infect* 2006; **63**: 47–54.

112 Green D, Wigglesworth N, Keegan T, Wilcox MH. Does hospital cleanliness correlate with meticillin-resistant *Staphylococcus aureus* bacteraemia rates? *J Hosp Infect* 2006; **64:** 184–86.

113 Griffith CJ. Hospital cleanliness and MRSA rates. *J Hosp Infect* 2007; **65:** 275–76.

114 Green D, Wigglesworth N, Keegan T, Wilcox MH. Hospital cleanliness and MRSA rates [authors' reply]. *J Hosp Infect* 2007; **65:** 276–77.

115 The Lancet. Infection controlled. *Lancet* 1973; **1:** 981–82.

116 Bartley PB, Schooneveldt JM, Looke DF, Moerton A, Johnson DW, Nimmo GR. The relationship of a clonal outbreak of *Enterococcus faecium* vanA to methicillin-resistant *Staphylococcus aureus* incidence in an Australian hospital. *J Hosp Infect* 2001; **48:** 43–54.

117 Mahamat A, MacKenzie F, Brooker K, Monnet D, Daures J, Gould I. Impact of hypochlorite disinfection on MRSA rates. Proceedings of the 17th European Congress of Clinical Microbiology and Infectious Diseases; Munich, Germany; March 31–April 3, 2007. Abstract 1732_16.

118 Verity P, Wilcox MH, Fawley W, Parnell P. Prospective evaluation of environmental contamination by *Clostridium difficile* in isolation side rooms. *J Hosp Infect* 2001; **49:** 204–09.

119 Worsley MA. Infection control and prevention of *Clostridium difficile* infection. *J Antimicrob Chemother* 1998; **41** (suppl C)**:** 59–66.

120 Samore MH, Venkatamaran L, DeGirolami PC, Arbeit RD, Karchmer AW. Clinical and molecular epidemiology of sporadic and clustered cases of nosocomial *Clostridium difficile* diarrhoea. *Am J Med* 1996; **100:** 32–40.

121 Cartmill TD, Panigrahi H, Worsley MA, McCann DC, Nice CN, Keith E. Management and control of a large outbreak of diarrhoea due to *Clostridium difficile*. *J Hosp Infect* 1995; **29:** 75–77.

122 McMullen KM, Zack J, Coopersmith CM, Kollef M, Dubberke E, Warren DK. Use of hypochlorite solution to decrease rates of *Clostridium difficile*-associated diarrhoea. *Infect Control Hosp Epidemiol* 2007; **28:** 205–07.

123 Mayfield JL, Leet T, Miller J, Mundy LM. Environmental control to reduce transmission of *Clostridium difficile*. *Clin Infect Dis* 2000; **31**: 995–1000.

124 Smith TL, Iwen PC, Olson SB, Rupp ME. Environmental contamination with vancomycin-resistant enterococci in an outpatient setting. *Infect Control Hosp Epidemiol* 1998; **19:** 515–18.

125 Boyce JM, Opal SM, Chow JW, et al. Outbreak of multidrug-resistant *Enterococcus faecium* with transferable *vanB* class vancomycin resistance. *J Clin Microbiol* 1994; **32:** 1148–53.

126 Noble MA, Isaac-Renton JL, Bryce EA, et al. The toilet as a transmission vector of vancomycin-resistant enterococci. *J Hosp Infect* 1998; **40:** 237–41.

127 Puzniak LA, Leet T, Mayfield J, Kollef M, Mundy LM. To gown or not to gown: the effect on acquisition of vancomycin-resistant enterococci. *Clin Infect Dis* 2002; **35:** 18–25.

128 Srinivasan A, Song X, Ross T, Merz W, Brower R, Perl TM. A prospective study to determine whether cover gowns in addition to gloves decrease nosocomial transmission of vancomycin-resistant enterococci in an intensive care unit. *Infect Control Hosp Epidemiol* 2002; **23:** 424–30.

129 Ray AJ, Hoyen CK, Das SM, Taub TF, Eckstein EC, Donskey CJ. Nosocomial transmission of vancomycin-resistant enterococci from surfaces. *JAMA* 2002; **287:** 1400–01.

130 Falk P, Winnike J, Woodmansee C, Desai M, Mayhall G. Outbreak of vancomycin-resistant enterococci in a burn unit. *Infect Control Hosp Epidemiol* 2000; **21:** 575–82.

131 Martinez JA, Ruthazer R, Hansjosten K, Barefoot L, Snydman DR. Role of environmental contamination as a risk factor for acquisition of vancomycin-resistant enterococci in patients treated in a medical intensive care unit. *Arch Intern Med* 2003; **163:** 1905–12.

132 Hayden MK, Bonten MJM, Blom DW, Lyle EA, van de Vijver DA, Weinstein RA. Reduction in acquisition of vancomycin-resistant enterococcus after enforcement of routine environmental cleaning measures. *Clin Infect Dis* 2006; **42:** 1552–60.

133 Huang SS, Datta R, Platt R. Risk of acquiring antibiotic-resistant bacteria from prior room occupants. *Arch Intern Med* 2006; **166:** 1945–51.

134 Scerpella EG, Wanger AR, Armitige L, Anderlini P, Ericsson CD. Nosocomial outbreak caused by a multiresistant clone of *Acinetobacter baumanii*: results of the case-control and molecular epidemiologic investigations. *Infect Control Hosp Epidemiol* 1995; **16:** 92–97.

135 Denton M, Wilcox MH, Parnell P, et al. Role of environmental cleaning in controlling an outbreak of *Acinetobacter baumanii* on a neurosurgical intensive care unit. *J Hosp Infect* 2004; **56:** 106–10.

136 Wu HM, Fornek M, Schwab KJ, et al. A norovirus outbreak at a long-term-care facility: the role of environmental surface contamination. *Infect Control Hosp Epidemiol* 2005; **26:** 802–10.

137 Cheesbrough JS, Green J, Gallimore CI, Wright PA, Brown DW. Widespread environmental contamination with Norwalk-like viruses (NLV) detected in a prolonged hotel outbreak of gastroenteritis. *Epidemiol Infect* 2000; **125:** 93–98.

138 Green J, Wright PA, Gallimore CI, Mitchell O, Morgan-Capner P, Brown DW. The role of environmental contamination with small round structured viruses in a hospital outbreak investigated by reverse-transcriptase polymerase chain reaction assay. *J Hosp Infect* 1998; **39:** 39–45.

139 Love SS, Jiang X, Barrett E, Farkas T, Kelly S. A large hotel outbreak of Norwalk-like virus gastroenteritis among three large groups of guests and hotel employees in Virginia. *Epidemiol Infect* 2002; **129:** 127–32.

140 Isakbaeva ET, Widdowson MA, Beard RS, et al. Norovirus transmission on cruise ships. *Emerg Infect Dis* 2005; **11:** 154–57.

141 Gallimore CI, Taylor C, Gennery AR, et al. Environmental monitoring for gastroenteric viruses in a pediatric primary immunodeficiency unit. *J Clin Microbiol* 2006; **44:** 395–99.

142 Evans MR, Meldrum R, Lane W, et al. An outbreak of viral gastroenteritis following environmental contamination at a concert hall. *Epidemiol Infect* 2002; **129:** 355–60.

143 Barker J, Vipond IB, Bloomfield SF. Effects of cleaning and disinfection in reducing the spread of norovirus contamination via environmental surfaces. *J Hosp Infect* 2004; **58:** 42–49.

144 Aiello AE, Larson EL. What is the evidence for a causal link between hygiene and infections? *Lancet Infect Dis* 2002; **2:** 103–10.

145 Dancer SJ. MRSA—the storm clouds gather. *J Hosp Infect* 2005; **61:** 265–67.

146 Sehulster L, Chinn RY. Guidelines for environmental infection control in health-care facilities. Centres for Disease Control and Prevention, Healthcare Infection Control Advisory Committee (HICPAC) [erratum in *MMWR Recomm Rep* 2003; **52:** 1025–26]. *MMWR Recomm Rep* 2003; **52:** 1–42.

147 Oelberg DG, Joyner SE, Jiang X, Laborde D, Islam MP, Pickering LK. Detection of pathogen transmission in neonatal nurseries using DNA markers as surrogate indicators, *Pediatrics* 2000; **105:** 311–15.

148 Rheinbaben F, Schunemann S, Gross T, Wolff H. Transmission of viruses via contact in a household setting: experiments using bacteriophage straight phiX174 as a mode virus. *J Hosp Infect* 2000; **46:** 61–66.

149 Klingenberg C, Glad GT, Olsvik R. Flaegstad T. Rapid PCR detection of the methicillin resistance gene, *mecA*, on the hands of medical and non-medical personnel and healthy children and on surfaces in a neonatal intensive care unit. *Scand J Infect Dis* 2001; **33:** 494–97.

150 Carling PC, Briggs JL, Perkins J, Highlander D. Improved cleaning of patient rooms using a new targeting method. *Clin Infect Dis* 2006; **42:** 385–88.

151 Dancer SJ, Coyne M, Speekenbrink A, Samavedam S, Kennedy J, Wallace PG. Methicillin-resistant *Staphylococcus aureus* (MRSA) acquisition in an intensive care unit. *Am J Infect Control* 2006; **34:** 10–17.

152 Hugonnet S, Chevrolet J-C, Pittet D. The effect of workload on infection risk in critically ill patients. *Crit Care Med* 2007; **35:** 76–81.

153 Pittet D, Hugonnet S, Harbarth S, et al. Effectiveness of a hospital-wide programme to improve compliance with hand hygiene. *Lancet* 2000; **356:** 1307–12.

154 Kim PW, Roghmann MC, Perencevich EN, Harris AD. Rates of hand disinfection associated with glove use, patient isolation, and changes between exposure to various body sites. *Am J Infect Control* 2003; **31:** 97–103.

155 Farr B, Salgado CD, Karchmer TB, Sherertz RJ. Can antibiotic-resistant infections be controlled? *Lancet Infect Dis* 2001; **1:** 38–45.

156 Dancer SJ. The real cost of MRSA. In: Gould IM, van der Meer JW, eds. Antibiotic policies: theory and practice. New York: Kluwer/Plenum, 2005: 281–308.

157 Gould IM. Costs of hospital-acquired methicillin-resistant *Staphylococcus aureus* (MRSA) and its control. *Int J Antimicrob Agents* 2006; **28:** 379–84.

158 Talon D. The role of the hospital environment in the epidemiology of multi-resistant bacteria. *J Hosp Infect* 1999; **43:** 13–17.

159 Voss A. Preventing the spread of MRSA. *BMJ* 2004; **329:** 533.

160 Budd R. Penicillin: triumph and tragedy. Oxford: Oxford University Press, 2007.

161 Skiest DJ, Brown K, Cooper TW, Hoffman-Roberts H, Mussa HR, Elliott AC. Prospective comparison of methicillin-susceptible and methicillin-resistant community-associated *Staphylococcus aureus* infections in hospitalized patients. *J Infect* 2007; **54:** 427–34.

162 Otter JA, French GL. Nosocomial transmission of community-associated methicillin-resistant *Staphylococcus aureus*: an emerging threat. *Lancet Infect Dis* 2006; **6:** 753–55.

163 Farr BM, Jarvis WR. Would active surveillance cultures help control healthcare-related methicillin-resistant *Staphylococcus aureus* infections? *Infect Control Hosp Epidemiol* 2002; **23:** 65–68.

164 Dancer SJ. Swinging back the MRSA pendulum? *J Hosp Infect* 1999; **42:** 69–71.

165 Dancer SJ. Mopping up MRSA. In: Gould IM, ed. MRSA in practice. London: Royal Society of Medicine Press, 2006: 101–07.