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<td>Aerobic colony count</td>
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<td>Automated endoscope washer disinfector</td>
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<td>ANOVA</td>
<td>Analysis of variance</td>
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<td>ATP</td>
<td>Adenosine Tri-phosphate</td>
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<td>CA-MRSA</td>
<td>Community acquired methicillin resistant <em>Staphylococcus aureus</em></td>
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<td>CFU</td>
<td>Colony forming units</td>
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<td>DSI</td>
<td>Direct swab inoculation</td>
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<td>ERCP</td>
<td>Endoscopic retrograde cholecysto-pancreatoscopy</td>
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<td>Patient environment action team</td>
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Summary

Healthcare associated infections (HCAI) place an economic burden on health services, and cause distress to patients and relatives. The recent rise in HCAI rates has been linked to poor standards of environmental hygiene, but clear evidence is lacking.

This thesis explores contamination on environmental and other surfaces, how it can be monitored, and its role in the spread of bacteria. Possible control measures and their incorporation into management strategy are also examined.

Investigations into different methods for sampling surfaces revealed that sampling efficiency could vary by 1000-fold. Such variation would hamper the management of decontamination intervention and highlights the need for standard methodologies.

The decontamination of medical instruments was assessed against an established standard, using methods developed in this study, and failure rates up to 45% were detected. Poor implementation, caused by poor process management and absence of routine monitoring, was a contributory factor.

Methods developed in this study were used to investigate the cleaning of ward surfaces. For some sites, benchmark cleaning values for bacteria were exceeded on 86% of occasions, and 100% of occasions for ATP. Simple modifications to cleaning practice produced significant improvements, but disinfectants did not offer advantages over detergents for routine cleaning.

Surface touches and their subsequent potential to contribute to the spread of bacteria was quantified using novel methodology, and it was found that the vicinity of the patients’ beds was of key importance in the transfer of bacteria to patients.

Data gathered in preceding work was used to model exposure routes and determine the effect of implementing control measures. Effective hand decontamination reduced the mean transfer of bacteria to patients by 98.7%, but reductions in surface contamination also reduced the spread of bacteria. The benefits of hand decontamination could be undone with 2 touches of contaminated surfaces.

Overall, evidence was found to support the theory that hospital surfaces contribute to the spread of bacteria, and that surface cleaning may have some role in the control of HCAI.
Hospital surfaces and their importance in cross contamination and the spread and transmission of bacteria

1 A review of Healthcare Associated Infections (HCAI)

1.1 Infectious disease
Infectious disease is a broad term that encompasses a huge range of diseases that can be transmitted from person to person, directly or indirectly, which are caused by infectious agents.

The types of agent that cause infectious disease include fungi, multi-cellular parasites, bacteria, viruses, protozoa and prion type proteins. Each type can encompass varying numbers of pathogens. The diseases they cause vary, from the destruction of brain tissue by prions to unsightly nail infections caused by fungi, and they can vary in result from lethal diseases to asymptomatic infections. Different infectious agents from the same group may have entirely different modes of transmission, methods of action, and cause entirely different symptoms. There is enormous diversity within the known causative agents of infectious disease, and there are probably more to be discovered. Indeed, it has been estimated that between 1972 and 1996, at least one new pathogen has been characterised every year (Schulke, 1996)

1.1.1 Developments in the understanding of infectious disease
Although it is likely that humans have always suffered infections, a lack of understanding about the mechanism of disease meant that methods of treatment were not successful. ‘Domestic Medicine’ (Buchan, 1769) was a popular contemporary medical text, and while it does recommend cleanliness in medicine, the treatment for gangrene would not be acceptable today. Advice included “WHEN these symptoms first appear the part ought to be dressed with London treacle, or a cataplasm made of lixivium and bran; should the symptoms become worse, the part must be scarified, and afterwards dressed with basilicum softened with oil of turpentine”. With treatment being somewhat haphazard, it is not surprising that many of the advances came in the prevention of disease, and some notable observations have contributed to the modern understanding of control of infectious disease, and significant milestones and individuals can be identified
Charles White, born in 1728, a Manchester physician, was an eminent surgeon in Northern England. In 1773 he published a book ‘A Treatise on the Management of Pregnant and Lying-in Women’, in which he recommended that the incidence of puerperal fever could be significantly reduced by isolating infected individuals, restricting visitor numbers, and maintaining a high standard of hygiene (Burgess, 1941).

Smallpox, a viral disease now confined to vials in a restricted number of laboratories, used to be a scourge of the populace. It has been estimated that across Europe over 50,000,000 died from smallpox in the 18th century (Reid, 1974). Primitive inoculation against the disease, using the pus from sores of those mildly infected, was already in use, especially in Mediterranean countries, but this could lead to full blown disease and death. Jenner was a country doctor and amateur scientist, and became aware that those who had been infected with the harmless cowpox did not suffer from smallpox. In 1796, he began to experiment by inoculating a young boy, Phipps, with cowpox. Once he had recovered from the cowpox infection, Jenner inoculated the boy repeatedly with smallpox. Fortunately for both boy and doctor, Phipps did not contract smallpox. Jenner had performed the first documented vaccination. With time, he refined the method, and vaccination began to spread across Europe, saving countless lives.

John Snow was an anaesthetist in London during the nineteenth century when cholera was rife. A cholera outbreak in 1848 persuaded him that the disease was a gut infection transmitted by the faecal-oral route. By investigating the geographical locations in one outbreak, he was able to pinpoint the fomite of infection (a water pump in Broad Street) and he had the pump handle removed. The removal of the handle caused the outbreak to subside, and subsequent investigations showed the pump shaft was being contaminated by a cesspool. His methodology has been used as a model for epidemiology since (Newsome, 2006).

Semmelweis was perhaps the first person to discern the link between human activity and hospital infection using a statistical approach. In 1846, he became house officer in one of two obstetrical wards in Vienna General Hospital. One maternity ward was run by medics who also performed post mortems in a side room, and the other ward was run by midwives who did not perform autopsies. Semmelweis’s ward had a mortality rate of 13.1% to puerperal fever, compared to the other ward’s rate of just over 2%. In 1847, a friend of Semmelweis injured his hand with a scalpel during a post-mortem examination and contracted a disease that proved to be puerperal fever. Semmelweis proposed that an agent
from the cadavers was responsible for the diseases, and that medical students who had worked on dead bodies were responsible for transferring the agent to the obstetrical patients. He introduced a policy requiring hands be washed in chlorinated lime solution after carrying out post mortems. This policy reduced the rate of puerperal fever to 2.4%, which was comparable with the midwives’ ward.

Florence Nightingale is usually regarded as the first person to bring professionalism into nursing. In the hospital where she worked during the Crimean War, the mortality rate for disease such as typhoid was drastically cut when ineffective sewers were flushed, ventilation was improved and hospital wards thoroughly cleaned. On her return to the UK in 1857, she was feted and enjoyed considerable influence. Nightingale continued to develop upon the principle of hospital hygiene, and incorporated hospital design as an important factor in maintaining a sanitary environment.

1.2 **The development of germ theory**

These individuals made many important contributions to the control and prevention of infectious disease, without insight into the nature of disease. Sadly, understanding about the methods by which disease was transmitted was still largely absent. Although van Leuwenhoek’s work in microscopy in the late 1600s had visualised ‘animalcules’ (microscopic organisms) for the first time, this was deemed to be evidence of spontaneous generation, whereby living creatures emerged from inanimate matter. This theory was eventually displaced by germ theory. The observations that established germ theory did not occur in one single study, but began with individual movements than grew to a crescendo toward the end of the 19th century.

It took the work Louis Pasteur to sound the death knell of spontaneous generation in a series of experiments that unpicked the tenets of spontaneous generation one by one. In work on fermentation, he showed the process was driven by a particular type of animalcules, and that a different type meant the fermentation was a failure. In his famous ‘swan-necked flask’ experiments Pasteur proved that growth in nutrient was due to particles in the air and not the due to the spontaneous generation (Reid, 1974).

Work on a particular disease of silkworm showed that the disease was infectious, and also that is was caused by a living thing which may have led him to believe that disease in humans was also caused by animalcule. Although Pasteur suspected that a disease might be caused by a single type of organism, he was not able to isolate the causative agent of cholera from the blood of a suffering victim.
Strong support for both germ theory came from the work of Joseph Lister. Lister, a surgeon, had seen Pasteur’s work on germ theory, and noted the similarities between the putrefaction of animal flesh and diseased wounds. Where Pasteur had used heat to kill bacteria, Lister theorised that agents used to treat decomposition in other situations could prevent the frequent infections that followed surgery. Lister treated wounds from compound fractures with carbolic acid, and dressed the wound with cloth soaked in carbolic acid. This method achieved an exceptional survival rate (Reid, 1974). Lister expanded the method to other sorts of wounds, and later to the treatment of the air in operating theatres and surgical instruments, with great success. His techniques are known as aseptic surgery. Although Lister’s innovations doubtless saved many lives, and gave good support to germ theory, it did not provide the conclusive proof that germs were the cause of disease.

The final piece of scaffolding for the germ theory of disease was provided by Robert Koch and his experiments into anthrax in cattle. Learning that a particular type of organism was always found in cattle suffering from anthrax, Koch began to investigate. Having worked for 3 years, in 1876 Koch was able to show that the rod-shaped cells of what we now call Bacillus anthracis were the sole causative agent for anthrax in cattle. This was the first time that a specific organism had been shown to be the only cause of a disease, and this new certainty would provide the foundations for medical advance in the treatment of infectious diseases that would follow.

1.3 The introduction of antibiotics

The approaches detailed above deal mainly with methods to prevent disease, but these days they are supplemented by the development of effective drug treatments. The discovery of antibiotics was a major advance in the treatment, rather than prevention, of bacterial disease. These compounds, frequently derived from the secondary metabolites of soil-dwelling bacteria or fungal species, interfere with a particular aspect of bacterial metabolism or physiology, killing the cell or rendering it non-viable.

The discovery of the first antibiotic in 1928 was by Alexander Fleming who became interested in a contaminating mould that had restricted the growth of staphylococci on an agar plate. The mould proved to be of the genus Penicillium, and Fleming called the active filtrate of a liquid culture of the mould penicillin. Although Fleming was aware of the value of the compound, whose high activity against Gram-positive organisms was augmented with low toxicity to humans, he did not believe that it would last long enough in the blood to be effective. He stopped his investigation in 1931, before restarting experimentation in 1934. Howard Florey and Ernst Chain worked on purification of the drug, and in March 1942,
Anne Miller became the first person to be treated using penicillin. The drug subsequently saved many thousands of lives during World War II, although difficulties in mass-production hampered supply. In 1944, Dorothy Hodgkin unravelled the structure of penicillin, a breakthrough that allowed Florey and Chain to develop a method of mass-production. Florey, Chain and Fleming shared the 1945 Nobel prize for medicine.

1.3.1 Penicillin
The method of action of penicillin-based drugs was found to be the inhibition of the formation of peptidoglycan crosslinks that strengthen the cell walls of actively growing bacteria. When the cells divide or undertake repairs on the cell wall, the weakened wall succumbs to osmotic pressure, leading to cell lysis. The beta-lactam ring, a defining feature of pencillins, is an analogue for an amino acid vital to the process of peptidoglycan formation by the transpeptidase enzyme (also known as penicillin binding proteins, or PBP), namely alanyl-alanine. It binds to the enzyme irreversibly, preventing the crosslinking from occurring.

The initial penicillin to be isolated had a limited spectrum of activity, and poor duration within the body led to the search for new and improved penicillin derived drugs. Numerous derivatives were later produced. Ampicillin, for example, exhibited a wider range of activity, and amoxicillin showed an improved half-life within the body.

1.3.2 Streptomycin
Other antibiotic groups were discovered in the so-called antibiotic period. Streptomycin was isolated from *Streptomyces griseus* in 1943 by Waksman and Schatz. This was the first of the aminoglycoside group to be discovered, and the first antibiotic available that was effective in the treatment of tuberculosis. This group is notable for heightened activity against Gram-negative bacteria, and acts through inhibition of protein synthesis by binding with bacterial ribosomes. As with penicillin, the initial structure of the streptomycin was developed to produce a range of other antibiotics, including neomycin and gentamycin.

These developments in antibiotics revolutionized the treatment of bacterial infections. Many infections, dangerous or minor, could be simply and effectively treated. It seemed that medicine had found a ‘magic bullet’ for such diseases. In 1969, the US Surgeon General stood before Congress and testified that “the time has come to close the book on infectious diseases”. However, such optimism was hopelessly misplaced, for bacterial...
resistance to antibiotics had already emerged and has been increasing in significance ever since.

1.4  Emergence of resistance to antibiotics

Resistance to antibiotics began to emerge through processes such as mutation, genetic transfer and natural selection. Resistance to penicillin was first reported in 1944 in staphylococci (Kirby, 1944), only a few years after mass production had begun. As described previously, many adaptations and variants to the initial penicillin were produced, and in 1960 a powerful new variant, methicillin, was introduced. In the same year, the first case of methicillin resistant *Staphylococcus aureus* (MRSA) was discovered in the U.S. Even at this early stage, the potential for these new drugs was realised (Fishman, 2006). In 1961, methicillin resistant *S. aureus* was isolated for the first time in the UK, quickly followed countries around Europe. In 1965, the first nosocomial infections due to a methicillin-resistant *S. aureus* were recorded in Australia (Rountree & Beard, 1968, cited in Givney et al., 1998). *S. aureus* has continued to acquire resistance to antibiotics as they have been introduced. Partial resistance to vancomycin was detected in Japan in 1996 (Hiramatsu et al., 1997) with overt resistance being confirmed in 2002 (MMWR, 2002). In 2003, resistance to the recently discovered antibiotic linezolid was recorded (Meka et al., 2004).

There are various mechanisms used by bacteria to resist the actions of antibiotics. A bacterial enzyme, beta-lactamase, cleaves the beta-lactam ring essential for penicillin to act and thus rendering it ineffective. A bacterium that produces this has resistance to penicillin, and many of its derivatives. An exception is methicillin, which is resistant to beta-lactamase, and instead resistance is mediated by a modified PBP (namely PBP2”) to which methicillin can not bind and produce its inhibitory effect. This is an example of target modification. Vancomycin resistant MRSA decrease the cell-wall damaging effects of the antibiotic by having a thickened cell wall (Cui et al., 2003). Another mode of resistance is to remove the antibiotic from the cell, usually with a trans-membrane pump. This is the mechanism that transfers fluconazole resistance to *Candida albicans* (Albertson et al., 1996).

1.5  Antibiotic stewardship

Fewer antibiotics are being developed today, so there is increasing emphasis on using existing antibiotics more effectively (Fishman, 2006). This is termed ‘antimicrobial stewardship’ and compromises 6 approaches:
1. Education programmes, to ensure best use
2. Restricted antimicrobial formularies, where stocked drugs are restricted in number to help control and ensure effectiveness
3. Prior approval programmes, where reasons must be given and other parties informed before antibiotics can be used. The additional work helps to prevent casual dispensing
4. Streamlining programmes, in which the initial use of a broad spectrum antibiotic is narrowed through experience
5. Drug cycling, to restrict the chance of resistance emerging against a single antibiotic
6. Computer programmes, which draw together disparate information to make better drug regime choices

Adapted from Fishman (2006)
These programmes help to reduce the development of, and selection for, antibiotic resistance, but have the additional advantages of increasing cure rate, reducing antibiotic costs, and reducing healthcare associated infections due to Clostridium difficile, vancomycin resistant enterococci and Gram-negative bacilli (Fishman, 2006)

1.6 Healthcare associated infections
A particular aspect of infectious disease is healthcare associated infection (HCAI). HCAIs are infections acquired while in hospital, residential care home or at other source of healthcare provision.

HCAI are a serious and worldwide problem. At least 100,000 HCAI were estimated to occur in the UK every year (National Audit Office, 2000) with an estimated cost to the NHS of £1,000,000,000 - figures that may have risen substantially since publication. In the US, the costs of HCAI are estimated at 5 to 6 billion dollars every year, and HCAI are thought to be responsible for 100,000 deaths every year (Murphy et al., 2007).

The effects of contracting a HCAI can be serious. They are estimated to cause 5000 deaths a year in the UK, and be a contributory factor to death in 15,000 more. Depending on organism, severity of infection and response to it (both medically and physiologically) non-fatal outcomes can range from vomiting and diarrhoea to limb loss and extended duration of stay. Estimates for the additional extra stay for a patient who acquires a HCAI range from 2 to 24 days (Coello et al., 1993; Department of Health, 1995). In addition, the various costs of treating HCAI are estimated at 1 billion pounds a year to the NHS, a figure which
excludes financial and social costs to the patients and their relatives (National Audit Office, 2000).

The idea that people who go in to a healthcare establishment to improve or maintain their health are at an increased risk of catching dangerous diseases does not sit well with the public, the media or with politicians, and concern over HCAI is frequently expressed. However, to some extent, some level of HCAI is perhaps inevitable (Pratt et al., 2007).

Diarrhoea caused by infectious gut organisms acts to spread the disease broadly across the environment (Mayer et al., 2003) facilitating its spread. Patients staying in hospital are often inherently vulnerable and more immunocompromised than the wider population, leaving them more susceptible to infection. In addition they may have injuries that compromise the integrity of the skin including a burn or scald, injuries sustained that led to admission, surgical wounds or the insertion of intravenous venous catheters. The increased risk of acquiring an MRSA infection is demonstrated by the decrease in the minimum infectious dose when the skin is compromised. Where $10^6$ cells were required to produce pus in healthy skin, where the skin was occluded or traumatised the required dose was 1000 fold less (IFH, 2006). In the case of some organisms, particularly MRSA, the patient may become colonised with the pathogen. This places the patient at a much higher risk of infection, as entering hospital while colonised with MRSA is associated with a 500% increase in the risk of infection (IFH, 2006).

1.7 Preventability of HCAI

It may be the case that the complete eradication of HCAI is an impossible dream, but reducing the incidence is certainly possible, as evidenced by Nightingale and Lister, amongst others. Exactly what proportion of HCAI is preventable is unknown. Haley and colleagues (1985) found roughly a third of HCAI could be prevented through improved infection control programmes, though these should now be thoroughly embedded in most hospitals. However, recent investigations have shown that many forms of HCAI can be significantly reduced. One report, as part of the Pittsburgh Regional Healthcare Initiative (2004), described simple processes and policies that virtually eliminated ‘central line associated bloodstream infections’ within 90 days. Although various types of HCAI may be more or less easy to tackle, this finding shows that some types HCAI are preventable, and that changes do not have to be dramatic to be effective (Department of Health, 2008)

1.8 The importance of selected pathogens in modern medicine

Many opportunistic pathogens can cause disease and HCAI, but some species and strains are more common causes of HCAI than others. Some have particular adaptations that offer a
selective advantage in a clinical setting. An HCAI caused by an antibiotic resistant strain of bacteria may take longer to treat than one caused by a susceptible strain. More powerful antibiotics may have to be used, with potentially dangerous side-effects. For some HCAIs, the outcome may be death for a patient.

### 1.8.1 MRSA

While a variety of factors can affect the overall numbers of HCAIs due to *S. aureus*, the ratio of MRSA to MSSA in bloodstream infections is an important indicator of how well infection control procedures are reducing the risk to patients. Today, 39.4% of bloodstream *S. aureus* isolates in the acute Hospital Trusts in England are resistant to methicillin according to the Health Protection Agency (2006a) (Table 1.8.1.1), or 44% according to the European Antimicrobial Resistance Surveillance System (EARSS 2005). Whichever figure is used, this figure is among the highest in Europe.

<table>
<thead>
<tr>
<th>Year</th>
<th>Methicillin Resistant</th>
<th>% Methicillin Resistant</th>
<th>Methicillin Sensitive</th>
<th>No Information</th>
<th>Total Infections</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>68</td>
<td>2%</td>
<td>3,924</td>
<td>865</td>
<td>4,857</td>
</tr>
<tr>
<td>1991</td>
<td>78</td>
<td>2%</td>
<td>4,101</td>
<td>788</td>
<td>4,967</td>
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<tr>
<td>1992</td>
<td>116</td>
<td>3%</td>
<td>4,373</td>
<td>558</td>
<td>5,047</td>
</tr>
<tr>
<td>1993</td>
<td>209</td>
<td>4%</td>
<td>4,899</td>
<td>639</td>
<td>5,747</td>
</tr>
<tr>
<td>1994</td>
<td>457</td>
<td>9%</td>
<td>4,784</td>
<td>719</td>
<td>5,960</td>
</tr>
<tr>
<td>1995</td>
<td>846</td>
<td>14%</td>
<td>5,124</td>
<td>631</td>
<td>6,601</td>
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<tr>
<td>1996</td>
<td>1,597</td>
<td>22%</td>
<td>5,515</td>
<td>654</td>
<td>7,766</td>
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<tr>
<td>1997</td>
<td>2,422</td>
<td>30%</td>
<td>5,555</td>
<td>1,367</td>
<td>9,344</td>
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<td>2,851</td>
<td>34%</td>
<td>5,430</td>
<td>1,930</td>
<td>10,211</td>
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<td>3,331</td>
<td>37%</td>
<td>5,583</td>
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<td>5,861</td>
<td>1,965</td>
<td>12,109</td>
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<td>2001</td>
<td>5,088</td>
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<td>1,380</td>
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<td>5,333</td>
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<td>2003</td>
<td>5,791</td>
<td>41%</td>
<td>8,207</td>
<td>1,370</td>
<td>15,368</td>
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<tr>
<td>2004</td>
<td>5,466</td>
<td>40%</td>
<td>8,357</td>
<td>1,151</td>
<td>14,974</td>
</tr>
</tbody>
</table>

Table 1.8.1.1 Change in number and percentage of bloodstream infections due to MRSA in the UK during period of voluntary reporting (Health Protection Agency 2006a).

As time has progressed, the ratio of MRSA to MSSA isolated from bloodstream infections has risen (Figure 1.8.1.1), as has the overall incidence of MRSA. From 1990 until 2004, the reporting of *S. aureus* bacteraemias was voluntary. The data submitted shows a clear increase in this period.

As the system of reporting was voluntary for this time frame, it could be argued that the increase in reported cases was solely due to better reporting. However, the percentage of
cases where methicillin resistance was found climbed twenty-fold over this period, which indicates that the epidemiology has changed.

In the year Oct 2004 to Sept 2005, after reporting became mandatory, MRSA was the cause of 7269 bacteraemias reported by acute trusts in England alone. This figure has remained more or less constant from 2001. The mandatory reporting figure is approximately double that reported under the voluntary scheme, although the proportion of infections caused by MRSA remained constant.

<table>
<thead>
<tr>
<th>6 month period</th>
<th>Total</th>
<th>MSSA</th>
<th>MRSA</th>
<th>% MRSA resistant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apr 01 - Sep 01</td>
<td>9059</td>
<td>5443</td>
<td>3616</td>
<td>39.9</td>
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<tr>
<td>Oct 01 - Mar 02</td>
<td>8874</td>
<td>5209</td>
<td>3665</td>
<td>41.3</td>
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<td>Apr 02 - Sep 02</td>
<td>9079</td>
<td>5495</td>
<td>3584</td>
<td>39.5</td>
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<tr>
<td>Oct 02 - Mar 03</td>
<td>9417</td>
<td>5611</td>
<td>3806</td>
<td>40.4</td>
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<tr>
<td>Apr 03 - Sep 03</td>
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<td>41.0</td>
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<td>5814</td>
<td>3525</td>
<td>37.7</td>
</tr>
<tr>
<td>Oct 04 - Mar 05</td>
<td>9194</td>
<td>5505</td>
<td>3689</td>
<td>40.1</td>
</tr>
<tr>
<td>Apr 05 - Sep 05</td>
<td>9097</td>
<td>5517</td>
<td>3580</td>
<td>39.4</td>
</tr>
</tbody>
</table>

Table 1.8.1.2 The number and percentage of bloodstream infections due to MRSA in the UK over 6 month periods, including mandatory reporting (Health Protection Agency 2006a)

In 2005, 2083 UK death certificates mentioned *S. aureus* as a factor, and of these 78% specified MRSA. This is much higher than the ratio of MSSA to MRSA bacteraemias reported, and suggests that MRSA is associated with much higher mortality than MSSA.

It may be the case that some *S. aureus* strains are particularly well adapted for a hospital existence. Certainly, the majority of HCAIs caused by MRSA in the UK come from specific epidemic (so-called E strains) strains, namely E-MRSA 15 and 16. In addition, outbreak strains of MRSA survive better on surfaces than other strains (Wagenvoort *et al.*, 2000b), which could be a useful adaptation for hospital existence.

### 1.8.2 CA-MRSA

Community acquired MRSA (CA-MRSA) strains, as the name suggests are mostly associated with acquisition outside of healthcare, but has recently been the cause of 2 deaths from nosocomial infections (CDR weekly, 2006a). A review of the incidence of nosocomially transmitted CA-MRSA found 12 occurrences worldwide (Otter & French, 2006). CA-MRSA strains are not believed to be related to current E-MRSA strains, and are often sensitive to multiple non beta-lactam antibiotics, a different resistance pattern than nosocomial MRSA. In addition, many isolates produce Panton-Valentine leukocidin (PVL) (Naas *et al.*, 2005), a toxin that cause tissue necrosis and leucopenia, which is not normally seen in E-MRSA. Although the incidence is currently low, the potential for HCAI due to
CA-MRSA to increase is present, especially as it may be brought from the community into the hospital on colonised individuals.

### 1.8.3 Clostridium difficile

*C. difficile* is another significant HCAI species, and one of growing importance. Between 1993 and 1996, the number of cases in hospitals rose from 1576 to 8211 (Wilcox & Smyth, 1998). In 2004, the number of infections was reported to be over 35000, a 23% increase on 2002 figures (CDR Weekly, 2005a), and in 2005 this figure had climbed to 51,690 in people aged over 65 alone (Health Protection Agency 2006b). Infections are also thought to be becoming more severe (Hawkyard & Bignardi, 2006). *C. difficile* is a normal inhabitant of the gut that produces toxins and is often associated with antibiotic treatment (Ayliffe et al., 2000), which disrupts the normal gut flora. Its toxins attack the epithelial cells of the gut, leading to diarrhoea. This can progress to pseudomembranous colitis and perforation of the colon, which is a life threatening condition. This is compounded by the fact that patients who have been prescribed antibiotics may be more likely to be immunocompromised. In recent years a new strain, ribotype O27, has emerged and has been found to be the cause of substantial HCAI outbreaks (Hawkyard & Bignardi, 2006; CDR Weekly 2005b). This strain has a deletion in the gene that regulates toxin production, leading to a 16 to 20-fold increase in toxin production (Smith, 2005). In addition, this strain shows increased resistance to the fluoroquinolone antibiotics used to treat the condition, and is associated with an increase in mortality (Smith, 2005). In 2005, 3807 death certificates mentioned *C. difficile* as a factor (Office of National Statistics, 2007) The organism sheds spores in the diarrhoea it causes, allowing for widespread dispersal (Verity, 2001). The spores are resistant to most disinfectants with good persistence. Wards should be thoroughly cleaned before reopening after an outbreak (Ayliffe et al., 2000).

### 1.8.4 Norovirus

The most common cause of infectious gastroenteritis in England and Wales is Norovirus, which causes Winter Vomiting Disease, accounting for 69% of all infectious intestinal disease in England. (Lopman et al., 2003), with an estimated cost of £115 million to the health service (Lopman et al., 2003),

It is often associated with large outbreaks in closed or semi-closed environments where people exist in close proximity, such as cruise ship, military camp, nursing homes and hospitals. The virus can be spread in many ways, through the air, the faecal oral route, via surfaces, or be transmitted in water. With just 100 particles needed to cause infection, and an estimated 30 million particles (Caul, 1994) released though projectile vomiting, 10 million
particles per gram of faeces, and good environmental persistence, the virus is highly contagious. In one reported incident, a person suffering from Norovirus was sick on the steps to a popular venue. It is thought that virus particles carried into the venue by the movement of people and through the air conditioning system were responsible for 500 people that subsequently fell ill from Norovirus (The Guardian, 2005).

It is an extremely common cause of HCAI, with 79% of the outbreaks reported to the Health Protection Agency being from hospitals or residential nursing homes (CDR Weekly 2005c). It is not generally a life threatening disease, causing short-lived symptoms including vomiting and diarrhoea. However, the effect through the disruption to the hospital can be significant. Once an outbreak has begun, the ward is frequently closed, causing major disruption to the hospital, causing operations to be cancelled and increasing staff absences while increasing the duration of patient’s stay. A New Zealand report found that a Norovirus outbreak infected 57% and 41% of patients and staff respectively, the outbreak lasted 14 days, with the ward closed for 11 (Lynn et al., 2004). Control measures include strict hygiene, increased cleaning and thorough disinfection of the ward (Chadwick et al., 2000).

1.8.5 Acinetobacter

Acinetobacter species, are multiply-antibiotic resistant Gram-negative bacteria, and a growing HCAI threat, especially A. baumanii (Coelho et al., 2004). They exhibit good persistence in the environment, and can cause fatal infections, especially in immunocompromised patient or those with burns. At the present it is not nearly as widespread as MRSA, although is increasing in prevalence. In 2001, 961 bacteraemias were reported in the UK, rising to 1127 in 2005 (CDR Weekly, 2006b).

1.9 Proposed role of environment in HCAI

There are various postulated reasons for the rise in MRSA rates since 1990, and the increased prominence of HCAI generally. These include better and more consistent reporting HCAI in hospitals, newer and more complex internal surgery and an older and more infirm patient base. Another possible factor that has been identified is a perceived degradation in the cleanliness of hospital wards (Dancer, 2004), perhaps since the introduction of internal markets within the NHS and competitive tendering for cleaning contracts (Pratt et al., 2007).

The ‘hospitals are dirty’ theory has certainly found favour with the public and national media, and HCAI headlines are rarely far from the news. There is a belief that poor cleaning carried out by poorly paid and disinterested contractors has led to a diminution in
cleaning standards (Dancer, 1999), compared to the days when Matron ruled the wards with an iron rod. Bacteria could be picked up from the environment by patients or transferred to them by doctors or nurses. This could result in colonisation or infection of the patient. Yet the accuracy of these beliefs is difficult to assess in the absence of any comparative studies of environmental contamination between these eras.

1.10 **Research and professional opinions of the role of the environment in HCAI**

Between two reports published by the National Audit Office (2000; 2004) on HCAI, the government and NHS have published a further 19 documents and initiated 6 campaigns and strategies (National Audit Office, 2004). For all the attention given, the link has not been proven beyond dispute and the importance of cleaning is far from accepted within the medical profession:

“The inanimate environment of the hospital (i.e. usually with minimal risk) is of little importance in the spread of endemic hospital infection” (Ayliffe *et al.*, 2000).

This was not the view espoused by Nightingale and peers, but the finding in work from the 1960’s onwards supported the view that the environment is not a contributory factor, (Danforth *et al.*, 1987; Maki, 1982; Collins 1988). However, much of this work concerned the effect on infection rates of disinfecting floors, rather than using a detergent to clean them. This approach clearly demonstrates that disinfection of floors does not provide benefits to HCAI, or perhaps that the floor is not the key factor in acquisition of HCAI. It would, however, not be accurate to say that these studies disprove the theory that the environment and cleaning are factors in HCAI. The role of floors was again considered when Dharan and colleagues (1999) found that although implementing a routine disinfection policy reduced bacterial counts it made no impact on infection rates. This study was used to support the argument that the environment has no effect on infection rates. The authors appear to have started the investigation with preformed views on the subject, as the discussion begins “It is rather difficult to convince nursing and housekeeping staff to discard routine disinfection of all surfaces and that floor contamination has very little to do with nosocomial infections”. In addition, changes to the cleaning regime part way through the study meant that different areas were cleaned with different disinfectants with different equipment on different days of the week.

It is difficult to isolate the effect of cleaning from the many potential risk factors in HCAI. These confounding factors include hand hygiene compliance, carriage of infectious
organisms, patient demographics, the potential for auto-infection and the sporadic nature of many HCAI. However, amongst infection control professionals at least, belief in the importance of the patient’s environment as a factor of HCAI has undergone something of a resurgence. At an international meeting of the Hospital Infection Society (HIS 2006, Amsterdam, Oct 15-18 2006), a society whose objectives are “to advance knowledge of, foster scientific interest in and disseminate information about the prevention and control of hospital and other healthcare associated infections”, a show of hands was taken to assess the perceptions of the attendees on whether the environment was a factor in HCAI. The vote recorded that 16% thought the environment was ‘not at all’ or ‘slightly’ important and 84% thought it was ‘very’ or ‘moderately’ important (Figure 1.10.1.1). This is especially relevant as delegates who attend such meetings and members of societies such as HIS are more likely to be familiar the literature surrounding the role of the environment, and have direct experience, rather than those gaining an impression from the wider media.

![Figure 1.10.1.1 A qualitative representation of the change in profession opinion on the importance of hospital hygiene in HCAI](image)

**1.11 Positive evidence of the influence of the environment on HCAIs**

In part, the change in viewpoint described above may be due to a growing body of evidence that supports the role of the environment in HCAI
1.11.1 MRSA

Rampling et al. (2001) reported that for 20 months, standard infection control practices failed to end an outbreak of E-MRSA16 in a male general surgical ward. The bacteria were found to be widespread through the environment including surfaces such as window sills, the bed, trolleys, handles, telephones and the nurse call button. The infection control team introduced a range of methods to help control the outbreak. These included a doubling of the cleaning hours, combined with increased environmental surveillance, defining responsibilities and establishing a rota for cleaning items of medical equipment. Importantly, an infection control group with representation from consultant to cleaner was formed. In the six months following the intervention, the MRSA acquisition rate dropped to 10% of the rate in the 6 months before the intervention, and the strain was no longer found in the environment. Interestingly, a cost benefit analysis showed that the increased cleaning saved an estimated £27,786 in the six months, a figure which did not include lost bed days, some staff costs associated with the higher infection rate, or the mental and financial costs to the patient. This suggests that attempting to reduce costs by reducing resources allocated to cleaning can be false economy.

A similar drive to reduce acquisition and infection by MRSA of cardiothoracic patients was implemented at Guy’s Hospital, London (Schelenz et al., 2005) using a range of approaches. These included improved ward and theatre hygiene, increased MRSA screening, isolation of some colonized patients with only 1 MRSA positive patient being allowed on the open ward at a time and specific nursing teams to care for MRSA positive patients. All these measures act to reduce the chance of contamination of the ward environment. The programme achieved a statistically significant reduction in both the number of patients acquiring MRSA on the ward, from 4% to 1.5% of cardiothoracic patient, and reduced the number of bloodstream infections due to MRSA by 82%.

1.11.1.1 The ‘Seek and Destroy’ strategy

The lowest ratio of MRSA to MSSA in Europe is to be found in The Netherlands, where less than 1% of *S. aureus* bacteremias are MRSA compared to 44% in the UK (EARSS, 2005). The disparity between these two modern and prosperous countries is startling. The health services of these countries have an entirely different philosophy for the control of MRSA. The Netherlands employs a method that has been described as ‘seek and destroy’, and combines isolation of colonised patients with screening of staff and patients, a strict antibiotic policy and a belief that “MRSA is not stronger than hospital hygiene”
(Wagenvoort, 2000a). Good antibiotic policy will help to reduce selective pressure that favours MRSA. Isolating patients removes a source of MRSA dissemination from the general environment, and screening healthcare workers for MRSA as well as patients will act to reduce cross contamination and good environmental hygiene helps to prevent colonisation of staff and patients in the first place. The Dutch approach therefore considers MRSA transmission in a more holistic manner, attempting to remove sources of contamination at several points.

1.11.2 Clostridium difficile
The incidence of diarrhoea, which would serve to increase contamination of the environment, has been found to be associated with an increase incidence of VRE (Weber and Rutala, 1997). Using hypochlorite to clean environmental surfaces also helped to reduce C. difficile acquisition in an American hospital (Mayfield, 2000). Disruption to a ‘Task Team’ (a group given specific responsibility to ensure the cleanliness of ward equipment) approach during construction works was associated with a near 3-fold increase in C. difficile cases from 4.08 to 11.75 a month. This figure fell to 5.74 cases a month when the ‘Task Team’ returned to their duties, showing the importance of environmental contamination (Kiernan et al., 2006). After Addenbrook’s hospital introduced initiatives to combat MRSA, including enhanced cleaning and hand hygiene, a side-effect was a reduction in cases of C. difficile compared to previous years (Sule et al., 2006)

1.11.3 Norovirus
While the aerosol transmission of Norovirus is the most significant method of dispersal of virus particle, it is thought that environmental surfaces may play a role in sustaining a sequence of outbreaks (Barker et al., 2004). Persistence on surfaces of over 7 days has been demonstrated (D’souza et al., 2006), although in one instance two carpet-fitters who removed a carpet 13 days after an outbreak of Norovirus in a hospital ward fell ill (Cheesbrough et al., 1997). Investigating the possible role of the environment in transmission of Norovirus, Barker et al. (2004) found that a finger contaminated with Norovirus could transfer virus particles to up to seven subsequently touched hard surfaces. In addition, transfer from hard surfaces to hands was demonstrated on 40% of occasions tested. Furthermore, it was found cleaning with detergent or disinfectant alone could not reliably remove all virus particles, and only when a detergent was followed by disinfectant was a successful clean achieved (Barker et al., 2004). This emphasises the difficulty of removing Norovirus from the environment.
1.11.4 Acinetobacter
Denton et al. (2004) investigated outbreaks of HCAI due to A. baumanii in a neurosurgical intensive care unit, with 7 cases reported in a single month. Environmental screening results showed many surfaces were contaminated with the bacteria. Although the ward was closed, more cases occurred after reopening, and subsequent environmental testing revealed that many sites were still contaminated. As with Rampling et al. (2001) deficiencies in cleaning practice were identified, including allocation of responsibilities and additional staff employed to ensure thoroughness. Denton et al. (2004) plotted the number of environmental A. baumanii isolates against the incidence of A. baumanii HCAI and found a strong correlation between the two, thus giving good evidence of a link between HCAI and hospital hygiene.

1.11.5 Vancomycin-resistant Enterococci (VRE)
Environmental contamination has been suggested as a factor in nosocomial acquisition of VRE (Martinez et al., 2003). Eckstein and co-workers (2007) examined the effectiveness of terminal cleaning in room occupied by patients colonised or infected with VRE, and found that existing practices did not eliminate the organism from hand contact surfaces. Drees and colleagues (2008) investigated the factors influencing the likelihood of patients acquiring VRE in private room in medical and surgical ICUs. The study used Cox proportional hazards to determine the importance of various factors in VRE acquisition. Of all the factors examined, the strongest predictors of VRE acquisition were prior occupancy of the private room by patients colonised and VRE positive environmental samples from the room.

1.12 Evidence based medicine
These examples provide evidence that the environment plays a role in some incidences of HCAI, but under the strictures of Evidence Based Medicine (EBM) they do not provide the necessary level of proof required to conclusively link HCAI and the hospital environment.

Strictly speaking, EBM relates to clinical practice, and has been defined as ‘the process of systematically reviewing, appraising and using clinical research findings to aid the delivery of optimum clinical care to patients’ (Rosenberg, 1995) or ‘evidence based medicine is the conscientious, explicit, and judicious use of current best evidence in making decisions about the care of individual patients’ (Sackett et al., 1996). It is an approach designed to ensure clinical effectiveness, cost effectiveness and safety by requiring that any new drug, preventative measure or practice have proven effectiveness supported by published evidence, and to reject approaches that could be described by “everyone else is doing it” or
“this is how we’ve always done it”. To help facilitate the ranking and evaluation of evidence, five credibility categories have been established.

I. Strong evidence from at least one systematic review of multiple well-designed randomised controlled trials.
II. Strong evidence from at least one properly designed randomised controlled trial of appropriate size.
III. Evidence from well-designed trials such as non-randomised trials, cohort studies, time series or matched case-controlled studies.
IV. Evidence from well-designed non-experimental studies from more than one centre or research group.
V. Opinions of respected authorities, based on clinical evidence, descriptive studies or reports of expert committees.

(Rosenberg, 1995)

1.13 EBM and the role of the environment in HCAI
The evidence to support the hypothesis that cleaning influences HCAI rates does not score highly under this system. Dettenkofer et al. (2004) reviewed the literature for studies in this area and found four that merited an evidence level equating to III on the above scale, and these largely related to the use of disinfectant to clean floors. The absence of more evidence is primarily due to the relative difficulty of carrying out studies of sufficient power and breadth. A controlled investigation would require two similar wards (in terms of specialty, size, design, modernity, and staffing) with similar patients (in terms of age, sex, medical condition suffered and morbidity). One of these wards would have to continue with the existing cleaning regime and practices, and the other ward would be required to implement a cleaning regime based on best practice guidelines. The study would have to be carried out over a significant time period, perhaps a year or more, due to the seasonality of some infections and to allow any preventative effect to build. The rate of HCAI, and causative organism, would need to be monitored. In addition, other indicators including the ratio of bloodstream infections caused by MRSA to MSSA, the rate of patient colonization, and the incidence of pathogens in the environment could be monitored. There are always many confounding factors in this type of study. Transfer of bacteria between wards by staff and patients is always possible. Patients admitted from nursing homes or transferred from other hospitals could introduce new reservoirs of pathogens into the ward.
Given the size, complexity and length of such an investigation, great commitment would be required to complete such an undertaking. Additional resources would be required, disruption to existing routines would be expected, contractual issues with changing working practices might arise, and discontent with the perceived slight on current cleanliness might antagonize staff. Cooperation between many factions such as nursing directorate, infection control, doctors and cleaning staff would be imperative. To date no studies on this scale have been completed. To achieve the highest level of credibility on the EBM scale, this kind of study would have to be carried out several times in different hospitals and subjected to meta-analysis. As it is, the study described above would merit only a grading of II.

1.14 Evidence based practice guidelines in the UK
Recently, the Hospital Infection Society, commissioned by the Department of Health, reviewed all the available evidence related to infection control as part of the second Evidence Based Practice in Infection Control (EPIC2) review (Pratt et al., 2007). These used a grading similar to that described above, but using an A to D system, where A was most supported by high quality evidence and D the least supported.

The EPIC2 guidelines cover many aspects of infection control, including hospital hygiene, and this review noted that “there was little research evidence of an acceptable quality upon which to base guidance related to the maintenance of hospital environmental hygiene”. Consequently, the evidence supporting the hypothesis “The hospital environment must be visibly clean, free from dust and soilage and acceptable to patients, their visitors and staff” was awarded a ‘C’ recommendation. The wording of this suggests that aesthetic considerations of cleanliness are of the most import, rather than the removal of bacteria from the environment. Increasing cleaning at time of outbreak was supported at the ‘D’ level, as was the use of hypochlorite during outbreaks. However, EPIC2 authors did find evidence to recommend at the ‘C’ level, that hands be decontaminated after any activity that could contaminated them, in order to minimise any cross contamination of the environment.

1.15 Models of how the environment might affect cross contamination and HCAI rates
Cross contamination between environmental surfaces, hands, staff and patients is a central plank in the hypothesis of environmental surfaces and HCAI.

A Swiss study defined the 5 steps necessary for patient to patient transmission of pathogens as “(1) organisms are present on the patient's skin or have been shed on to fomites in the patient's immediate environment; (2) organisms must be transferred to health-care workers’
hands; (3) organisms must be capable of surviving on health-care workers' hands for at least several minutes; (4) handwashing or hand antisepsis by the health-care worker must be inadequate or omitted entirely, or the agent used for hand hygiene inappropriate; and (5) the caregiver's contaminated hand(s) must come into direct contact with another patient or with a fomite in direct contact with the patient” (Pittet et al., 2006). This comprehensive review paper found evidence to support each of these stages, especially the importance of handwashing.

The model presented by Pittet and colleagues (2006) gives a specific, sequential and direct route from patient to patient, and hinges on good handwashing practice, and also acknowledged that transfer of bacteria from the environment as a factor. However, it could be better to consider that the transmission of pathogens around the ward as part of a web, rather than as a linear route. While a linear route as described by above is perfectly possible, it may also be the case that a healthcare worker who performed hand decontamination with exemplary diligence may subsequently touch a contaminated surface before patient contact. Pathogens existing on surfaces in wards can act a reservoir of infection where infectious agents can be picked up by hands and transmitted to patients. Patients could transfer pathogens directly to other patients or pick up pathogens directly from surfaces themselves. With many patients, visitors and healthcare worker touching the multitudinous ward surfaces, a web of interactions and possibilities exist, creating zigzag transmission (Block, 1991) routes that may circumvent rigid infection control procedures. This is demonstrated in figures 1.15.1 and 1.15.2. Figure 1.15.1 shows four simple scenarios. In scenario A, healthcare worker (HCW) A opens the door, touches the patient’s notes, then the bedframe, and then washes hands before examining the patient.
Figure 1.15.1 Some examples of possible cross contamination routes in hospital wards. Arrows show a sequence of touch actions between various surfaces. Solid and dashed lines represent the touch actions of different HCWs, (a) and (b)

These straightforward actions are all combined together in figure 1.15.2. Although scenarios A to D are not complicated sequences, and represent only a small fraction of the surfaces within a ward, the complexity of interactions is greatly increased.
Certainly studies have shown links between patient’s bacterial flora, environmental flora and the actions of others. Boyce et al. (1997) found that healthcare workers who had no physical contact with a patient would contaminate their gloves with MRSA by touching contaminated surfaces. The study also reported that isolates found near colonized patients and on colonized patients were often the same or a closely related strain. These two findings suggest that environmental surfaces can play an important role in the distribution and transfer of MRSA between patients in close proximity, such as on a hospital ward.

One study examined surfaces before and after routine care was delivered to VRE positive patients by healthcare workers. It was found that 10.6% of sites that had previously been tested and found to be free of VRE were contaminated after being touched by a HCW who had previously touched a site contaminated with VRE (Duckro et al., 2005).

A similar approach to the diverse control measures used routinely by the Dutch to control MRSA was implemented in an Australian hospital to control an outbreak of VRE (Pearman, 2006). A high-level group was set up to deal with the problem, emphasising the importance of visible commitment to the programme. Additional funding was gained to enhance infection control procedures, which comprised: increased screening of patients; staff cohorting; environmental monitoring combined with enhanced cleaning services; medical record analysis; specific arrangements for patients and contacts after discharge from
hospital. Targeting relentlessly the avenue by which the bacteria could spread in a zigzag fashion through cross contamination achieved a drop in VRE acquisition from 33.3% to generally below 2%.

Verity et al. (2001) examined contamination of side-rooms housing patients suffering from *C. difficile* infection, and found that 25% of sites sampled over a 4 week period were contaminated with *C. difficile*, with the same strain being isolated from both patient and environment. However, 90% of these were the same strain, which limits the discriminatory power of this study in this area.

1.16 Defining ‘clean’
The routine removal of bacteria from surfaces in hospitals is attempted by cleaning or disinfection, although studies have found that it is not necessarily effective (Cooper et al., 2007; Malik et al., 2003). Cleaning could be defined as the removal of soil, which may be defined as matter out of place (Dillon & Griffith, 1999), although fine grooves, imperfections, crevasses and nicks on a surface mean that the complete removal of soil is not practically achievable. The point of cleaning is to make something clean, but ‘clean’ is a difficult term to define, and is context dependent. A teenager and their parents may have different views on when something is clean. What is ‘clean’ for the cowshed is not appropriate for the meat processing plant, and what is clean enough for the meat processing plant is not appropriate for a surgical theatre. Because perceptions and requirements for cleanliness can differ, ‘clean’ is often determined against a set level as part of the planning process (Dillon & Griffith, 1999).

1.16.1 Existing standards for assessing hospital hygiene
By considering the minimum essential standards that must be reached for a surface to be considered clean enough to be able to achieve its function, one can begin to define standards and benchmarks against which surfaces can be compared.

1.16.2 The Spaulding classification
One attempt to classify the appropriate cleaning for medical instruments according to their infection risk was devised by Dr Earl Spaulding in 1968. This became known as the Spaulding classification and was made up of three categories: critical, semi-critical and non-critical. Infection risk was determined by the various barriers to infection associated with the human body. Critical items were defined as those that breeched the mucous membranes, since these are physical barriers to infection. When a device penetrated mucous membranes,
their value as a barrier was lost and any infectious agents present were able to ingress into the body. Hence, items rated as critical must be sterilised between uses. Instruments that come into contact with the mucous membranes, but do not breach them were designated as ‘semi-critical’. Semi-critical has sometimes been split into two areas, semi-critical A and B (Martiny et al., 2004). The division is between those devices that have areas that are difficult to reach and clean, for example they have a lumen. Semi-critical A is for items that do not have such areas, and semi-critical B is for those items that do. Flexible endoscopes are an example of semi-critical B items, because although they are passed into body cavities, these instruments themselves do not penetrate mucous membranes. Endoscopes are lumened instruments, and have ports and valves that are awkward to clean, giving them a semi-critical B classification. They are often used in conjunction with tools that do penetrate membranes, which are therefore rated as critical. Items that only come into contact with intact skin, such as blood pressure cuff are regarded as non-critical items and require only low-level disinfection with a detergent. General surfaces in and around the ward would also be included in this category.

**1.16.3 The current standard for surface hygiene**

In addition to the Spaulding classification, different groups and individuals have proposed various standards for routine cleaning in hospitals. One definition used by the Department of Health is that surface should be “visually clean with no blood or body spillages, dust, dirt, debris or spillages” (NHS Estates, 2004a). The standard infection control procedures recommend “The hospital environment must be visibly clean, free from dust and soilage, and acceptable to patients, their visitors and staff.” (Pratt et al., 2007) allocates responsibility for ensuring this to NHS Trust Chief Executives. From an aesthetic point of view, visual cleanliness is a realistic and appropriate requirement, but if the aim of cleaning is to reduce the number of bacteria in order to lower the infection risk to patients (and the presence of the standard in infection control guidelines implicitly means that this is the case), then standards based on visual assessment are inadequate.

**1.17 Hygiene indicator choice**

An important part of defining a standard is defining what is to be measured. Standards might be based on the number of bacteria in a specified area, for example. Types of bacteria could be specified, so allowing subtlety to be used in standard definition. Distinction could be made between pathogenic bacteria (that would pose a significant risk to health if present in the finished product), and those that might be indicative of the presence of pathogens
(without posing health risks themselves). Rather than a particular number, the standard could require the absence of a particular organism.

For microbial assessment there are two main approaches in deciding what to test for. The first is to directly measure the level of something that provides a significant risk. While this initially seems foolproof, there can be significant drawbacks to it. If the risk factor is present in lower numbers, then it is more likely that the test will not pick them up. An example is testing water for faecal pathogens. Pathogens such as *Salmonella* maybe present in water if it has been recently contaminated with faecal matter, and this would present a public health risk. However, even in an individual suffering from salmonellosis, the ratio of *Salmonella* to other enteric bacteria will be small, and the presence of salmonella cells could be missed. Therefore a representative sample must be tested and conditions that guarantee the isolation and identification of any pathogens present must adopted.

A different approach is therefore to test for other factors characteristically present when the pathogen is. In the *Salmonella* example, it is more sensible to test for the much more numerous and easily recognized enteric bacteria. As *Salmonella* is a gut organism, enteric bacteria will be present in large numbers where water has been faecally contaminated, making detection more likely. The number recovered can then be checked against previously determined standards that determine when a significant risk is present. Hence enteric bacteria are indicator organisms.

This principle can also be applied to surfaces. In food production, the number of pathogenic bacteria on an important surface is likely to be low and maybe missed by a test. Testing for general evidence of contamination or poor cleaning will yield results that can be compared to defined standards. In addition, because the numbers will be higher, the data can be analysed in more ways. Taking the indirect approach a stage further is to assess the level of residual soil on a surface, rather than count the number of bacteria present. A high level of residual soil indicates that the surface is not clean, and therefore may contain unacceptable levels of bacteria or other organism.

1.18 Quantitative standards proposed for hospital use

Using microbiology and ATP bioluminescence, some studies examined 5000 surfaces after being cleaned using good practice and used them to determine what an achievable level of cleanliness was (Griffith, 2005; Griffith *et al.*, 2001; Harrison *et al.*, 2001) and for an assessment of hospital cleanliness (Griffith *et al.*, 2000). These recommended that fewer than 2.5 cfu/cm² or 500RLU were present.
In 2004, further standards for microbial contamination of hospitals were proposed (Dancer, 2004). These standards were based on US Department of Agriculture and the Swedish Food Standards Agency, but were less stringent, recommending that hand contact surfaces should have an aerobic colony count of <5 cfu/cm\(^2\), and that indicator organisms (including MRSA, \textit{C. difficile}, resistant Gram-negative bacilli and Salmonella species) should not be present in the clinical environment above 1 cfu/cm\(^2\).

1.18.1 Bioluminescence and ATP

Another method of assessing surface hygiene used in hospitals is ATP bioluminescence (Malik et al., 2003; Cooper et al., 2007). ATP is often referred to as ‘the common energy currency of all living cells’. It is an organic compound, produced in mitochondria as a product of respiration in eukaryotes and the plasma membrane of prokaryotes. ATP is used to power many energetically unfavourable reactions in cells, and is constantly recycled. As a result ATP is present in quantity in all organic matter. This makes ATP an excellent indicator of organic matter, as where ATP is present organic matter must also be present. In this way, the amount of ATP present can be an indicator of the hygienic status of a surface, and used as a measure of cleaning efficacy. The advantage of using ATP as a measure of organic matter is that it can be used to drive enzymatic reactions, and so be easily coupled to detection methods. ATP bioluminescence utilises the reaction that fireflies use to produce their characteristic yellow-green light.

By swabbing a surface, or taking a water sample, and adding it to the correct mix of reagents (but lacking in ATP), any ATP present in the sample will start the reaction and light will be produced. Microbial ATP is only a portion of the total ATP on a surface, and because the quotient is not known prior to sampling and may vary, no correlation between ATP levels and bacterial numbers can be expected. The amount of light is proportional to the amount of ATP, and hence organic soil, present, and is usually measured in a luminometer. These devices measure the amount of light produced by the use photomultiplier tubes - where photons cause cascades of electrons that create a measurable electrical signal. Both luminometers and test kits are available commercially from a variety of manufacturers and typically the entire procedure, from sample to result, can be completed within a minute. Other methods used to measure surface hygiene include protein detection, lipid detection, NAD assessment (Griffith, 2005).
1.18.2 Microbiological sampling methods
There are various methods that have been employed for sampling for bacteria in hospitals. However, their efficiency at recovering bacteria has not been compared, and results obtained can not be considered equivalent between methods. Validation or monitoring of cleaning with different methods could therefore produce different results. This would preclude the setting of national standards without a defined sampling method. In addition, if a sampling method is not suitable for a standard set (for example, not sensitive or discriminatory enough) then the value of the standard is diminished.

1.19 Effectiveness of hospital cleaning
Griffith and colleagues (2000) investigated the cleaning of 113 ward and operating surfaces with a variety of methodologies, including general microbiological count and indicators of organic soil. No significant differences in these measures were found before and after routine cleaning, and in some instances, higher levels were found after cleaning.

Cooper and colleagues (2007) assessed the effectiveness of cleaning of surfaces in 4 ward areas in general and surgical wards of 4 UK hospitals by examining various hygiene indicators before and after cleaning. In total, over 3000 hygiene assessments were performed, and showed a high level of contamination compared to standards. In addition, little or no improvement in surface hygiene was found after cleaning had been performed, and the results showed a high degree of variability, a result which may be indicative of poor process management (Dillon & Griffith, 1999).

Significant attention has been given to cleaning in DoH and NHS initiatives (National Audit Office, 2004), and the NHS cleaning manual gives detailed instructions for cleaning many aspects of hospitals wards (NHS Estates, 2004a), but does not require any monitoring or measurement of the efficacy of the task performed. The most recent guidelines from the Hospital Infection Society for the prevention and control of MRSA suggest that cleaning programmes and their efficacy be regularly audited (Coia et al., 2006). However, the audit scheme used is likely to be important. Malik et al. (2003) investigated the use of a variety of audit tools to assess cleaning efficacy in hospitals, and found that those audit systems that relied upon visual assessment consistently rated surfaces cleaner than those that required quantitative hygiene indicators to be measured.

If the aim of improving hygiene by increasing cleaning is to enhance patient safety rather than the public perception of cleanliness, it is essential that the cleaning reduces the number of pathogenic bacteria on surfaces if the resources invested are not to be wasted. The issue
is more complex than simply the number of hours spent cleaning. If the cleaning is not implemented effectively, by using the correct materials and protocols consistently on the necessary locations, then it will not have the desired effect no matter how many hours are spent carrying it out.

1.20 Importance of defined cleaning schedule
One method to ensure that cleaning is carried out effectively is to use a cleaning schedule to define the methodology that should be used. A schedule should include information on how and when the site should be cleaned, including requirements for material and agents used, timescales and steps that need to be followed, such as rinsing or drying (Dillon & Griffith, 1999). Without a clear and defined methodology the risk exists that one cleaner’s thorough clean with a disinfectant is another’s wipe-down with a damp rag.

1.21 Importance of the validation of cleaning methodology
It is important that these defined cleaning schedules and methods actually be able to achieve their aim; an ineffective clean that is assumed to be effective is counter-productive and may cause over-confidence in the cross contamination risk posed by the surface. Therefore a cleaning schedule must be validated to ensure it can consistently meet the defined goals. These goals could be quantitative values. Incorporating benchmarks for pass and fails into cleaning could bring the process to a more objective level, and would allow cleaning to be better managed, on the principle that “you cannot manage what you do not measure” (Griffith, 2005).

A common standard where appearance is paramount is that surfaces must be visually free from dirt. Such a standard might allow a casual observer to determine whether cleaning has been satisfactorily carried out. However, where a more rigorous definition of clean is required, for example in a food production plant, standards cannot be based on a simple visual assessment, because this has been shown to be a poor measure of cleanliness (Cooper et al., 2007; Griffith et al., 2000). Certainly, it should be advised that any attempt to change and improve hospital cleaning should be validated and monitored against quantitative standards and benchmarks in order that desired performance can be achieved by the method (the validation) and is attained in practice (the monitoring).

1.22 Importance of surfaces in cross contamination
In the zigzag model of microbial transmission, surfaces act as reservoirs of microbes, from which they can be transferred. On a hospital ward, there may be thousands of surfaces, but not all are equally important in cross contamination. If limited resources are available for
improved or targeted cleaning and decontamination, it is logical to focus on those surfaces that are more important. For example Verity et al. (2001) found that the bed frame was the site most often contaminated with *C. difficile* in the rooms of patients suffering from diarrhoea. Results from such studies could be used to inform the writing of cleaning schedules for rooms that have housed patients suffering for *C. difficile* to maximise the effect of that cleaning on bacterial numbers.

As well as information on the number and type of pathogens on a surface, another factor in determining the importance of a surface in a cross contamination zigzag model is the frequency with which a surface is touched, and what is touched subsequently touched. Such information has been gathered for studies on food safety (Harrison et al., 2001), using a technique called notational analysis which can be used record frequencies and patterns in behaviour, although it has not yet been used in a healthcare setting.

### 1.23 Risk analysis and assessment

Many methods and practices used to reduce the spread of bacteria to the product in the food industry are based upon risk analysis. One of these, Hazard Analysis and Critical Control Points (HACCP), is widely used in food production worldwide, and has been examined as a potential management strategy for hospitals (Griffith, 2006). Risk analysis comprises 3 factors, risk assessment, risk management and risk communication (Mitchell, 2000). Risk assessment comprises a further 4 aspects, hazard identification, hazard characterisation, exposure assessment and risk characterisation (Mitchell, 2000). For hospital hygiene, the hazard could be identified as a patient acquiring an infection from bacteria spread through the environment, and the hazard characterised as the potential outcomes of that disease. In risk assessment of hospital hygiene, exposure assessment would include the number of bacteria transferred to a patient, but also could include the complex interactions that determine colonisation and infection. Without the inclusion of these patient/bacteria interactions, exposure assessment would be better characterised as assessments of exposure routes. The advantage of locating and defining exposure routes, and of risk assessment generally, is that it allows a rational basis for decision making over the implementation of control measures. The effect of changing policies or practices on outcomes can be measured using risk assessment, which is especially important where additional resources are scant. By choosing interventions that provide the ‘most bang for the buck’, the most efficient reduction in risk can be achieved.
1.24 Exposure assessment and risk characterisation

Information collected on the number of bacteria on a surface, using notational analysis for example, could be combined with data on the frequency and patterns of surface touches in order to create a model that can be used to investigate spread of bacteria and transfer to patients. This would allow assessments of exposure routes to be made, and could also help in risk characterisation. It could allow informed decisions to be made on where best to allocate cleaning resources, or whether some practices increase the exposure of patients to pathogens.

A variety of approaches have been used to model cross contamination and HCAI (Matthews & Woolhouse, 2005). These include mathematical formula to model the spread of pathogens in an intensive care unit (Sebille et al., 1997), an approach also utilised to investigate the effect of various infection control practices on aspects of VRE HCAI (Austin et al., 1999). In contrast Cooper et al. (1999) used stochastic modelling to analyse transmission dynamics in HCAI and O’Neill & Marks (2005) used Bayesian model choice to assess Markov chain Monte Carlo models of Norovirus outbreaks. A stochastic approach was also used by Pelupussy et al. (2002) when assessing the importance of various colonization routes in healthcare, and Cooper & Lipsitch (2004) applied hidden Markov models to infection data. These studies have examined the transfer of pathogens from person to person, but modelling could be used to evaluate the importance of the environment. An approach that been used to assess the risk of the spread bacteria of in food preparation is the use of decision trees (Harrison et al., 2001), combined with Monte Carlo analysis, but this has not been tried in healthcare.

1.25 Thesis aims

Since the role of environmental surfaces in the spread of bacteria that could cause HCAI is not yet elucidated, the aim of this study is to explore these relationships. This will be attempted by the following objectives:

To examine the implementation of a defined cleaning standard for the decontamination of a medical instrument.
To assess the relative merits and performance of bacterial sampling protocols as tools for monitoring cleaning of environmental surfaces in hospitals.
To evaluate the effectiveness of existing and ‘best practice’ cleaning regimes in a hospital with reference to proposed and ‘in use’ standards.
To determine frequencies and pattern of touch actions on environmental surfaces within a selected hospital ward.
To create a stochastic event tree model for analysing cross contamination routes with a hospital ward and use it to identify important factors in cross contamination.
2. The management of endoscope decontamination with microbial and rapid methods

The cleaning standards for medical instruments were laid down by the Spaulding classification. In order to investigate the efficacy of a defined cleaning standard within hospital practice, flexible endoscopes were selected. This commonly used instrument is rated as semi-critical under Spaulding as it comes into contact with, but does not cross, mucosal surfaces.

2.1 Overview of an endoscope
With an estimated 14.2 million colonoscopies and 2.8 million sigmoidoscopies (Seeff et al., 2004), being performed every year in the US alone and demand for endoscopies rapidly increasing (Babb & Bradley, 1995), flexible endoscopes are an important diagnostic and treatment tool. Flexible endoscopes are tools for visually exploring internal areas and volumes of the body without surgery. These spaces include the stomach, intestines and lungs. Some specialised methods can explore internal channels, such as the bile duct in a technique known as ‘endoscopic retrograde cholecysto-pancreatostoscopy’ (ERCP).

An endoscope body consists of three main sections (Figure 2.1.1). The distal tip contains the charged couple device used for imaging, a light source, and the exits of the channels that run along the endoscope. There are channels that provide suction, a water and air supply to improve visibility, and an operating channel which provides the route for any tools required by the procedure. Such tools include biopsy forceps, cytology brushes, snares, banding devices and cautery probes (Alvarado & Reichelderfer, 2000). The tip of the endoscope is flexible to allow ease of navigation and to allow more informative images to be captured. The tip is controlled by wires that run though the shaft of the endoscope. The middle section provides the endoscope with its length, and simply houses the channels and wires that run between the tip and the bottom. It varies in length and diameter, depending on the type of scope in question. Lengths range from 65 cm to 240 cm (Alvarado & Reichelderfer, 2000). The bottom section is sometimes known as the control head, consisting of controls for the flexible tip, entrance port for the operating channel, valve and buttons for the suction and air/water functions and electrical connections for the camera images. The control head is connected to a central unit. This unit provides the light source, suction vacuum, air and water pumps, and is where the image is processed and displayed. As with any television, several image function buttons, such as colour and brightness, are present.
2.2 **Limitations and pitfalls in decontaminating flexible endoscopes**

According to the Spaulding classification, because endoscopes are rated as semi-critical, they require high-level disinfection (HLD) between uses. HLD requires the removal of all vegetative bacteria, but not necessarily spores. Some of the tools and instruments used with endoscopes, such as biopsy forceps or loops for removing cysts or polyps, do cross these membranes and are therefore rated as critical items under the Spaulding classification that require sterilisation between uses. Endoscopes are not easy to decontaminate effectively, and have been described as ‘the instrument from hell’ (Favaro, 2003) in reference to the difficulty of decontamination. Under the Robert Koch Institute classification, endoscopes...
are rated as ‘semi-critical B’, which relates to the difficulty of reprocessing (Martiny et al., 2004) because of the difficulties in assessing cleanliness by visual inspection. This difficulty arises from the various channels and ports present in an endoscope.

The channels are a maximum of a few millimetres in diameter, and may be metres long. Some channels can only be cleaned by flushing them with liquid, which is significantly less effective than brushing (Dietze et al., 2001). It has been reported that removed air/water channels had distinct black discolouration and large amounts of material was removed (Martiny et al., 2004). This suggests that a significant bio-burden can accumulate in these non-brushable channels. In addition, the small size of air/water channels makes effective cleaning more difficult (Pajkos et al., 2004). The condition and build-up of material in these channels can not be inspected visually. In one study, a rigid arthroscope was passed along the channels of a flexible endoscope (Favaro & Bond, 1991). Kinked channel surfaces in tubing and the suction valve housing of a brand new endoscope were demonstrated, and a build up of patient material at these sites in a used scope was found. Patient material was also found on valve seats and in holes in the surface of a channel.

An Australian study examined samples of tubing from 13 endoscopes using scanning electron microscopy, and found bacterial deposits on all samples (Pajkos et al., 2004). In addition, on 5 of the suction/biopsy channels and 12 of the air/water channels evidence of biofilm was found. In addition to the microorganisms and lymphocytes, material similar to faecal matter was found. Microscopic scars (up to 20 µm x 50 µm) were observed in the endoscope tubing, often associated with biofilm formation. The endoscopes were obtained from servicing departments, so their condition may not be an accurate representation of the wider population of endoscopes, but the accumulation of material must have been present during use. The management of servicing and the replacement of damaged endoscopes is also complicated by the difficulty of inspection. Although servicing intervals can be specified, problems cannot be easily identified and corrected earlier.

Residual contamination and biofilm in endoscopes is more than an aesthetic issue. Biofilms are aggregations of bacteria, embedded in a polysaccharide matrix, and are usually associated with phase interfaces. They can achieve high cell densities and jointly exhibit properties that would not be expected from individual cells (Hall-Stoodley et al., 2004). One of these properties is increasing the resistance of the cells in the biofilm to disinfectant. Therefore, it is harder for endoscope channels containing biofilm to be cleaned sufficiently to meet the demands of the Spaulding classification. Biofilm can spread either by increasing
the number of cells and thus the area covered, or when a clump of cells is detached from the main body of the biofilm and is transferred to another colonisable area. This is relevant to endoscopy because clumps of bacteria could be dislodged during use either by the instrumentation used or by the flow of water.

Organic matter left in endoscope channels can reduce the efficacy of disinfectants, especially disinfectants with an oxidising action (Alvarado & Reichelderfer, 2000). Organic matter can also be fixed by disinfectants such as glutaraldehyde, which forms cross-links between proteins. Another disinfectant, peracetic acid, can also fix blood protein (Kampf et al., 2004), making it hard to remove. Favaro and Bond (1991) found that organic matter present within the tubing had the potential to cause instruments passed through the tube to deflect into the wall of the tube and cause visible damage to the channel. Damage to the wall of the tube would make the channels more difficult to clean as pathogens would be harder to remove from the damaged areas.

Another problem associated with residual matter is that it can harbour pathogenic agents. An investigation into the disinfection of endoscopes revealed that 23.9% of the internal channels of gastrointestinal endoscopes sampled grew over $10^5$ bacterial colonies (Kaczmarek et al., 1992). This observation was confirmed by a German study in which inadequate reprocessing of endoscope was found in 57%, 50% and 12% of cases in manual, semi-automatic and automatic processing respectively (Bader et al., 2002, cited in Martiny et al., 2004).

Analysis of a two year quality assurance programme found that after processing, the exterior of GI endoscopes were contaminated on over 60% of occasions, and on over 40% of occasions, internal channels were contaminated (Merihi et al., 1996). It has been stated that it is ‘virtually impossible to consistently achieve a state of high-level disinfection’ for endoscopes (DiMarino & Bond 1996).

### 2.3 Endoscope related infections

Poor disinfection can lead to endoscope-related HCAI, because pathogenic agents can be transferred from the endoscope to the patient being examined, which increases the risk of infection. Between 1988 and 1992, the infection rate from endoscopy has been estimated at 1 infection per 1.8 million endoscopies carried out (Spach et al., 1993). However, this is likely to be an underestimate of the true figure (Cowen, 2001; Peterson, 1999). Only confirmed infections were included in this analysis but it is likely that not all infections linked to the endoscopic procedure would be recognised as being associated with it. If a
cluster of infections occurred, or a patient acquired unusual infectious agents, it might be linked to endoscopy. However, sporadic infections, asymptomatic infections, diseases with a long incubation period, and self-limited infections may not be included in statistics (Spach et al., 1993), because there is no reason to associate them with the endoscopy. If endoscopy-related infections were prospectively sought, a higher and more accurate estimate could be obtained. In one study where this was attempted, reported rates of bacteremia following colonoscopies and gastroscopies were as 10% and 25% respectively (Casas et al., 1999). It is also recognised that practitioners may not be motivated to report such infections.

A French study on the incidence of hepatitis C virus (HCV) antibodies in patients who had undergone endoscopies found some evidence that having a biopsy during an endoscopy posed a risk of acquiring HCV. Comparing the HCV antibody status of over 2600 hospitalized patients who had undergone endoscopies with biopsies demonstrated that the prevalence of HCV antibodies in patients who had been biopsied in their endoscopic procedure was significantly higher than for those who had not (7.2% compared to 4.0%) (Andrieu et al., 2005). This suggests that HCV was acquired during the collection of the biopsy and presumably it was transferred from the endoscope when the mucous membranes were broken. It is important to realise that even if the rate of transmission of infection by endoscopy is low, the sheer number of endoscopies performed every year makes it a significant problem. Endoscopic procedures are the most frequently reported cause of medical device related infection worldwide (Heeg, 2004).

Whatever the true rate of endoscope-related HCAI, some instances have resulted in serious infections. In 1975, a fatal outbreak of Serratia marcescens was traced back to a poorly disinfected bronchoscope (Webb & Vall-Spinosa, 1975). A report from 1983 implicated endoscopic transmission in a patient acquiring hepatitis B, when air/water channels were not disinfected in accordance with manufacturers instructions (Birnie et al., 1983).

In 1995, an endoscope contaminated with HCV from one patient was proven to have transmitted the disease to two further patients (Bronowicki et al., 1997). The infective agent was not removed during disinfection. The biopsy-suction tube had not been ‘thoroughly cleaned with an appropriate brush’ and the biopsy forceps presumably became contaminated in passing through the channel and, with other factors, caused the outbreak. In this case, although the forceps would have been sterilised in accordance with the Spaulding classification, their contact with a contaminated surface compromised the sterility.
In 1997, a contaminated bronchoscope was identified as the likely vector of transmission for tuberculosis between two patients (Michele et al., 1997). The report suggests that the difficulty of cleaning the suction valve and tubing may have been a contributory factor. The difficulty of disinfecting endoscopes that may be contaminated with *Mycobacterium tuberculosis* or other mycobacteria is increased by their relative resistance to disinfectants (Sehulster & Chinn, 2003), due to the hydrophobic waxy cell wall which reduces permeability. It has also been demonstrated that the organism often implicated in acute gastric mucosal lesions, *Helicobacter pylori*, can be transmitted by endoscopy (Sugiyama et al., 2000) (Nürnberg et al., 2003).

Devices used in endoscopy must be decontaminated properly. A recent outbreak of *S. marcescens* in a neonatal intensive care unit was traced to a larygoscopic blade that was disinfected with 70% isopropyl alcohol (Cullen et al., 2005). As these blades cross the skin barrier, they should have received sterilisation rather than disinfection.

More recently, two outbreaks were reported with a common cause. In the first institution, a series of patient specimens following bronchoscopy were found to be positive for *Ps. aeruginosa*, or *S. marcescens* (Kirschke et al., 2003). An investigation found biopsy port caps were loose, and the cap’s screw thread and interior had a ‘dark green film’, which could have been biofilm. Many of these tested positive for *Ps. aeruginosa*, or *S. marcescens* or both. One of these endoscopes went through three disinfection cycles and still remained positive for *Ps. aeruginosa*; this highlights the difficulties of removing of bacteria in awkward areas or in biofilm.

At a similar time in a different hospital, the recovery of *Ps. aeruginosa* from patient bronchoalveolar-lavage specimens increased from 10.4% to 31.0% (Srinivasan et al., 2003), in conjunction with a cluster of *Ps. aeruginosa* infection. This suggested that the bronchoscopes were associated with the infection, and samples showed that a loose biopsy port caused the outbreak. It was thought that a contaminated bronchoscope might have contributed to the deaths of three patients.

The discovery of this manufacturing fault led the manufacturer to recall 14,000 bronchoscopes worldwide (Kirschke et al., 2003).

Given the range and potential severity of diseases that may be transmitted by unclean endoscopes, the necessity of having clean endoscopes for each procedure is clear. Ideally, sterile, single-use scopes would be used, however the delicate nature of the materials and
electronics used in flexible endoscopes prevents heat-sterilisation between uses, and their cost (around £20,000 each), prevents disposal after use. Sheathed endoscopes offer a possible compromise. Sheathed endoscopes differ from standard flexible endoscopes in that the various channels that run through the body of the endoscope are removed and discarded after the procedure has been completed. A new, sterile sheath is used for each procedure (Sardinha et al., 1997). Control knobs require disinfection between procedures, but otherwise no disinfection is required (Sardinha et al., 1997). This process saves on reprocessing time and cost, and because the channels do not require cleaning, eliminates the potential for a poorly managed and implemented cleaning system to cause infection. However, costs of using this system are higher than for conventional endoscopes (Sardinha et al., 1997), and physician satisfaction with the system was lower than with a standard endoscope (Mayinger et al., 1999).

As described previously, endoscopes require ‘high-level disinfection’ between use, and several guidelines for the decontamination process have been developed (Anon. 2003; British Society of Gastroenterology 1998; European Society of Gastrointestinal 1999; Systchenko R. et al., 2000). Although there are minor differences between these guidelines, all recommendations are broadly similar. However, although all guidelines seek to describe the various steps required, they do not precisely outline how the process is to be managed. Guidelines on the disinfection of bronchoscopes are less well developed, with a non-evidence-based position statement being the most recent publication addressing these issues (Mehta, 2005). These are largely derived from GI endoscope disinfection guidelines and advise on the steps required for disinfection, but do not address the issue of how to manage the process effectively.

2.4 The process of endoscope decontamination

In this thesis ‘decontamination’ refers to the entire endoscope decontamination process, from when the endoscope is flushed to remove the gross debris after the endoscopy of the patient is completed, to the completion of reprocessing by the removal of the endoscope from the automated washer-disinfector. Decontamination encompasses ‘disinfection’ which refers solely to the period of time when the endoscopes is immersed in disinfectant within the decontamination process.

After a clinical investigation has been completed, the used endoscope will invariably be flushed to remove gross debris and deposits. The scope will then be given a thorough, meticulous manual clean. Each major channel will be brushed through with a specialised
brush, with different brushes available for different channels and different channels sizes. Some channel cleaning brushes are reusable, and are often cleaned between uses with a domestic nylon-bristled toothbrush. Other brushes are single-use disposable items. A strong detergent, often with a multi-enzymatic action, is used to help break down any remaining residues. The exterior of the scope will also be cleaned.

After manual cleaning, the endoscope will usually be transferred to an automated endoscope washer-disinfector (AEWD). AEWD are recommended for use because they reduce the chance for mistakes and short-cuts in practice. Bader found that automated processing gave better results than manual reprocessing or semi-automatic reprocessing (Bader et al., 2002). AEWDs disinfect the endoscope by soaking the scope in a specified disinfectant for a validated time and at a validated temperature. Connectors are attached to the ports and channels so that these areas are ensured contact with the disinfectant. If flow through the channels is not detected, the AEWD can sound an alarm. With a manual soaking process, if the disinfectant does not fully penetrate the channels then those areas will not be disinfected and the decontamination process will be compromised. Typical disinfectants are glutaraldehyde, peracetic acid, or super-oxidised water, although glutaraldehyde is becoming unpopular due to occupational health concerns and has been banned in some countries (Darbord, 2004). Indeed, the NHS has banned the use of glutaraldehyde since May 2002. Once the disinfection cycle has been completed, the AEWD rinses the scope with potable quality water to remove any traces of disinfectant.

Some guidelines recommend flushing the decontaminated endoscope with alcohol to hasten drying for every decontamination, whereas others specify that alcohol is used at the end of the day. The decontaminated endoscope will then be removed from the machine and placed on to a surface to be prepared for clinical use. The processed is summarised below (Figure 2.4.1).
Figure 2.4.1 A simple flow chart showing the steps and stages in the endoscope disinfection process

### 2.5 Pitfalls in the decontamination process

The manual clean is accepted as a crucial factor in the success of the disinfection step, and thus to the overall decontamination process. However, as the interior of the tubes cannot be inspected, it is not easy to decide whether this has been carried out effectively. In addition to traditional microbiological methods, other methods have been proposed to assess whether the channels have been cleaned properly, including radionucleotides (Schrimm et al., 1994), ATP measurement (Sciortino et al., 2004) and DNA amplification (Deva et al., 1998).

One cause of endoscope-related HCAIs is cross contamination. The endoscope receives no further cleaning after the disinfectant has been applied in the AEWD, so any bacteria contaminating the endoscope after this point could be transferred to the next patient. Additionally, rinse water used to remove disinfectant has been shown to be contaminated with pathogens (Merihi et al., 1996), and this has been linked to outbreaks of infection (Schlenz & French, 2000). Regular monitoring of rinse water has been suggested (Muscarella, 2002), because it has been shown that it is not be possible to guarantee bacteria-free rinse water (Cooke et al., 1998).

The outer surface of a decontaminated endoscope can also become contaminated from the environment. If it is placed on surfaces that are dirty, or is touched with contaminated hands, then the potential for cross contamination exists. In the same way, poorly cleaned surfaces or hands can contaminate the exterior of the endoscope. Inadequately cleaned internal surfaces and channels can contaminate biopsy forceps (Bronowicki et al., 1997).
When sterile devices that are rated as critical under the Spaulding classification are passed along inadequately decontaminated endoscope channels, the sterility of the device can become compromised.

Management plays an important role in the continued success of any cleaning programme because it helps to ensure that “a plan is consistently followed and resources are well used” (Dillon & Griffith, 1999). There are 3 stages essential for good endoscope decontamination. Firstly; a thorough manual clean of the endoscope channels; secondly, effective disinfection; and finally, rinsing with water of suitable quality. If these are achieved then the overall disinfection will meet the designated standard. For the management of this approach to be truly effective, real-time information is required so that if necessary, corrective actions can be taken before the endoscope is reused. Although microbiological tests can be regularly carried out, and are indeed required in Germany (Heeg, 2004), the results of these tests can be slow to arrive. With between 24 and 48 hours required for a simple assessment of bacterial load, a contaminated or badly cleaned endoscope would be likely to have been reused before the laboratory results were available. In situations where the contamination is systemic, such as a compromised rinse water system, malfunctioning AEWD, failure in endoscope integrity or repeated failure of staff to perform the required actions properly, then multiple incidents of contamination could occur before microbiological results were available. Similar issues are experienced with the DNA amplification and radionucleotide methods, as described above. Although both have specific advantages, both also require specialist knowledge and equipment, and must be performed at a site distant from the decontamination process

2.6 Aims

The aim of this study was to evaluate the decontamination of endoscopes, and its management. To achieve this, the following objectives were set:

To compare ATP bioluminescence and traditional microbiology as tools for assessing stages in endoscope decontamination

To assess the efficacy with which important steps within the endoscope decontamination process were carried out in two endoscopy units

To evaluate the management of the decontamination process in both units.
2.7 Method

2.7.1 Study setting

A convenience sample of two hospital endoscopy units was taken. Unit A was part of a newly built 500-bed District Hospital, with 2 endoscopy theatres. Each theatre had a small disinfection process area containing a sink and 2 AEWD units. Unit B was a part of a 538-bed District General Hospital. Unit B had a single endoscopy theatre. The reprocessing was undertaken in a separate dedicated room with sinks and 4 AEWDs.

Both units followed the British Society of Gastroenterology (British Society of Gastroenterology, 1998) guidelines for disinfecting endoscopes. These guidelines specify that endoscopes are disinfected at the start and end of each list and between patients, and that alcohol is used to flush the endoscope at the end of the day to aid drying to prevent bacterial growth in storage.

2.7.2 Sampling sites chosen

Ten sites believed to be important in the successful decontamination of gastrointestinal endoscopes were selected for study (Table 2.7.2.1). The locations were chosen by analysing the decontamination process, and determining which stages had the potential to compromise the overall success of the disinfection. Monitoring of the biopsy and suction channel after cleaning would allow assessment of the success of manual cleaning, vitally important in the success of the overall decontamination. The same channels were sampled after disinfection to measure the quality of the disinfection. Contaminated channel cleaning brushes and toothbrushes could lower the efficacy of their functions. Rinse water was also sampled, because of its role in some reported endoscope HCAI (Cooke et al., 1998; Muscarella 2002). The surfaces on which decontaminated endoscopes were rested after use were tested because of their potential to contribute to cross contamination. Contamination collected from environmental surfaces in the endoscopy theatre by the endoscope operator’s hands, could be transferred to the endoscope shaft subsequently passed into the patient.
In total, sites were sampled during the decontamination of 63 endoscopes, over a two week period, and samples were taken either immediately prior to or immediately after disinfection, whichever was appropriate. Sampling was carried out using two methods at each site. The first of these was with traditional microbiological methods, the second was taken with ATP bioluminescence technology.

### 2.7.3 Microbiological sampling

Microbiological sampling was undertaken using dipslides, which have been found to have advantages in surface testing (Moore & Griffith 2002b; Salo et al., 2000). Although dipslides are primarily designed for sampling surfaces or liquid samples, they can be used as regular microbiological media, and have advantages in ease of storage, transportation and organization, especially when full laboratory facilities are not available.

Where endoscope resting surfaces and the image function buttons were being tested, dipslides containing plate count agar and neutralizer were pressed on to the surfaces for 10 seconds with a force of approximately 25 g/cm² without any lateral movement (Moore, 2005). To achieve a consistent pressure at this level, many practice applications were carried out using a top pan balance.
Endoscope channels were sampled using the sterile brushes that were routinely in use in each of the units. The brushes were moistened in sterile 1/4 strength Ringers solution, and fully inserted into the relevant channel at the distal tip of the endoscope. On removal, the brush was rinsed in 5 ml of sterile 1/4 strength Ringers solution, and vigorously shaken for 5 seconds to release microbial cells and any other residual soil. Aliquots of 60 µl of the resultant suspension were pipetted on to dipslides. The channel cleaning brush and the toothbrush were sampled by rinsing the bristles in 5ml of sterile 1/4 strength Ringers and the suspension pipetted on to the dipslides as above. Dipslides were fully immersed in the rinse water. Endoscope tips were sampled with a sterile hygiene swab moistened with sterile 1/4 strength Ringers solution that was immediately swabbed on to a dipslide. All microbiological tests were incubated for 24 hours at 37°C, and individual colonies were counted.

2.7.4 ATP bioluminescence sampling

ATP bioluminescence tests were carried out using Clean-Trace (Biotrace Ltd, Bridgend) tests for surfaces and Aqua-Trace (Biotrace Ltd, Bridgend) for water samples. Both were measured using Uni-Lite (Biotrace Ltd, Bridgend) luminometers. Clean-Trace tests were used on endoscope resting surfaces, image function buttons and the distal tip of the endoscope. For the first two of these, 100 cm² was swabbed and processed according to manufacturer’s instructions. For the distal tip of the endoscope, 30 cm² was tested in order to provide a consistently sampled area.

The endoscope channels, channel cleaning brush and toothbrush were all assessed using the rinse water obtained as described in microbiological sampling using Aqua-Trace kits according to manufacturer’s instructions. Microbiological tests were carried out before the ATP tests, because the latter contained a chemical to rupture cells to release somatic ATP that would have altered the results for microbiological tests. AEWD rinse water was sampled by dipping an Aqua-Trace device in the rinse water. Aqua-Trace devices were processed immediately in accordance with manufactures instructions. Both types of test were measured in a Uni-Lite luminometer. Slight adjustment to ATP and microbiological techniques were made to accommodate small differences in procedural activities in use at each of the units. For example in Unit A, a disposable cytology brush was used to sample endoscope channels, whereas a disposable channel cleaning brush was used in Unit B. Negative controls were routinely performed.
2.7.5 Benchmark values used

The use of both dipslides and ATP bioluminescence for surface sampling has been found to offer superior repeatability to traditional swabbing. The coefficient of variation of ATP testing has been found to be 24% (Davidson et al., 1999), and a 31% for dipslides (Salo et al., 2000) compared to 130% for swabbing (Davidson et al., 1999). This allows setting of precise benchmark values. Pass/fail limits were set at $\geq 3$ cfu per sample and >500 RLU per sample, based on adapted previously published figures (Griffith et al., 2000) for adequately cleaned surfaces. No correlation co-efficient can be determined between ATP and microbiological counts as each measures different parameters, and correlation depends on the ratio of organic matter to microorganisms. Although this can be relatively constant for hand-contact surfaces, it varies considerably where fluctuating amounts of organic soil are encountered (Griffith et al., 2000). A better comparison is the pass/fail frequencies in relation to benchmark values for adequately cleaned surfaces (Griffith et al., 2000). Benchmarks for microbiological tests were defined as greater than 1 cfu per sample, and greater than 500 RLU per sample for ATP bioluminescence. Results were recorded as numerical values, and were also interpreted as pass/fail.

2.7.6 Assessment of process management

In addition to the quantitative assessment of bacteria and ATP, the way in which the process was managed was analysed. Documentation and protocols related to the cleaning of the endoscope, record keeping and action tracking, and the physical flow of the stages in the decontamination process were examined. This information was collected by observation during sampling, and in formal and informal discussion with endoscopy staff. This aspect of endoscope management is relevant as both a mechanism for investigating outbreaks or patterns in patient bacterial screening, and also as a method for their prevention. The investigation of one outbreak was complicated by the inability to link patients to endoscopes (Srinivasan et al., 2003).

2.8 Results

In total, five hundred and four tests on 63 endoscopes were performed to assess the efficacy of the decontamination process and the acceptability of the final decontaminated product (Table 2.8.1.1).

2.8.1 Pass/failures against benchmarks

In unit A, 7 microbiological and 43 ATP tests exceeded benchmark clean values, while 25 microbiological results and 52 ATP results exceeded the benchmark values in unit B.
Locations where benchmark values were exceeded differed between units and in some cases by test method (Table 2.8.1.1). The patterns described by the failures (defined as results above benchmark values) are quite distinct with each combination. In unit B, many of the ATP failures in both suction and biopsy channels pre-disinfection with ATP were clustered together. This cluster is located on the right hand side of Table 2.8.1.1 in rows ‘Suction channel pre-disinfection’ and ‘Biopsy channel pre-disinfection’.

Samples taken from the suction and biopsy channels after cleaning had microbiological counts which, although low, were above benchmark clean values on 18% of occasions in unit B (Table 2.8.1.2). In unit A, suction and biopsy channels prior to disinfection were found to exceed the benchmark values in 4% and 0% of samples respectively. The failure rate of channels was generally higher in both units when sampling with ATP, with 42% and 45% of post-cleaning suction and biopsy channel exceeding benchmark ATP values in unit B respectively.
### Table 2.8.1.2 Percentage of samples exceeding benchmark clean values at sites tested. Benchmark ATP was 500 RLU, benchmark microbiological value was set at 1 cfu per sample.

Post disinfection, for both channels, no failures were reported using either ATP or microbiological methods in unit B. Low channel failure rates associated with low levels of contamination were indicated with both methods in unit A. The tips of freshly decontaminated endoscopes from both units were assessed to be below benchmark values using microbiological methods, and thus acceptable. However, failure rates of 44% at unit A and 16% at unit B recorded using ATP, often at levels many times the benchmark values (Table 2.8.1.3).

### Table 2.8.1.3 Mean values and ranges (in italics) of the samples taken with both methods used, and at both units investigated. Unit A n = 25; unit B n = 38.
The rinse water used after disinfection was demonstrated to be of good quality in both units by both assessment methods. Endoscope resting surfaces in unit B had higher failure rates than unit A by both assessment methods. In unit A, image function switches had high failure rates with ATP (92% with a mean value of 5322 RLUs). Unit B recorded failure rates of 13% with ATP for the same surfaces.

2.8.2 Examination of process management

Detailed descriptions and protocols of the decontamination process were not available in unit A but were in unit B, although staff were not seen to refer to the documentation during the decontamination process.

Operations were more easily traceable in unit B, where the AEWD system used in unit B featured an electronic recording system. All endoscopes and endoscopy personnel carried a radio tag with an individual signature and the system required that the machine read the tag of the endoscope and the staff member doing the decontamination, before disinfection could commence. Unit A did not have this system in place.

The decontaminations areas in unit A were so confined that a linear physical flow through the process was not possible, so that some surfaces were sometimes used for both decontaminated and undecontaminated endoscopes. The larger room in Unit B had designated areas for specific activities but the design of this room meant that at one place the physical route of a decontaminated endoscope exiting the area would cross the route of an undecontaminated endoscope entering the area. However, having the designated areas meant that clean and dirty scopes were kept separate, and no breaches of this were seen during the observation period.

Infections in patients examined by the 63 endoscopes tested were not followed up, due to confidentiality and ethical reasons.

2.9 Discussion

Endoscopes are rated as semi-critical under the Spaulding classification, requiring high level decontamination between uses. Failures in cleaning, through poor practice or poor management, can lead to subsequent patients becoming infected as a result of an endoscopy. One study indicated that rates of bacteraemia following colonoscopies and gastroscopies may be as high as 10% and 25% respectively (Casas et al., 1999). An independent review on the process of endoscope decontamination drew together a list of 55 recommendations,
many of which pertain to management in endoscope decontamination and risk management within that process (Anon., 2005) and it has been reported that all recent incidences of endoscope-related infection have been caused deviations from best practice (Anon., 2003).

One possible improvement in the management of endoscope decontamination is to monitor the stages crucial to the overall success of the process. In doing so, the success of these steps can be validated, and any stage that has not been completed adequately can be repeated before patients are exposed to a cross-infection risk. ATP bioluminescence may be a suitable technology to accomplish such routine in-process monitoring.

Sampling reported here was completed before the 2003 British Society of Gastroenterology guidelines were published (British Society of Gastroenterology 2003), but reprocessing did conform to the previous edition (British Society of Gastroenterology 1998).

2.9.1 Patterns of failures of decontamination against benchmarks
From the distribution of failures in table A, it can immediately be seen that there are differences in their frequency and location between units and sampling methods. The image function panel in unit A failed to satisfy benchmark values far more often with ATP than microbiological test, whereas failure rates for the same location were lower in unit B. Such differences indicate that the methods and practices used in each unit were different, and this difference had an effect on the reprocessing on endoscopes.

2.9.2 Endoscope channels
Endoscope suction and biopsy channels in unit B appeared to be more effectively cleaned than in unit A. This may be because the brushes used for sampling in unit B were a tighter fit than those used in unit A, and therefore removed more residual soil from the channels. In both units, high levels of ATP in the channels after manual cleaning were seen on occasions, indicating considerable levels of organic soil in the channels of the endoscopes remained after manual cleaning. Although these were not matched by high bacterial levels in these instances, the lack of correlation between ATP and microbiological results could be due to low bacterial numbers after effective cleaning, or that the techniques and methods had differing sensitivities. However, the presence of ATP at these levels indicates that manual cleaning was not effectively performed on occasions. This concurs with the opinion of DiMarino and Bond (1996), who stated that it is ‘virtually impossible to consistently achieve a state of high-level disinfection’ and these findings indicate that achieving high
levels of cleanliness is similarly difficult when measuring inorganic soil as it is when quantifying bacteria.

Interestingly, the ATP results from pre-disinfection channels in unit B show a marked increase in failures at the end of the study period. This is symptomatic of inconsistencies in the cleaning process, showing that Unit B operated in such a way that a different person was responsible for the cleaning on each day. The variation in observations might reflect differences in method between operators, which could arise either from inconsistencies in training, or through drift in practice over time. Although no bad practice was observed during the study period, it is possible that differences could lead to a poor manual clean at some time. ATP technology may therefore have additional uses in assessing operator’s practice efficacy or as a training tool.

### 2.9.3 Cleaning brushes

The channel cleaning brush used in Unit A was a reusable metal brush, whereas unit B used a disposable plastic brush. Although unit A disinfected the brushes in glutaraldehyde between uses, the higher ATP and microbiological results suggest that this process may not be totally effective. This is likely to be due to the twisted wire shaft of the brush. The gaps between the strands of wire would provide niches for dirt and debris to cling to. In the same way that endoscopes cannot be adequately disinfected unless they have been properly cleaned, such endoscope brushes cannot be totally disinfected. However, as these brushes are used to clean endoscopes before disinfection, the risk of contributing to cross-infection risk is low, although their efficacy in cleaning may be reduced.

The higher bacterial counts and ATP levels present on the tooth brush used to clean debris from the channel cleaning brush at unit A were due to infrequent disinfection, whereas unit B disinfected their toothbrushes after every endoscope decontamination. Although there is minimal risk of cross-infection through a contaminated toothbrush, it is perhaps surprising that the disinfection step was not included as it would require no additional time or resources other than an additional toothbrush for use whilst the other was unavailable.

### 2.9.4 Endoscope exterior

ATP levels found on the exterior tips after disinfection were higher than expected, considering that the exterior was relatively simple to clean compared to the interior. Both units had double figure failure rates, indicating that high levels of organic matter were present. This could be explained by direct (i.e. touch) or indirect cross contamination.
Another possibility may be that ATP from previous disinfection cycles remained in the glutaraldehyde. Glutaraldehyde used for disinfecting is re-used for up to 14 days (Alvarado & Reichelderfer, 2000), and it is possible that ATP persists in the disinfectant, as both ATP-degrading enzymes and microbes would be inactivated by the action of the disinfectant.

2.9.5 Rinse water
The rinse water used during reprocessing in both units returned low ATP results and is unlikely to be the source of high ATP levels. The quality of the rinse water is significant, because contaminated rinse water is a known risk factor for endoscopy-related HCAI. It has been found that maintaining bacteria-free rinse water may be impossible and that mycobacteria could be regularly recovered from rinse water despite regular filter changes and the addition of an antibacterial agent called Pera-clean (Cooke et al., 1998). The methods used here would not have recovered mycobacteria, although faster growing and less fastidious organisms would have been recovered. Given the critical nature of the rinse step in endoscope decontamination, it has been advised that rinse water monitoring should occur (Cooke et al., 1998). Tests for ATP levels in water are already in use for other applications, for example in assessing levels of organic matter in water cooling towers, in paper manufacture and in brewing, amongst others.

2.9.6 Environmental surfaces
Environmental surfaces that could contribute to zigzag cross contamination were a cause for concern in both units. For example, the endoscopes in unit A, after disinfection, were placed on a paper mat that was replaced after use (endoscope resting surface), whilst unit B used a cotton towel, which was replaced daily. The cotton towel became slightly damp with water from the decontaminated endoscope. Bacteria from the air (the decontamination room had a window that was often open) or hands would be likely to survive in these conditions and could be transferred to the endoscope. This was evident from the frequent failures seen at Unit B. However, this is unlikely to be a source of extensive contamination. Image function switches in both units were contaminated, but particularly those in unit A. These switches are activated by hand, and bacteria acquired from these switches might result in a zigzag transmission of organisms to the endoscope during the procedure. In addition, bacteria could be transferred from the endoscope in use to the switches, and ultimately on to another patient. In both units it was stated that the switch panels were regularly treated with alcohol wipes. This could not be verified as the panels were wiped during the procedure, which the researcher could not observe for ethical reasons. The high failure rates of the switches in unit A could be due to its textured finish, making cleaning / disinfection more
difficult than in unit B, where the surfaces were smoother. The design, construction and finish of equipment are known to be important determinants of cleaning efficacy (Dillon & Griffith 1999).

2.9.7 Assessment of process management

Although, in Unit B, documentation was not referred to during the decontamination process, this may not present issues where the staff were fully trained and informed (according to training records). However, for new and inexperienced staff, such documentation could play an important role in training and subsequently in the efficacy of decontaminations performed in the future. In unit B, differences in results when different members of staff were performing the decontamination were observed. This may have been due to variation in the manner or thoroughness which they performed the disinfection steps. In addition, documentation would be important if unusual or complex situations arose.

The recording system built in to the AEWD units at unit B helped in tracking down any problems that arose. As this system was not in place at unit A when the investigation was carried out corrective actions and policies would be more difficult. However, recent British guidelines, formulated after this part of the study was complete, specify that records must be kept on which endoscope was used on which patient (British Society of Gastroenterology, 2003).

ATP may be more advantageously used as a management tool within the decontamination process. Because the manual cleaning of the endoscope prior to disinfection is so critical to the process, the ability of ATP bioluminescence to assess quality of cleaning in a quantitative manner would allow the manual cleaning step to be monitored against validated standards. In this way, aspects of the decontamination process could be managed as opposed to the current reliance on staff routinely performing the operation without deviation from a protocol providing no advice on ensuring repeatability. In the endoscope related infection described by Bronowicki and colleagues (1997), a badly cleaned channel contaminated biopsy forceps that in turn transmitted HCV to the patient. ATP bioluminescence would not have detected ATP-free virus particles, but the residual soil left by the poor cleaning would have provided an ATP reading that would indicate that the channel had been poorly cleaned. Corrective action could therefore have been applied before the scope was reused.
2.9.8 Quality of decontamination against ATP benchmarks

At unit A, there were 3 incidences where the channels of a decontaminated endoscope failed by microbiological standards and while bacterial numbers were low, the Spaulding classification for endoscopes requires that any vegetative bacteria be removed. Although the bacteria recovered in this study were not characterised, their presence demonstrated a failure under the Spaulding classification and presented a risk of transmission to the patient. In one instance, a biopsy channel sampled post-disinfection returned a failure against benchmark values using both ATP and microbiological sampling. The ATP result was available immediately, whereas the microbiology result took 24 hours. However, while ATP is a proven method of assessing cleaning, a low ATP reading can not be assumed to equate to an absence of bacteria. In this sense, ATP can not be used as a post-decontamination tool to prove that a particular disinfection has met the Spaulding classification. However, it could be of use in detecting gross failures, which would pose a greater cross-infection risk. Sciortino and colleagues (2004) found that ATP bioluminescence was a useful tool to monitor the end product of the process. The results of this study support those findings with the reservation that ATP is not sufficiently sensitive to test against the ‘semi-critical’ Spaulding classification of no vegetative bacteria being present. However, given the strictness of this classification, it is unlikely that any existing methodology would be sensitive enough to achieve this.

2.9.9 Microbiology and ATP as tools for assessing endoscope decontamination

In terms of the time required for test results to be available, microbiological tests, whilst producing an indication of bacterial numbers, were only obtained after 24 hours – too late for any corrective action to be taken. ATP results were obtained within 2 minutes and allowed for immediate corrective action. In addition, the equipment used for ATP bioluminescence testing is small, self-contained, non-technical in nature and does not require specialist knowledge to use. This would aid its implementation into the normal working practice of an endoscopy unit. Used routinely, the results could be used to monitor patterns and trends in result. This can identify problems before they become problematic. Routine ongoing surveillance of post decontamination culture could inform on emerging trends and problems, but would miss the one-off incidences of failure.

However, limitations were also identified. In this study, ATP monitoring before disinfection did not pick up the instances of microbiology failures after disinfection. It is not expected that a correlation between the presence of ATP and the presence of bacteria will always be
found, because the level of one is not dependant on the other, but the presence of bacteria does denote the presence of at least trace levels of ATP. Any reasonably accurate monitoring system is better than none at all, but methods must be able to detect failures reliably in order to be of value. This difference maybe due to methodology, especially as there is no agreed method for sampling endoscopes channels. Benchmarks used in this study were based on achievable clean values for surfaces which are used in quite a different way to endoscopes.

The use of ATP for monitoring the rinse water needs further examination. ATP bioluminescence is widely used and accepted for monitoring the levels of organic matter in water and some ATP monitoring systems, such as Autotrack (Biotrace Ltd, Bridgend), can continually monitor ATP levels in water. ATP bioluminescence compares well with traditional microbiology in terms of overall cost, but in endoscopy routine monitoring is not carried out. ATP bioluminescence thus incurs a cost penalty.

2.9.10 The importance of managing endoscope decontamination

From 1992 to 1996, all 281 incidences of gastrointestinal endoscopy-related cross-infection were found to be due to breaches of current guidelines in cleaning and disinfection practice, or defective equipment (Anon. 2003). From 1992 to 2003, only 5 further incidences of GI endoscopy-related cross-infection were recorded, and these were associated with poor practice (Anon. 2003). Although standardised and validated guidelines undoubtedly are important in improving practice, they cannot ensure alone that the steps required by guidelines are effectively carried out. Many authors have found evidence of poor compliance with guidelines (Kaczmarek et al., 1992; Jackson & Ball, 1997). Bader and colleagues (2002) found that 12% of endoscopes were inadequately decontaminated using automated processing. Jackson and Ball (1997) found numerous deficiencies in practice, and although training helped, it did not eliminate all deficiencies. This shows that whilst compliance with published guidelines, with detailed steps for each stage of the process, can effectively decontaminate endoscopes, inconsistencies, errors, omissions and misunderstandings in their implementation can pose cross-infection risks for patients. The importance of managing endoscope decontamination and prevention of cross-infection, rather than simply through cleaning guidelines, is emphasised by recent incidents and studies.

An investigation into the decontamination of a variety of types of endoscopes in Northern Ireland (Anon., 2004) raised concerns over the disinfection of 16 endoscopes, and a raft of
recommendations were published as a result (Anon., 2005). Many of these recommendations dealt specifically with the wider management of endoscope decontamination, rather than the individual steps involved. These include training needs analysis and training record keeping, audit programmes for the decontamination process, microbiology support and enablement of risk management approaches (Anon, 2005).

A recent outbreak of 17 *Ps. aeruginosa* infections was determined to be due to “major deviations from hospital policies” (Bou et al., 2006). At weekends, cleaning was inadequate and high-level disinfection not performed, consisting of rinsing the scope with povidione after the procedure before replacing it, still wet, in its storage case. Shortcomings were also identified during decontaminations performed on weekdays. The lack of consistency in decontamination practices is an indication of poor management practices.

The importance of good management systems in endoscope decontamination is underlined by a review of 70 endoscope related outbreaks spread over 39 years. This study found that 91% could have been prevented with an improvement or implementation in quality control systems (Seoane-Vasquez et al., 2006). Rather than quality control, where samples are taken and tested for conformity to standards, quality assurance may be more applicable to managing endoscope decontamination. Quality assurance requires that key processes are monitored against validated standards to ensure that the final product is safe, without testing the finished product. The approach has been briefly considered in principle for general hospital applications (Yoshikura, 2000).

### 2.9.11 The ‘Cidex Incident’

Given that poorly decontaminated endoscopes can transmit infections, an incident in Belgium where some 35,000 patients were examined using endoscopes that had been disinfected with an inactive batch of Cidex disinfectant might have been expected to have had a larger impact on infections. (Carsauw, 2003). Errors in the production of batch of Cidex, a trade name for a glutaraldehyde based disinfectant made by Johnson and Johnson, meant that the glutaraldehyde concentration was below the effective level of 2%. This meant that endoscopes that had been used on one patient would have received the manual clean required by guidelines, but that the disinfectant used to kill or inactivate any remaining infectious particles was not at the strength previously validated to be effective. In consequence, the chances of one patient carrying infectious agents cross-infecting a subsequent patient indirectly via the endoscope used are that much greater.
The error in concentration was uncovered by hospitals, and Johnson and Johnson were informed. The manufacturers recommended cessation of use, and that any of the affected batches should be placed in quarantine. Once the error had been confirmed, investigations were carried out to determine which patients had been exposed to the risk of endoscope mediated HCAI. Nearly 35,000 exposed patients were identified. Eight bacterial infections in exposed patients were also recorded. From the 35,000 patients exposed, this figure represents an infection rate of approximately 1 in 4700. However, these infections can not be attributed specifically to the endoscopy, and the link may only have been considered in this instance because of the ineffective disinfectant. Of the exposed patients, 26,930 responded to an invitation for a blood test. The blood test was performed in order to determine seroprevalance of infections with Hepatitis B and Hepatitis C within the populations of exposed patients, and to compare these figures to the wider population.

The result showed no significant difference in the seroprevalence of either agent, although the role of the endoscopy in the acquisition of relevant antibodies in some patients could not be excluded. As the patients HCV and HBV status was not determined before the procedure, the presence of those antibodies can not be attributed to the procedure. In addition, acquisition after the examination can not be excluded. This result is initially surprising, as the ineffective disinfection would be expected not to fully remove all virus particles, leaving the potential for them to infect subsequent patients. However, there are other factors that may be involved. Recommended glutaraldehyde concentrations were determined to eliminate hardier organisms than either hepatitis A or B, and so the reduced strength of the faulty batch of Cidex may still have had enough power to inactivate the virus particles. A review of the risks of blood-borne cross-infection following endoscope decontamination failure found that the risks of transmission were small (Morris et al., 2006), although this is in contrast to the efficient transmission shown by Bronowiki et al (1997) when a sterilised brush was passed down an undecontaminated endoscope channel. This suggests that a likely reason for the paucity of hepatitis cross-infections when using under-strength glutaraldehyde may be that the meticulous cleaning of endoscope channels, using the correct materials in the specified manner as per written guidelines, is effective at removing any material accumulated from the previous patient. This illustrates that whether cross infection occurs can depend heavily on the management of endoscope decontamination.
2.10 Conclusions

No dangerous outcomes were observed during the course of the study, which suggests that the BSG guidelines employed by the two units were robust. Unit A had 3 instances where bacteria were recovered from the channels of a decontaminated endoscope, which meant that it did not conform to the requirements of the Spaulding classification. Although the figure of 1 infection in 1.8 million may be a significant underestimate of endoscope-related HCAI, it might be unlikely to find a poor decontamination in 63 endoscopes examined. However, the number of bacteria recovered here was low. Some shortcomings in the management of decontamination at both hospitals were found. In unit A, the cramped decontamination area and lack of documentation had the potential to lead to a decontaminated endoscope becoming recontaminated. In addition, the design of some of the imaging equipment made it difficult to clean properly. In unit B, endoscopes could have been contaminated immediately following decontamination.

If an inadequate decontamination had occurred, it is likely that the length of time needed by microbiological methods would not have prevented that endoscope being used. ATP bioluminescence would provide results in sufficient time to allow corrective action, although expense may prove to be a problem. ATP bioluminescence has previously been adjudged to be a useful quality control method for the overall decontamination of endoscopes (Sciortino et al., 2004), which the results of this study partially support. However, a more appropriate use of monitoring would be to assess the residual soil levels present in endoscope channels after manual cleaning. This approach would ensure that the disinfectant applied subsequently would be more efficacious, and that if there were problems with the disinfection process, as identified in the Cidex incident in Belgium, that the cross-infection risk is minimised.
3 Assessment of seven methodologies for sampling environmental surfaces for MRSA

In the previous chapter, the effectiveness of the decontamination of medical instruments against a well-defined standard using validated protocols was explored. In contrast, the importance of the decontamination of ward surfaces in cross-contamination and HCAI cross-infection is not known. One problem in investigating this relationship is a lack of understanding of the relative merits of methods for determining pathogen numbers on surfaces.

3.1 Hygiene assessment methods

Although it has been shown that visual cleanliness is of no value in assessing the level of bacterial contamination (Griffith et al., 2000, Malik et al., 2003), at present the UK guidelines for surfaces in wards is that they be ‘visually clean’ (Pratt et al., 2007), and it has been advised that routine environmental sampling is rarely indicated (Ayliffe, 2000). Microscopy techniques have been developed that can examine surfaces minutely for bacteria (Lipscombe et al., 2006), but any large-scale examination would require substantial amounts of time. Other measures of assessing surface cleanliness are available, from residual protein, ATP, reducing sugars or carbohydrates (Moore, 2005). However, these can only provide an indication of the level of contamination on surfaces rather than an assessment of the size of microbial populations and species present, which is important for attempting to assess the extent of microbial contamination. Instead, the most frequently used method of assessing bacterial numbers is to remove bacteria from the surface and grow them on a nutritive medium, and count any resultant colonies.

3.2 Considerations of microbiological sampling

The principle of removal followed by cultivation, although simple in concept, is affected by numerous factors that make comparison between results difficult. Areas of a surface that have been touched, were poorly cleaned or have been contaminated by dust can all have higher levels of contamination than surrounding areas. Therefore, contamination is not equally spread over the whole surface. Samples taken must be representative of the surface, but unless all of the surface can be sampled, some uncertainty over contamination on the unsampled area must remain. Therefore, a larger surface area may be advantageous. Alternatively, more of the surface could be sampled by using several tests to gather more information.
The finish of a surface affects the ease with which a surface can be cleaned, and chips, cracks and scratches can harbour higher levels of bacteria, which will also affect the density of bacteria across a surface. This is especially relevant for sampling in hospitals, as 9.3% of surfaces have been found to be damaged in some way (Chapter 4). As with surface area, larger tests or more repeats are a good way to lessen the random effects of sample site location.

Bacteria can attach strongly to surfaces, and surfaces are not perfectly smooth. Therefore, all bacteria will not be removed from the surface by a sampling method (Salo et al., 2000). This means that all methods inherently give an underestimate of the true number of cell present in the area sampled. In addition, different sampling methods and materials have varying ability to remove bacteria from the surface, which can lead to disparities in results obtained (Moore, 2005). A method with lower sampling efficiency (SE) will paint a better picture of the amount of bacterial contamination present than a method with higher sampling efficiency. Furthermore, for a sampled cell to be recorded, it must grow into a colony of sufficient size to be counted. A further confounding factor is the tendency of some bacteria to clump. Staphylococci under magnification, for example, are commonly described as forming grape-like clusters (Koyama et al., 1977). Such a ‘clump’ picked up by a method would have to be completely broken up in order for the cultivation to identify each cell individually, for example by use of a detergent (Koyama et al, 1977)

### 3.3 Microbiological sampling methods

There are many methods of recovering bacteria from a surface, though they can be grouped into two main areas (Figure 3.3.1). One area requires surface swabbing and the other area are methods using direct agar contact.
Figure 3.3.1 Representation of relationships between some microbial surface sampling methods

3.3.1 Swab-based methods

Surface swabbing requires that a hygiene swab (usually moistened to increase recovery (Moore, 2005)) is rubbed over a defined area. In some protocols, the swab is then inoculated directly on to a solid growth medium, a process called direct plating. The growth medium is then incubated at specified conditions, and the number of resultant colonies counted. This method can be used for quantitative enumeration. In other methods, the swab is used to inoculate a liquid medium which can then be used for other processes. In one of these, the pour plate method, the swab is used to inoculate a buffered liquid that will neither damage cells nor allow them to grow. Vortex mixing or shaking maybe used to help release the gathered cells from the swab bud. From the suspension created, dilutions can be made, and this can allow very high titres of cells to be calculated. Pour plating and direct swabbing inoculation are quantitative methods.

If only a qualitative result is needed, the liquid medium inoculated by the swab can contain nutrients that allow bacteria to grow and increase in numbers. The culture can then be used to inoculate agar plates. This method is more suited to screening patients to see if they are colonised by MRSA than for obtaining MRSA counts on a surface, because of the enrichment stage.

Swab methods are often used because they can be easily used to sample irregular, textured, uneven or curved surfaces and the area sampled can be varied according to test protocol. However, there are significant drawbacks to the technique. Differences in the pattern the swab traces over the surface, and the pressure applied to the swab during swabbing are known to lead to high variability. It has been found to be poor at recovering bacteria from dry surfaces (Davidson et al., 1999; Moore & Griffith, 2002a), which is particularly relevant for hospitals as the vast majority of surfaces are dry (Malik et al., 2003; Chapter 4). All swabs are not the same, and can differ in several aspects. The material of the bud was also found to be factor in some cases, though this may have been due to flexibility in the swab shaft affecting the mechanical energy applied during the swabbing (Moore & Griffith, 2002a). These uncertainties highlight the problems that arise without a standard protocol for surface sampling.

3.3.2 Direct agar contact methods

Another common method of sampling surfaces is by direct agar contact, either using dipslides or contact plates. These consist of a frame or dish containing the growth medium.
The surface of the solid medium is higher than the edge of the structure, so that contact can be made between the surface and the agar. The growth medium is pressed directly on to the surface, so that bacteria are transferred from the surface sampled to the growth medium. The growth medium is incubated in the normal fashion. Direct contact methods have often been found to have advantages over swab methods in terms of detection limits for Gram-negative rods (Moore & Griffith, 2002b) and reproducibility (Salo et al., 2000). However, direct contact methods do generally require a flat surface, although recent developments have produced more flexible dipslides. Contacting the agar directly to the surface means that in addition to collecting bacteria from the surface, the method can transfer other substances to the agar. This can be a problem as these substances may affect the results of the test. Some cleaning chemicals can inhibit the growth of bacteria, and some can affect the chemical reactions required for the agar to function properly. For example, colour changes in indicator dyes added to some agars can be produced by the pH of detergent residue on a sampled surface. Some contact plates are supplied with neutralising agents to reduce this effect.

3.3.3 Direct agar contact versus swab based method for surface sampling

Some studies (Moore & Griffith 2002a, Salo et al., 2000) have compared methods for surface sampling, although they have concentrated on food preparation surfaces. None have examined surface sampling in relation to important HCAI bacteria, although Lemmen and colleagues (2001) did assess merits of using contact plates for recovery of Gram-positive and Gram negative bacteria. Unfortunately, the use of an enrichment step for Gram-negative, but not Gram-positive bacteria, rendered the conclusion that the technique was more effective for Gram-negative species, rather weak. Therefore sampling methodology, together with the different types of agar that may be used, could have a significant effect on the number of bacteria recovered, and consequently on any attempt to quantify the hygiene status of any surface sampled. In addition, the recovery of bacteria from dry surfaces that the cells have adsorbed to and wet surfaces that the bacteria have not adsorbed to is also compared. This is known to be an important factor for recovering Salmonella species (Moore & Griffith 2002a) with swabs, and may therefore also be important for MRSA.

3.4 Medium choice for surface sampling

When searching for a specific micro organism, it is often advantageous to use a selective medium. Non-selective media can support the growth of numerous types of bacteria, as well as yeasts and fungi. The presence of a variety of colonies makes it more difficult and time consuming to identify target species, which could even be masked by competing flora.
Elimination or reduction of non-target species can therefore reduce time and resources wasted on examining non-target species, and can improve accuracy. Selective agars are therefore attractive but such agars utilise specific metabolic and physiological traits to ensure that the growth of other species is prevented or inhibited. For example, the membranes of many bacteria are disrupted by bile salts (rendering them unable to grow) whereas enteric bacteria, which live in the gut where they are normally exposed to bile, are not affected. Hence a medium containing bile salts will screen out non-enteric bacteria. The use of particular carbon sources can select for certain bacteria. Enterobacteriaceae are able to use glucose, but of that group, only coliforms can use lactose. A media containing bile salts and lactose alone as a carbon source will select for coliforms. Adding a chemical known as 4-methylumbelliferyl-ß-D-glucuronide helps to identify *E. coli* from the other coliforms, as *E. coli* has the enzyme ß-glucuronidase, which cleaves this chemical to give a fluorescent end product. The addition of this chemical does not act to prevent growth of other species, but as an indicator that makes distinguishing target colonies from non-target colonies easier.

### 3.4.1 *S. aureus* selective media

Many agars for the isolation of *S. aureus* have been developed and these agars use a variety of methods to achieve their selectivity. The high salt tolerance of staphylococci makes an effective physiological screen, as few other bacterial or fungal species can grow in these conditions. Mannitol salt agar (MSA) contains 7.5% sodium chloride as an inhibitor to other species. The mannitol in MSA can be fermented by *S. aureus*, and the pH drop that results turns the phenol red indicator in the agar yellow. Other staphylococci species can not ferment the mannitol. Therefore yellow colonies are likely to be *S. aureus*, although this can not be used as a confirmatory test. Baird Parker medium contains lithium chloride and tellurite as inhibitor for other species. Some of these have methods for discriminating between various types of staphylococci. In the case of Baird-Parker medium, species can be initially distinguished by the appearance of the colony.

### 3.4.2 MRSA selective media

Many of the agars for the isolation of MRSA are modifications of existing staphylococcal media, such as the inclusion of an antibiotic. Oxacillin may be added to MSA as an analogue for methicillin (which is no longer manufactured) to inhibit MSSA. One study found that cefoxitin was a good marker for methicillin resistance when used in MSA (Smyth & Kahlmeter, 2005). In the case of Baird-Parker media, the addition of the antibiotic ciprofloxacin has been recommended (Health Protection Agency, 2005a). A number of
studies have examined the use of standard media with the addition of antibiotics for the screening of MRSA screening swabs, and these reviewed more extensively by Brown and colleagues (2005).

A special agar is not essential for the growth of MRSA. As a strain of *S. aureus*, it is happy to grow on a variety of media, including general purpose media such as nutrient agar, or typtone soya agar. However, some companies have produced commercially available MRSA isolation media. Oxoid have developed Oxacillin Resistance Screening Agar Base (ORSAB), to which a supplement containing oxacillin and Polymixin B (to inhibit Gram-negative bacteria). This media is a variation on MSA, but instead of the red to yellow colour change caused by the phenol red, a change from a dull grey to a deep blue (aniline blue) indicates mannitol fermentation.

Another media manufacturer, CHROMagar produces CHROMagar MRSA. This medium claims that MRSA isolates grow in a rose or mauve colour, MSSA isolates grow blue, and other bacteria grow colourless, blue or are inhibited by the media completely. Partly sponsored by Biomeriuex, Perry and colleagues developed MRSA ID, an agar developed from *S. aureus* ID agar. The *S. aureus* ID agar uses the presence of a *S. aureus* specific enzyme, alpha glucosidase (Perry *et al.*, 2004), to generate a green colouration. The agar is supplemented *S. aureus* ID agar with 4mg of cefoxitin per litre.

In Japan, Denke Seiken manufactures a contact plate specifically for MRSA. Details of the make-up of this agar are not available, but MRSA colonies recovered with the plate are yellow.

A more recent entry into the field is MRSA select, from BioRad. This chromogenic media claims to produce bright pink colonies from MRSA cells, and other cells are either inhibited or produce white colonies.

### 3.5 Performance of MRSA selective agars

Different studies have found differing performances for these agars (Table 3.5.1), in terms of their sensitivity and specificity. Dias *et al.* (2004) found that MSA with oxacillin performed as well as ORSAB in detecting MRSA from clinical samples. Kluytmans and colleagues (2002) found that while CHROMagar *S. aureus* was as sensitive (98.6% compared to 97.1%) and more specific than ORSAB (97.1% to 92.1%) without its oxacillin supplement, when antibiotic supplements were added to both media, the sensitivity of the CHROMagar MRSA was significantly worse than ORSAB (77.5% compared to 91.4%) with a similar specificity. Kircher *et al.* (2004) found that CHROMagar MRSA had a
specificity of 98% and a sensitivity of 91%. Ben Nsira and colleagues (2006) reported a sensitivity and specificity for MRSA select of 99.8 and 99% respectively, based solely on colony colour. Louie and colleagues (2006) recorded a sensitivity of 98% and a specificity of 90% for MRSA-Select. For MRSA-ID, Diederan (2006) reported a sensitivity of 96.4% after 24 hours, increasing to 98.8% after 48 hours, whereas specificity was 98.2% after 24 hours but fell to 89.7% after 48 hours. Nahimana et al., (2006) evaluated ORSAB, MRSA-ID, MRSA-Select and CHROMagar MRSA against each other, and found similar results for specificity and sensitivity for all agars. Testing ORSAB as a medium for screening swabs, Blanc and colleagues (2003) found ORSAB to have a sensitivity of 74% when used directly for swabs, rising to 88% when an enrichment broth was used. One study examined 831 nasal swabs from 321 patients using CHROMagar MRSA and found a sensitivity of 95.6% (Loulergue et al., 2006). This figure was higher than for medium of trypticase soy agar enriched with horse blood, possibly because of competition from commensal species.

<table>
<thead>
<tr>
<th>Specificity of various agars</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRSA ID</td>
</tr>
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</tr>
<tr>
<td>100%</td>
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<tr>
<td>98%</td>
</tr>
<tr>
<td>&gt;94%*</td>
</tr>
<tr>
<td>98%</td>
</tr>
<tr>
<td>98%</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Sensitivity of various agars</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRSA ID</td>
</tr>
<tr>
<td>-----------------------------</td>
</tr>
<tr>
<td>51%</td>
</tr>
<tr>
<td>82%</td>
</tr>
<tr>
<td>&gt;94%*</td>
</tr>
<tr>
<td>91%</td>
</tr>
<tr>
<td>95.60%</td>
</tr>
<tr>
<td>77.50%</td>
</tr>
<tr>
<td>74%</td>
</tr>
</tbody>
</table>

* Where incubation time was 48h and coagulase test performed

Table 3.5.1 Summary of the results of studies investigating the sensitivity and specificity of various MRSA selective media
3.6 Aims
This study aims to investigate a variety of sampling methods and growth media (enriched, general and selective) for the recovery of different clinical isolates of MRSA from a stainless steel surface to assess the sensitivity of the combinations.

3.7 Method
The variety of sampling methods and media used combined with the use of 5 different cultures at 4 different bacterial densities each meant that the experiment was too large to be completed in a single session. For this reason, the assessment was split into discrete parts. Each part consisted of testing the recovery of a single culture with each method where it had and had not adsorbed to the surface.

3.7.1 Culture growth
Five isolates of MRSA cultured from infected wounds (Cooper et al., 2002) were used in this study, to make some allowance for the variety of MRSA strains that could be found in the environment. Each strain was aseptically inoculated into 100 ml of tryptone soya broth (TSB) (Oxoid Ltd, Basingstoke, UK) in a 250 ml flat-bottomed flask and grown overnight in a shaker-incubator (37°C, 18 h, 100 rpm). For each part, the population density of the culture used was determined using a total viable count. Serial decimal dilutions of the culture down to 10^-7 were made using sterile ¼ strength Ringers solution (Oxoid Ltd) and used to make pour plates prepared with tryptone soya agar (TSA) (Oxoid Ltd). These were incubated for 24 hours at 37°C before counting, and the density of the initial culture calculated.

3.7.2 Surface cleaning and preparation
A stainless steel table, marked with 10 cm x 10 cm squares (84 were made in a 12 by 7 arrangement) was cleaned using a validated protocol for each part of the experiment (Moore, 2005) in order to remove any existing bacteria and surface contaminants. The table was sprayed with a 1% Virkon solution and left for 30 minutes. Virkon is an oxidation-based disinfectant, utilising potassium peroxomonosulphate in conjunction with an anionic surfactant. Like any other oxidative based cleaner, Virkon loses efficacy in the presence of organic matter, so it was ensured that the table was visually clean and free from gross debris. The table was then rinsed with 1.5 litres of freshly boiled water to remove any Virkon residues that might affect survival of bacteria. A detergent (<5% amphoteric, 5-15% non-ionic and 15-30% anionic), boiling water and unused rayon cleaning cloth were used to clean the table with a vigorous action for approximately 2 minutes. This was to remove any
grease, protein or other non-microbial contaminants. The table was then rinsed three times with 1.5 litres of boiling water each time to remove any remaining traces of chemical agent. The table was left for approximately one hour to dry completely, and to cool to ambient temperature. This method of cleaning has been shown to reduce microbial contamination of the surface to less than 1 cfu/cm².

Dilutions of $10^{-3}$, $10^{-4}$, $10^{-5}$ and $10^{-6}$ of the MRSA culture being tested were prepared in sterile $\frac{1}{4}$ strength Ringers solution, and aliquots of 100 μl were pipetted on to a square and evenly spread with a disposable spreader. Five replicate squares for each dilution were made. Where sampling of adsorbed cells was undertaken, the inoculated squares were left to dry for 30 minutes, at which point all squares were visibly dry. When testing for unadsorbed cells, the squares were sampled immediately after inoculation while the surface was still wet.

One uninoculated control square for each dilution and each sampling method was also employed to check for contamination of the sampling surface as a negative control.

### 3.7.3 Media used

**Enriched medium:** An enriched medium was selected in order to maximise recovery of bacteria from the surface. Such media typically are formulated to provide an environment that does not challenge the growth of organisms, and provide additional nutrients and growth factors. This should ensure that bacteria recovered from the surface have optimal conditions to form a countable colony. Blood agar is commonly used to culture MRSA (Ref, Brown?) and was thus used here.

Blood agar was prepared using blood agar base (Oxoid Ltd) and 7% v/v defibrinated horse blood (Oxoid Ltd).

**Standard medium:** Although Tryptone Soya Agar (TSA) is considered to be a less rich medium that blood-based media, it is not a selective medium for MRSA. TSA was selected for use as a general purpose culture media that would stand between the enriched blood medium and the selective medium. TSA was prepared according to manufacturers instructions (Oxoid Ltd).

**Selective medium:** Although many media selective for MRSA are available, Oxacillin Resistant Screening Agar was chosen because, as a modified form of Mannitol Salt Agar, the ingredients were known. In use on hospital surfaces, any flora or residue on the surface would not be known, and unexpected interaction with any surface residue could be
investigated with a known medium, where this would not be possible where constituent components were not described.

ORSAB consists of Oxacillin Resistant Screening Agar Base, and an antibacterial supplement containing oxacillin and polymyxin B. MRSA are able to grow on this medium, however, due to the elevated salt concentrations and presence of antibacterial agents, this agar would not provide optimal conditions for recovering bacteria from surfaces.

ORSAB was prepared from oxacillin resistance screen agar base (Oxoid Ltd) and ORSAB selective supplement (Oxoid Ltd) according to manufacturers instructions..

Double-sided ORSAB dipslides were supplied pre-prepared by Dimanco Ltd (Henlow, UK). Each side of the dipslide had a surface area of approximately 10 cm$^2$, giving a total area of 20 cm$^2$.

Another selective agar tested was used in pre-prepared MRSA selective contact plates (MecA) were provided by Denke Seiken (Tokyo, Japan). Although the ingredients for the medium were not provided by the manufacturer, these tests were purpose designed for testing surfaces for MRSA. The plates are designed to produce yellow MRSA colonies on the blue agar, and have a surface area of approximately 4 cm$^2$.

3.7.4 Sampling methodologies used

*Pour plates:* Wooden handled, cotton tipped sterile hygiene swabs (Technical Services Consultants Limited, Lancashire) were moistened with sterile ¼ strength Ringers solution immediately before use. Wooden handled swabs were used as the rigid shaft may allow more kinetic energy to be applied to the surface. Moistening the swab bud is known to improve recovery. Each square sampled was swabbed entirely in two directions at right angles to each other in a close zigzag pattern whilst rotating the swab along its axis. A total of 100 cm$^2$ was swabbed per sample The swab was then placed in 10 ml of sterile ¼ strength Ringers solution in a test tube and vortex-mixed for 10 seconds at approximately 2000 rpm to release MRSA cells into suspension. 1 ml of the bacterial suspension was pipetted into a Petri dish and approximately 20 ml of molten TSA agar (at 45°C) poured on top. The plate was swirled gently to evenly distribute the bacteria around the plate, and left to set before incubation. Blood agar was not used for pour plating because its opacity would have prevented accurate recording of bacteria recovered.

Direct swab inoculation (DSI): Using the swabbing technique described for pour plates above, each square sampled was swabbed with a moistened hygiene swab. A total of 100
cm² was swabbed per sample. An agar plate was then immediately inoculated using a zigzag pattern and swab rotation, then incubated.

Dipslides: Each dipslide was removed from its respective container and pressed on to the surface for 10 seconds with a force of approximately 25 g/cm² (measured with use of top pan balance) without any lateral movement. The dipslide was turned over and another area of the square was sampled, so that the areas did not overlap. The total area sampled was 20 cm² per dislide. The dipslide was returned to the tube and incubated.

MecA contact plates: The lid was removed from the contact plate and the plate was pressed to the surface, as for dipslides. The total area sampled was 4 cm² per contact plate. The lid was then replaced and the contact plate incubated.

### 3.7.5 Sample cultivation

All plates, dipslides and contact plates were incubated for 24 hours at 37°C, before the number of characteristic colonies was counted and viable population numbers calculated.

A dilution was included in the results where all 5 replicates with all 5 strains had over 10 typical colonies, to ensure that the methods were reliable and not being skewed by unlikely results. The figure of 10 colonies, rather than the more usual figure of 30, was chosen as the number of replicates increased the reliability of the results.

### 3.7.6 Calculations

In order to compare the effectiveness of the method/medium combination, two factors were examined. The first of these was the ability of the test to pick up bacteria from the area sampled and for them to grow and be counted, known as sampling efficiency. This factor is independent of the test area sampled. It is a measure of sensitivity of the combination, but may not reflect the actual use of such a test. The second calculation allows for the surface area sampled by each protocol. This is important because an exceptionally sensitive test will not be of use for sampling hospital surfaces if it only samples a very small area. Therefore both sensitivity and area sampled need consideration.

The total initial count for each culture (i.e. inoculated onto the surface of each stainless steel square) was calculated from the sample taken from the initial culture. Sampling efficiency for each recovery protocol was calculated using figures taken from the lowest dilution that
yielded 10 or more colonies for each replicate. This was to determine the sensitivity at the edge of the detection limit.

### 3.7.6.1 Sampling efficiency

Sampling efficiency (SE) was defined as the ratio of the number of bacteria applied to the surface tested and those subsequently recovered from it.

\[
SE = \frac{(n*d)}{I}
\]

- **SE** = Sampling efficiency
- **n** = mean cfu recovered by a method
- **d** = Dilution factor of replicate
- **I** = cfu inoculated on to test area

The calculation for SE was derived from Whyte *et al.* (1989), and makes the following assumptions:
- no growth or death of bacteria;
- no additional contamination of sampled site;
- the number removed by a sampling method is equal to the number counted in the sample;
- the efficiency of removal remains constant (Whyte *et al.*, 1989). In addition, this calculation only includes bacteria which form countable colonies after removal from the surface. Cells that are not released from the swab, or which fail to form countable colonies are not included.

### 3.7.6.2 Sampling effectiveness

Although SE is a useful measure of the efficacy of a protocol, it can not be considered without reference to the area that protocol samples. A larger sampling area will negate a lower SE because although fewer bacteria of those present will be recovered, potentially more bacteria will be present in the larger sampling area. In addition, as discussed previously, a larger sampling area will lessen the effects of uneven distribution of bacteria across a surface. The largest test area used in this study was 100 cm\(^2\) so smaller tests were normalised to sensitivity per 100 cm\(^2\). Sensitivity per 100 cm\(^2\) was calculated as the minimum number of cells that would need to be in 100 cm\(^2\) for each respective protocol to recover one cell. For example, a sensitivity of 23 cfu/100 cm\(^2\) means that 23 bacteria would need to be present on 100 cm\(^2\) to produce at least 1 colony on the growth medium.

\[
S=\frac{100}{(A*SE)}
\]

- **S** = sensitivity per 100 cm\(^2\)
- **A** = area tested by method combination
- **SE** = sampling efficiency
3.8 Results

The methods used greatly affected the recovery of MRSA, with marked differences between the recovery of adsorbed and unadsorbed cells, and between sampling combinations.

By making comparisons between protocols that utilised the same media it can be seen that direct agar contact sampling methods had greater sampling efficiency (SE) than swabs for adsorbed cells. For example SE for ORSAB dipslides was 51.3% but 0.47% for ORSAB DSI (Table 3.8.1), which represented an improved SE by a factor of 109 (Table 3.8.2). The data contained in Table 3.8.2 can be interpreted by reading across from left to right, and then upwards. Each respective box shows the ratio of SE between the two corresponding protocols. The grey box indicates that for unadsorbed MRSA cells ORSAB dipslides had an SE 42.7 times greater than ORSAB pour plates.
<table>
<thead>
<tr>
<th>Adsorbed MRSA</th>
<th>Sampling efficiency</th>
<th>Sensitivity 100cm²</th>
<th>Test area cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range of sampling efficiencies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TSA pour plate</td>
<td>0.12%</td>
<td>825.8</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>0.04 - 0.20%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ORSAB pour plate</td>
<td>0.07%</td>
<td>1440.1</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>0.02 - 0.12%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TSA DSI</td>
<td>1.52%</td>
<td>65.7</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>0.07 - 2.29%</td>
<td></td>
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</tr>
<tr>
<td>ORSAB DSI</td>
<td>0.47%</td>
<td>212.4</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>0.15 - 1.05%</td>
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</tr>
<tr>
<td>Blood DSI</td>
<td>3.85%</td>
<td>26.0</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>2.26 - 5.97%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ORSAB dipslide</td>
<td>51.33%</td>
<td>9.7</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>44.7 - 68.8%</td>
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</tr>
<tr>
<td>MecA contact plate</td>
<td>72.50%</td>
<td>27.6</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>31.0 - 100.3%</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Unadsorbed MRSA</th>
<th>Sampling efficiency</th>
<th>Sensitivity 100cm²</th>
<th>Test area cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range of sampling efficiencies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TSA pour plate</td>
<td>1.14%</td>
<td>87.4</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>0.52 - 2.91%</td>
<td></td>
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</tr>
<tr>
<td>ORSAB pour plate</td>
<td>1.13%</td>
<td>88.2</td>
<td>100</td>
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<tr>
<td></td>
<td>0.33 - 1.48%</td>
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<tr>
<td>TSA DSI</td>
<td>11.40%</td>
<td>8.8</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>6.22 - 16.13%</td>
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</tr>
<tr>
<td>ORSAB DSI</td>
<td>9.01%</td>
<td>11.1</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>3.17 - 16.0%</td>
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</tr>
<tr>
<td>Blood DSI</td>
<td>11.38%</td>
<td>8.8</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>5.94 - 17.3%</td>
<td></td>
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</tr>
<tr>
<td>ORSAB dipslide</td>
<td>48.36%</td>
<td>10.3</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>39.9 - 65.3%</td>
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<tr>
<td>MecA contact plate</td>
<td>63.73%</td>
<td>31.4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>38.9 - 114.2%</td>
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Table 3.8.1 Comparison of the sampling efficiency, variability and sensitivity per 100 cm² of seven sampling protocols for MRSA.

In considering sensitivity per 100 cm² for adsorbed cells, ORSAB dipslides were the most sensitive at 9.7 cfu/100 cm² (i.e. 9.7 cfu would need to be present on 100 cm² to recover one cell), followed by blood DSI (26.0 cfu/100 cm²). DSI methods had greater SE than pour plate methodology, 12.6 times higher for TSA and 6.78 times higher for ORSAB. Blood agar had the highest SE for DSI methods, 2.53 times more sensitive than TSA agar and 8.18 times more sensitive than ORSAB agar. However, this difference was much less pronounced for unadsorbed cells.
Table 3.8.2 Ratio between the sampling efficiency of seven sampling methodologies for adsorbed and unadsorbed cells (3sf). Matrix to be read left and upwards, for example, ORSAB dipslides are 42.7 times more sensitive than ORSAB pour plates for unadsorbed MRSA.

ORSAB had an SE of 9.01%, TSA 11.40% and 11.38% for blood agar. Blood and TSA DSI had the greatest sensitivity per 100 cm² (both 8.8 cfu/100 cm²) followed by ORSAB dipslides (10.3 cfu/100 cm²).

The SE of direct agar contact methods did not significantly alter between sampling adsorbed and unadsorbed cells. Swab methods showed significant increases in SE when sampling unadsorbed cells. For example, when sampling adsorbed cells ORSAB dipslides had a SE 739 times greater than ORSAB pour plate, and 109 times greater than ORSAB DSI. When sampling unadsorbed cells, the differences fell to 42.7 and 4.24 times greater respectively. MecA contact plates had an even greater SE, 72.5% for adsorbed cells. This is over 1000

<table>
<thead>
<tr>
<th></th>
<th>Adsorbed MRSA</th>
<th>Unadsorbed MRSA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TSA pour plate</td>
<td>ORSAB pour plate</td>
</tr>
<tr>
<td>TSA pour plate</td>
<td>1.74 0.08 0.26 0.03 0.00 0.00</td>
<td>0.11 0.11 0.01 0.01 0.01 0.00 0.00</td>
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<tr>
<td>ORSAB pour plate</td>
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<td>0.06 0.06 0.01 0.01 0.01 0.00 0.00</td>
</tr>
<tr>
<td>TSA DSI</td>
<td>12.6 21.9 3.23 0.40 0.03 0.02</td>
<td>1.33 1.34 0.13 0.17 0.13 0.03 0.02</td>
</tr>
<tr>
<td>ORSAB DSI</td>
<td>3.89 6.78 0.31 0.12 0.01 0.01</td>
<td>0.41 0.42 0.04 0.05 0.04 0.01 0.01</td>
</tr>
<tr>
<td>Blood DSI</td>
<td>31.8 55.5 2.53 8.18 0.08 0.05</td>
<td>3.37 3.40 0.34 0.43 0.34 0.08 0.06</td>
</tr>
<tr>
<td>ORSAB dipslide</td>
<td>424 739 33.7 109 13.3 0.71</td>
<td>44.9 45.3 4.50 5.70 4.51 1.06 0.81</td>
</tr>
<tr>
<td>MecA contact plates</td>
<td>599 1044 47.6 154 18.8 1.41</td>
<td>63.4 64.0 6.36 8.05 6.37 1.50 1.14</td>
</tr>
<tr>
<td>TSA pour plate</td>
<td>9.45 16.5 0.75 2.43 0.30 0.02 0.02</td>
<td>1.01 0.10 0.13 0.10 0.02 0.02</td>
</tr>
<tr>
<td>ORSAB pour plate</td>
<td>9.36 16.3 0.74 2.41 0.29 0.02 0.02</td>
<td>0.99 0.10 0.13 0.10 0.02 0.02</td>
</tr>
<tr>
<td>TSA DSI</td>
<td>94.2 164 7.49 24.2 2.96 0.22 0.16</td>
<td>9.97 10.1 1.27 1.00 0.24 0.18</td>
</tr>
<tr>
<td>ORSAB DSI</td>
<td>74.4 130 5.92 19.1 2.34 0.18 0.12</td>
<td>7.88 7.95 0.79 0.79 0.19 0.14</td>
</tr>
<tr>
<td>Blood DSI</td>
<td>94.0 164 7.47 24.2 2.95 0.22 0.16</td>
<td>9.95 10.0 1.00 1.26 0.24 0.18</td>
</tr>
<tr>
<td>ORSAB dipslide</td>
<td>399 696 31.8 103 12.6 0.94 0.67</td>
<td>42.3 42.7 4.24 5.37 4.25 0.76</td>
</tr>
<tr>
<td>MecA contact plates</td>
<td>526 918 41.9 135 16.5 1.24 0.88</td>
<td>55.7 56.2 5.59 7.07 5.60 1.32</td>
</tr>
</tbody>
</table>
times the SE of ORSAB pour plates. However, MecA contact plates were only 56 times more sensitive than ORSAB pour plates for unadsorbed cells.

The differences in SE between media were also reduced when sampling unadsorbed cells. Blood DSI had a SE 31.8 time greater than TSA and 55.5 times greater than ORSAB when sampling adsorbed cells. This changed to 1.00 and 1.26 times greater respectively when sampling adsorbed cells. Similarly, the difference between TSA and ORSAB pour plates for adsorbed cells (1.74) was not significant for unadsorbed cells.

3.9 Discussion

Concern over the reported increase in prevalence of nosocomial infections of MRSA and the perceived public decrease in hygiene standards (Dancer, 1999) have led to calls for an improvement in cleaning. However, without a standardised and validated method for the monitoring of the efficacy of cleaning, the resources allocated may be wasted. As a facet of this argument, hospital surfaces are often identified as fomites for the spread of nosocomial infections. Standards for hospital have been proposed (Dancer, 2004), but no standard method exists with which to assess cleaning against them. In order to assess compliance with standards, it is necessary to sample with standardised and sensitive methods.

3.9.1 Evaluation of sampling methods

The choice of sampling method was found to be more important in determining SE than the choice of medium for both adsorbed, and unadsorbed cells. This is important because this has not been reported in the medical-biased literature, where choice of medium is given more attention.

Direct contact methods could have a SE over ten times greater than swab methods. This finding echoes that of Salo et al. (2000), and of Moore & Griffith (2002b), who also concluded that the contact method had an advantage in sensitivity over swabbing methods. However, the erosion of this advantage when surface area was considered is a disadvantage as surface area may be more important when searching for specific pathogens that may only be present in low numbers (Griffith, 2005). Lemmen and colleagues (2001) used contact methods to recover a wide range of bacteria, including MRSA and VRE, from a wide range of hospital surfaces.

The SE of swab methods improved when sampling unadsorbed cells compared to sampling adsorbed. However, there was no difference between sampling adsorbed and unadsorbed
cells when using direct contact methods. MRSA strains, especially epidemic type strains, are known to be able to survive well in the environment (Wagenvoort, 2000b), and as all other factors remained constant, it is possible that the difference is due to damage caused to the cells during swabbing of the surface. Cells that have not adsorbed to the surface would not experience the same shear forces as those absorbed cells that must have their physical bond with the surface broken. Damaged cells would either be killed or have their viability compromised so that they failed to grow into distinct colonies on the growth medium.

The media used subsequent to sampling is known to have an effect on the recovery of stressed cells (Brashears et al., 2001) and injured S. aureus have been shown to lose tolerance to high salt concentrations and to antibiotics (Hurst, 1977), presumably because damage to cellular integrity is exacerbated by these agents. This may be due to damage to the cell membrane (Moore, 2005). This hypothesis is supported by the SE of different media when using DSI method. When sampling unabsorbed cells, the differences in SE between media were insignificant, suggesting that the media are equally capable of growing MRSA. However, when sampling adsorbed cells, blood agar was consistently better than TSA agar, and TSA agar was consistently better than ORSAB agar. It is likely that the higher salt and antibiotics used in ORSAB agar led to the lower SE, whilst the enriched blood media may have helped cells to recover, leading to a higher SE. It is, therefore, suggested that medium choice also considers the likely physiological state of the bacteria being sampled.

Sampling adsorbed cells (dry surfaces) is more relevant in practice than sampling unadsorbed cells (wet surfaces) since typically 97% and 98.4% of hospital surfaces have been found to be dry (Griffith et al., 2000), (Malik et al., 2003). Although flexible dipslides are in development, direct contact methods are usually limited to flat surfaces, whereas swab methods can be used for more irregular surfaces. For swab methods, pour plating had a lower SE than DSI, probably because of the dilution factor required in preparation.

3.9.2 Evaluation of media used
The choice of medium was more important when sampling adsorbed rather than unadsorbed cells. Whilst selective media were less sensitive than general or enriched media, this can be compensated for by choice of method. Additionally their use can exclude many non-target organisms, reducing processing time and costs. However, selective media do have drawbacks over more general media, in addition to loss of sensitivity if using a swab method. Information on other significant pathogens will not be recorded, which may give a false impression of the cross contamination risk posed by a surface. For example, a MRSA
selective agar may show a surface contaminated with *C. difficile* to be free of MRSA, but it would be wrong to interpret that the surface as being safe with regards to cross-infection.

### 3.9.3 Use of other MRSA selective media for sampling surfaces

In addition to the various forms of *S. aureus*, the range of other bacteria on surfaces can be large. If searching specifically for MRSA, individually screening every colony recovered to see if it is MRSA would require significant time and material. Therefore a selective agar used to restrict the variety of organisms recovered would reduce the resources required for sampling. However, because the makeup and distribution of the flora can not be known until sampling, it is difficult to know how well selective agars perform under these conditions. With the diversity and interactions between different species, surfaces contaminants and cleaning product residues, the potential exists for the various agars to perform differently than more staged examinations of performance. The study by Loulergue and colleagues (2006) assessed the sensitivity of agars in a more open-ended manner by using nasal samples, which increases the challenge to the agar, although the potential range of species is likely to be lower than on a surface. Ultimately, the specificity can only be truly tested on actual hospital surfaces, although even then performance of different media will be affected by the nature of the cells sampled. As Brown *et al.* (2005) noted, “a selective medium containing ciprofloxacin may perform better in a location where prevalent strains are ciprofloxacin resistant”.

Most of the above studies, the exception being Loulergue, evaluated the various agars using known isolates originating from culture collections, or samples submitted for MRSA screening. The ‘test’ bacteria used to examine the discriminatory power of the agar were therefore either generally methicillin-sensitive *S. aureus*, or another staphylococcal species, such as *S. epidermidis*, or unknown agents causing the infection. While this is a natural comparison for agar that will be used to screen clinical samples, it is less relevant when used for sampling surfaces. Diederen and colleagues (2006) noted that their study was limited by the high inoculum levels used for testing the isolates, compared to the low numbers found in clinical isolates, and that the influence of other species was not assessed. Both of these points are as applicable, if not more so, to recovering MRSA from surfaces as they are to recovering MRSA from clinical samples. Other species have been found to be give similar results to some of the standard tests for *S. aureus*. Pottumarthy *et al.* (2004) and colleagues found that two wound isolates initially determined as *S. aureus* with standard tests had been misidentified. The isolates displayed the morphology of staphylococci under Gram staining, and were found to be coagulase positive; the classic test for *S. aureus*. Testing with a latex
agglutination test for the penicillin binding protein (PBP 2a), which confers resistance to methicillin, proved positive, giving the identification of MRSA. However, subsequent testing with microbiological and molecular methods found the isolates to be *S. intermedius*.

### 3.9.4 Pitfalls in the use of ORSAB in hospitals

Recently, it was discovered that many of the MRSA ‘scare stories’ published in UK newspaper originated from a single source. One hospital, which was reported in the press as having 71% of surfaces in public areas (as distinct from wards or surgical areas) contaminated with MRSA, performed an internal investigation into environmental MRSA contamination as this rate was substantially above other peer-reviewed estimations (Manning *et al.*, 2004). Their recovery protocol employed swabs, enriched in broth overnight and streaked on to an enriched agar, and recovered no isolates of MRSA. A repetition of the sampling, using ORSAB dipslides as in the initial work, also failed to recover any MRSA isolates (although more coagulase negative staphylococci were recovered using dipslides than with swabs, a finding that fits with the advantages of contact methods seen in this study). On further investigation it was found the methods used to identify MRSA for the newspaper survey were not robust and that many isolates identified as MRSA were coagulase-negative staphylococci. It was realised that coagulase-negative staphylococci were not readily distinguishable from MRSA on ORSAB media. Further testing of samples collected for the scare stories demonstrated that all isolates had been mistakenly identified as MRSA, and that a simple coagulase test would have screened out many false positives (Kearns *et al.*, 2005).

The use of ORSAB as an identification method alone therefore is ill-advised, and should only be used as part of approach using other confirmatory methods. Such tests include coagulase production, presence of protein A (a surface protein) and a heat stable nuclease (Brown *et al.*, 2005). Other MRSA selective media such as CHROMagar MRSA-ID and MRSA-Select are available and could potentially be used for dipslides or swab methods, although comparative data on SE is unavailable. Although MRSA is used as a blanket term for methicillin-resistant *S. aureus*, there is a diverse range of strains within that definition. Most infections in the UK are caused by epidemic strains known as EMRSA-15 and EMRSA-16. These, and their close relations, would be the strains that were commonly represented in the culture collections used to evaluate the agars.

### 3.9.5 Sampling for CA-MRSA

One factor in the consideration of selective agar choice is CA-MRSA. In recent years, new variants of MRSA, community-acquired MRSA (CA-MRSA), have been isolated. These
strains are often found causing boils, impetigo or other skin and soft tissue infections (SSTI), may only be resistant to beta-lactam antibiotics, and have been found to be the cause of nosocomial infections in the UK (CDR weekly, 2006a). Media designed to screen out MSSA and methicillin-resistant coagulase-negative staphylococci by the use of non beta-lactam antibiotics would also eliminate CA-MRSA. This was illustrated by Otter and co-workers (2007) when investigating an outbreak of E-MRSA 15 in a neonatal ward. Ciprofloxacin-containing media was used to screen colonised babies, but further screening with a ciprofloxacin-free medium identified 2 further individuals. The isolates recovered from all neonates were spa type t022 and were indistinguishable by PFGE. In addition, the ability of these media has not been tested on hospital surfaces in daily use, where factors such as unknown species and strains, surfaces conditions, disinfectant residues can not be controlled.

3.10 Conclusions

Despite the shortcomings, any media or method that increases the selectivity of the process would be advantageous, and further work could assess the efficacy of other selective media on actual hospital surfaces and microbiologically diverse laboratory tests. Another avenue could be to design a selective medium specifically for sampling surfaces for MRSA (or any other nosocomial pathogen).

It is important to emphasise that there is a difference between sensitivity and accuracy when sampling surfaces. The methods tested exhibited a wide range of sensitivities, with contact methods as the most sensitive. However, this does not mean that they are an accurate technique. The results of this study found some variation between replicates and between strains sampled. Other studies have shown that both contact methods and swabbing methods have degrees of variation in recovery of cells. In addition, this study attempted recovery and enumeration of staphylococci, which naturally form clumps. These clumps consist of irregular numbers of agglomerated cells, but will only grow as a single colony on agar because of their initial proximity. Therefore, any count made with a dipslide or contact plate could be underestimating the true numbers of bacteria on that surface. Swab methods incorporating a vortex mixing step which may act to break up such clumps and release more cells from the swab fibre matrix. However, the results show that these effects, were not enough to offset the inefficiencies caused by the dilution step. For pour plating, the swab was rinsed in 10 ml of Ringer’s solution. From this, 1 ml was used as an inoculum, giving a tenfold dilution, which was approximately the difference in SE between pour and spread plates. A smaller volume could be used to release bacteria from the swab, but it is not clear that an increase in efficacy will increase proportionally with decreasing volume.
4 The effects of modified cleaning practices on hospital hygiene

In Chapter 3, various methods for sampling environmental surfaces for a specific pathogen were examined in order to provide information that could be used to investigate the role of environmental surfaces in cross contamination. Unlike hospitals, sampling surfaces to estimate levels of contamination levels is an activity that is routinely performed in the food industry, because the food industry considers it essential for preventing cross contamination (Griffith, 2005).

4.1 The approaches to surface sampling in food and hospitals

While food production and hospital wards are different environments with different activities and expectations, from the ‘perspective’ of infective agents there may be parallels in the role of the environment in cross contamination. Both patient and food product inevitably have some interaction with their immediate environment, which could result in transfer of bacteria to the patient or product. In the food industry, this possibility is reflected in the approach to surface sampling that is often used, where the philosophy could be defined as ‘organisms that are present in the environment now may turn up in the product in future’. Therefore, monitoring of the environment is an early warning system that aims to detect the presence of agents that may impair the quality or safety of the product in the production area. Where sampling is not carried out as a matter of routine, it is usually carried out as a part of a defined control programme, rather than on an ad hoc basis.

Hospitals in the UK do not generally share this philosophy, and routine sampling for bacteria is not attempted. It could be said that routine environmental sampling in hospital wards has been discouraged; Ayliffe wrote that “Unless there is an outbreak of infection, routine bacteriological sampling of floors, walls, surfaces and air is rarely indicated” (Ayliffe et al., 2000). This attitude could derive either from a belief that the environment does not contribute to cross-infection, or that nothing can be done about environmental contamination. While not carrying out routine sampling, hospitals may instigate environmental sampling programmes in response to outbreaks, usually in search of a specific organism.

4.2 The cleaning of environmental surfaces in hospitals

The hygienic status and cleaning of environmental surfaces in hospitals has attracted media attention in recent years and concern has been expressed over the contribution of ‘dirty
hospitals’ to HCAI. NHS cleaning guidelines have been published (NHS Estates 2004b) but their use is not compulsory. Data on validation of the guidelines are not provided, and it is unclear whether such validation has been undertaken. In addition, the guidelines do not require that the effectiveness of cleaning implementation is monitored.

Carling et al. (2006) applied a fluorescent solution to 1404 areas in 157 patient rooms across three hospitals. The solution would be easily removed by cleaning, but if not removed it would be easily detectable by ultraviolet light. The sites were found to be cleaned in the three hospitals on only 45, 42 and 56% of occasions. Clearly, where cleaning has not occurred, it can not be considered effective. However, even where cleaning has been carried out, it may be ineffective. Cooper and colleagues (2007) found that routine cleaning did not always reduce the numbers of bacteria on hospital environmental surfaces. In this last study the contamination levels on 3000 surfaces in 4 acute hospitals were monitored to assess the effectiveness of cleaning processes. The results clearly demonstrated that hospital cleaning often failed to improve surface hygiene. Mean bacterial counts on surfaces before and after cleaning often showed little difference, indicating that cleaning had failed to reduce bacterial contamination. In some instances, more bacteria were recovered after cleaning had taken place. This study also used ATP to assess residual soil on surfaces, and no significant difference was achieved in ATP levels before and after cleaning. In addition high variability was observed in ‘after cleaning’ results, indicative of inconsistent practice (Dillon & Griffith, 1999). The hospitals included in this study did not have structured cleaning plans which may have been a factor in the failure to improve cleanliness.

An earlier study (Griffith et al., 2000) examined the cleanliness of hospital surfaces before and after cleaning over 14 days. Using microbiology, ATP and visual assessment to evaluate cleaning, 70, 76 and 12% of sites sampled failed against the respective standards set, highlighting the ineffectiveness of visual assessment as a tool for monitoring cleaning. No significant difference was observed in ATP or general microbiology in results before and after cleaning.

French and colleagues (2004) examined the number of surfaces contaminated with MRSA in ward side rooms before and after terminal cleaning (defined as ‘environmental cleaning after the discharge of an infectious patient’). It might be anticipated that cleaning a room known to have been occupied with a patient colonised with MRSA might have attracted increased vigilance in terminal cleaning, but in the above study the proportion of surfaces contaminated with MRSA before and after cleaning was 86.5% and 66.1% respectively. It was reported that the hospital had service level agreements that met NHS standards. This
indicates that either the standards or the hospital’s implementation of them were not adequate to remove MRSA, even when it was expected to be present.

The above studies tested for specific pathogens, indicator organisms, general microbiology and ATP in order to assess hospital cleaning effectiveness. However, for routine assessment of cleaning practice, other than for research studies, such approaches have been rejected in favour of visual assessment. At present, the latest evidence based research for the prevention of HCAI advises that visual assessment is used to assess whether cleaning has been carried out effectively (Pratt, 2007). The Patient Environment Action Team (PEAT) survey, an attempt by the NHS to gather information on the hospital environment and that is available to the public via the internet (Pratt et al., 2007), also requires visual inspection to evaluate cleaning. Visual inspection has previously been shown to be a poor indication of both residual soil and microbial contamination (Griffith et al., 2000; Malik, et al., 2003; Cooper et al., 2007).

4.3 Improvements to hospital cleaning
If existing cleaning protocols fail to offer any reduction in either the number of bacteria or in the levels of residual soil on environmental surfaces, then simply increasing the number of hours spent on cleaning is not likely to be effective. Increasing the effectiveness of how cleaning is performed could be a more successful approach. This is especially relevant as hospitals are under increasing financial pressure, and funding ineffective cleaning is not a prudent use of scant resources (Bery, 1999)

4.4 The use of disinfectants and detergents
One method of increasing the effectiveness of cleaning may be to use more potent agents to remove bacteria. Chemical disinfectants, with strong anti-microbial actions, have the potential to reduce surface contamination by killing microorganisms. However, there is debate over whether disinfectants are appropriate for routine use in hospitals as concerns have been raised over the possibility of emergent resistance and risks to health from exposure to such chemicals (Rutala & Weber, 2001; Ruden & Daschner, 2002; Voss et al., 2003). In the UK, guidance suggests that a disinfectant should generally only be used where a specific infection control risk is present (for example, where blood has spilled) rather than for routine use (Pratt et al., 2007).

Whilst disinfectants have anti-microbial action, detergents have greater ability to release adherent bacteria from surfaces. However, unless detached bacteria are removed, reattachment and recolonisation of surfaces might occur as the anti-microbial actions of
many detergents is limited, if present at all. A reservoir of detergent solution, such as that used with a mop and bucket during the cleaning of a floor, will become contaminated when bacteria removed from the floor are transferred to the bucket. Bacteria in the cleaning solution can be transferred to a new area of floor when the mop is next used, perhaps in a new ward. Similarly, cloths used to clean one surface can transfer bacteria to another surface (Dharan et al., 1999; Barker et al., 2004). For this reason, NHS cleaning guidelines recommend that cleaning solutions are regularly changed and cloths are discarded after use (NHS Estates, 2004a), although compliance has not yet been measured.

4.4.1 Disinfectant and detergents acting together

The contrasting modes of actions of disinfection and detergent can act synergistically to remove contamination. Barker and colleagues (2004) investigated the effects on the transfer of norovirus when using different agents to decontaminate surfaces. This study found that hands touching a contaminated surface could transfer virus particles to up to a further 7 subsequently touched surfaces. Such rapid and widespread transfer between hand contact surfaces could be a factor in the ability of the virus to cause significant outbreaks in closed communities, where the same surfaces may be used by many individuals. In this study, the efficacy of using a detergent alone, a disinfectant alone, and a combination of the two was evaluated. Use of either detergent or disinfectant alone failed to remove all norovirus from surfaces, but where surfaces were cleaned with detergent before disinfection, norovirus was eliminated. These findings are similar to the principles applied for decontaminating endoscopes (Chapter 2) where a thorough clean with detergents is a key prelude to effective disinfection.

Detergents are currently used for routine cleaning in hospitals, so the implementation of cleaning could be improved to reduce surface contamination. A suitable approach may be to use the principles of good cleaning practice and management described in Chapter 1.

4.4.2 Hydrogen peroxide vapour

Another method to reduce the number of bacteria on surfaces could be to use hydrogen peroxide vapour (HPV). By evaporating liquid hydrogen peroxide in a room, French and colleagues (2004) reduced the incidence of MRSA on surfaces from 71.8% to 1.2% compared to a reduction from 89.5% to 66.1% by conventional methods. This system has drawbacks however. The HPV vapour is toxic, so the room must be empty. This may preclude its routine use for open wards, because of the disruption caused by moving all patients and staff from the area for the duration. In addition, decontamination by HPV requires an average of 5 hours for a side room, perhaps as long as 12 hours for an entire
ward (Otter et al., 2006). Such a lengthy decontamination process is possibly appropriate for a ward that has been the subject of an outbreak causing systemic contamination, or where contamination is persistent (Jeanes et al., 2005).

4.5 Standards for hospital cleaning

Whichever cleaning methodology is chosen, if the removal of organisms and soil from surfaces is done to reduce the risk of cross contamination rather than for aesthetic reasons, then levels of remaining residual organisms or soil must be estimated to ensure that the risk has actually been reduced. Visual assessment is known to be an inadequate indicator of bacterial populations but standards based on bacterial and residual soils levels have also been proposed for hospital surfaces (Malik et al., 2003; Dancer, 2004). One of these is based upon evidence-based estimations of achievable hygiene level, and the other derived from standards used in the food industry of the US and Sweden and modified for use in hospitals. There is a need to assess and compare the various standards and sampling strategies before any are implemented to ensure they are both achievable and appropriate.

4.6 Aims

The aim of this study, therefore, was to evaluate routine hospital environmental cleaning and to assess available methods and proposed standards. This was attempted by the following objectives:

To use a range of visual, microbial and non-microbial methods to assess hospital cleanliness and cleaning efficacy after normal cleaning procedures over a two week period.

To compare the effect of modifying routine cleaning by introducing best practice and either a detergent or disinfectant

To characterise bacteria isolated during the monitoring periods

To examine the usefulness of existing and proposed hospital cleaning standards

4.7 Methods

4.7.1 Study setting

A general surgery ward in a recently built 500-bed Welsh hospital was selected as a convenient sample. The mixed-sex ward (Figure 4.7.1.1) consisted of 4 eight-bed bays along a central corridor, side rooms, a nurse’s station, 2 toilets, a bathroom, examination room and storage area. The existing cleaning regime was assessed and routine cleaning practices observed. The schedule used for current cleaning practices was obtained and examined (Appendix 1).
Figure 4.7.1.1 Representation of the ward studied, showing approximation of layout and location of items and areas.

### 4.7.2 Sites selected

Ten sites in the ward were selected for routine sampling. Site selection criteria included frequency of hand contact by staff and patients, movement patterns within the ward, data from previous studies (Griffith et al., 2000; Malik et al., 2003), potential for contamination and proximity to patients.

The sites selected were: tap handles in the patients’ toilet; door handle in the patients’ toilet; tap handles of the ward sink; bedframe; patients’ phone trolley; notes trolley; treatment trolley; sluice handle and the ward floor. Four of these sites were selected, based upon previously found levels of contamination for more extensive microbiological examination to examine their compliance with Dancer’s extended standards for specific pathogens. These were the tap handles of the sink, the tap handles in the patient toilet, the ward floor and the patient’s telephone receiver. Microbiological air quality was also monitored.

### 4.7.3 Cleaning methods

Three separate sampling phases were undertaken within 15 minutes after the morning cleaning, every day for 14 days. After the first sampling phase, based on existing cleaning regimes, two revised documented cleaning protocols for each surface were produced for use in the other two phases (Table 4.7.3.1). One specified that the surface be initially wiped
with a damp paper towel to remove gross debris. The surface was then cleaned with a clean rayon cloth for at least 15 seconds using the non-ionic detergent normally used for surface cleaning in the ward. The surface was then rinsed by means of a potable water spray, and immediately dried with an unused paper towel. The third phase used the same modified cleaning protocol, except that a disinfectant (quaternary ammonium compound) was used in place of the ordinary non-ionic detergent (Table 4.3.7.1). Quaternary ammonium compounds (QAC) have been described as sanitisers – compounds that possess both detergent and disinfecting properties (Dillon & Griffith, 1999), but will be referred to as a disinfectant in this work.

<table>
<thead>
<tr>
<th>Cleaning protocol elements</th>
<th>Existing cleaning methods</th>
<th>Modified cleaning with detergent</th>
<th>Modified cleaning with disinfectant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment defined</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Chemicals defined</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Method defined</td>
<td>Partially</td>
<td>Completely</td>
<td>Completely</td>
</tr>
<tr>
<td>Frequency defined</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Performance Standards set</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Requirement for monitoring</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Potential hazards defined</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Cleaning agent type</td>
<td>Non-ionic detergent</td>
<td>Non-ionic detergent</td>
<td>Cationic detergent / disinfectant</td>
</tr>
<tr>
<td>Agent application method</td>
<td>Spray</td>
<td>Spray</td>
<td>Spray</td>
</tr>
<tr>
<td>Clean cloth used</td>
<td>Not necessarily</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Surface rinsed after cleaning</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Surface dried after cleaning</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 4.7.3.1 Description and breakdown of the features and methods utilised in the three cleaning protocols.

### 4.7.4 Hygiene indicators used

The ward floor was not cleaned using the spray detergent, as this product was designated as a cleaning agent for surfaces and not for floor cleaning.

Following cleaning, test sites were assessed for visual cleanliness, presence of moisture and physical condition (Griffith et al., 2000). Sites were then sampled using microbiological and rapid chemical techniques (Table 4.7.4.1)
<table>
<thead>
<tr>
<th>Testing for</th>
<th>Description</th>
<th>Manufacturer</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACC</td>
<td>Plate count agar (PCA) dipslide</td>
<td>Biotrace Ltd</td>
<td>Bridgend, Wales</td>
</tr>
<tr>
<td>Enterobacteriaceae</td>
<td>Violet red bile agar (VRBA-glucose) dipslide</td>
<td>Biotrace Ltd</td>
<td>Bridgend, Wales</td>
</tr>
<tr>
<td>Staphylococci</td>
<td>Baird-Parker dipslide</td>
<td>Biotrace Ltd</td>
<td>Bridgend, Wales</td>
</tr>
<tr>
<td>MRSA</td>
<td>Oxacillin resistant screen agar (ORSAB) plus supplements dipslide</td>
<td>Biotrace Ltd</td>
<td>Bridgend, Wales</td>
</tr>
<tr>
<td>Salmonella</td>
<td>Path-Chek swab test</td>
<td>Microgen</td>
<td>Camberley, Surrey</td>
</tr>
<tr>
<td>VRE</td>
<td>VRE agar contact plates (VRE agar base and supplements)</td>
<td>Oxoid</td>
<td>Basingstoke, Hants</td>
</tr>
<tr>
<td><em>Clostridium difficile</em></td>
<td><em>Clostridium difficile</em> agar base + supplements as contact plates</td>
<td>Oxoid</td>
<td>Basingstoke, Hants</td>
</tr>
<tr>
<td>ATP</td>
<td>Clean Trace</td>
<td>Biotrace Ltd</td>
<td>Bridgend, Wales</td>
</tr>
<tr>
<td>Air</td>
<td>SAS sampler</td>
<td>PBI</td>
<td>Milan, Italy</td>
</tr>
</tbody>
</table>

Table 4.7.4.1 Suppliers of the various materials used in the microbiological testing procedures

Microbiological analyses at each site consisted of an aerobic colony count, enterobacteriaceae, staphylococcal and MRSA counts. Colonies matching the relevant colonial morphology on Baird-Parker agar, as described in the Oxoid Manual, were used to provide a presumptive staphylococcal and *S. aureus* count. The large number of colonies recovered precluded coagulase testing of all presumptive *S. aureus* colonies. MRSA counts were derived from colonies isolated on ORSAB agar, followed by supplementary testing.

In addition, testing for *Salmonella*, VRE and *C. difficile* was carried out at four sites. Contact based counting methods were employed as these have been shown to have superior sensitivity for dry surfaces, compared to swabbing (Salo et al., 2000; Chapter 3), that were easy to use. All sites were additionally sampled for ATP, which has been shown to be a useful indicator for surface soil and cleaning effectiveness (Griffith, 2005).

### 4.7.5 Sampling protocols

Sites were microbiologically sampled with contact based methods by pressing the agar of the dipslide or contact plate onto the surface being sampled for 10 seconds at a pressure of 25 g/cm², without any lateral movement of the agar (Moore, 2005). Samples were incubated aerobically at 37°C for 48 hours, except *C. difficile* samples, which were incubated anaerobically at 37°C. Characteristic colonies were individually counted except where there was high density of growth, which was interpreted using the manufacturer’s visual guidelines. Path-Chek swabs were moistened in ¼ strength Ringers solution, and an area of up to 100 cm² was swabbed in a close zigzag pattern. The test was then activated, incubated for 48 hours at 37°C and examined according to manufacturer’s instructions. Clean-Trace swabs were swabbed over an area of 100 cm² in a close zigzag pattern using the manufacturer’s guidelines. The activated tests were immediately read in a Uni-Lite
luminometer providing a reading in relative light units (RLUs). Air samples of 100 litres were taken with an SAS air sampler (Jeanes et al., 2005) using plates of Tryptone Soya Agar (TSA), VRBA, Baird-Parker and ORSAB agar. Places were incubated for 48 hours at 37°C, and resultant colonies counted. Where possible, a different area of the same site was sampled on each occasion, for example a different patch of floor, or a bedframe from a different bed, in order to prevent accumulative effects from additional daily cleaning. Sites where this was not possible were patient’s toilet tap handle, patient’s toilet sink handle, ward phone and sluice handle.

4.7.6 Supplementary microbiological testing

After primary isolation, colonies recovered from ORSAB agar were subcultured and further characterised. Presumptive MRSA colonies were Gram-stained and tested for oxacillin resistance by disc. Disc diffusion was carried out using Mueller-Hinton agar (Monsen et al., 2003)

Oxacillin resistant isolates of Gram-positive cocci were initially tested for coagulase activity (Brown et al., 2005) with Staphaureux coagulase tests according to manufacturer’s instructions. As some problems have been identified with testing for surface-bound coagulase and protein A for MRSA (Kuusela et al., 1994), negatives were re-tested using the tube-coagulase method in order to assess free coagulase production, using standardised methodology (Rossney et al., 1990) where 0.1 ml of rabbit plasma in saline buffer was added to 0.5 ml of overnight culture in a sterile tube. Tubes were incubated for 24 h at 37°C, and were examined for any clots forming after 1, 3, 6, and 24 hours.

Further characterisation was performed on all isolates, using API Staphylococcus (BioMérieux, France) according to manufacturer’s instructions. Where an identification probability above 75% was not obtained, isolates were tested using BBL crystal gram-positive kits (Becton Dickinson, USA), following manufacturer’s guidelines.

Some isolates were further characterised using PCR for the MecA and nuclease gene, thought to be good markers to identify MRSA (Brown et al., 2004). Isolates were grown overnight on plates. A 5 µl loop of bacteria was picked off with a sterile loop and was suspended in 200 µl of Chelex solution in a 500 µl Eppendorf tube. The suspension was heated to 95°C for 15 minutes before being spun at 15000 g for 5 minutes. The supernatant (DNA template) was removed.
4.7.7 PCR
To a PCR bead (Pharmacia, Sweden), 18 µl of sterile water, 3µl of DNA template, 1 µl of each of the 4 primers was added.

Primers used (Fang & Hedin, 2003)

MECA1
5'-GCAATCGCTAAAGAATAAG-3'

MECA2
5'-GGGACCAACATAACCTAATA-3'

NUC1
5'-GCAGATGATGGTTGATACGCTT-3'

NUC2
AGCCAGCCTTGACGAACTAAGC-3'

The PCR cycle used was:

95°C 15 minutes

95°C 60 seconds }
55°C 60 seconds } 32 cycles
72°C 60 seconds }

72°C 10 minutes

5 µl of loading buffer was added to the tube and mixed, and 10 µl of resulant solution added to a 1.5% agarose gel submerged in TBE buffer. Size standard was also added to the gel.

Electrophoresis was carried out for 60 minutes at 3.5 v.cm⁻¹, and the gel was stained for 20 minutes in 0.5 µg/ml ethidium bromide before destaining with tap water and was photographed under UV transillumination.

4.7.8 PFGE
Suspected MRSA isolates were subjected to pulsed-field gel electrophoresis (PGFE) using the Bio-Rad CHEF equipment and modular Bio-Rad reagents and enzymes. This was carried out according to manufacturer’s instructions. Banding patterns were compared to the most common pulseotypes of EMRSA-15 and 16, supplied by Colindale Staphylococcus culture collection.

4.7.9 Standards used
Two sets of pass / fail levels were used based upon 2 previously suggested levels for aerobic colony counts after cleaning. One was based on philosophical / risk based considerations
(Dancer, 2004). The other was based on attainable levels (microbial and ATP) achieved after implementing good cleaning practice. For indicator organisms, standards were proposed for staphylococci and enterobacteria. These were set lower than published ACC standards as these would contribute only a portion to ACC counts. In addition, visual assessment was used to assess levels of dirt in the test area. If dirt was visible from a distance of approximately 60 cm, a fail was recorded.

4.7.10 Statistical analysis
Comparisons between cfu/RLU levels from specific sites after different cleaning regimes were made using ANOVA with Tukey comparisons using Microsoft Excel with minimum significance set at $P=0.05$.

4.8 Results

4.8.1 Visual inspection and surface condition
Visual inspection results from the test sites (Table 4.8.1.1) indicated the vast majority were dry, the only wet sites being associated with sinks or toilet areas. With the exception of the bedframes, which were often chipped, surfaces were in good condition. Visual assessment of residual soil from 60 cm found that modified cleaning methods produced no failures, whereas existing cleaning regularly failed to remove all visible soil (Table 4.8.1.2)

<table>
<thead>
<tr>
<th>Site Sampled</th>
<th>Surface dryness</th>
<th>Good physical condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ward floor</td>
<td>100%</td>
<td>86%</td>
</tr>
<tr>
<td>Patients’ toilet tap handle</td>
<td>98%</td>
<td>100%</td>
</tr>
<tr>
<td>Ward phone</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Ward tap handle</td>
<td>95%</td>
<td>98%</td>
</tr>
<tr>
<td>Bed frame</td>
<td>100%</td>
<td>12%</td>
</tr>
<tr>
<td>Notes trolley</td>
<td>100%</td>
<td>93%</td>
</tr>
<tr>
<td>Treatment trolley</td>
<td>100%</td>
<td>98%</td>
</tr>
<tr>
<td>Patients’ toilet door handle</td>
<td>95%</td>
<td>95%</td>
</tr>
<tr>
<td>Sluice handle</td>
<td>98%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 4.8.1.1 Assessment of surface dryness and the physical conditions of test surfaces after existing cleaning had occured

<table>
<thead>
<tr>
<th>Site Sampled</th>
<th>Existing cleaning</th>
<th>Modified cleaning with detergent</th>
<th>Modified cleaning with disinfectant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ward floor</td>
<td>11%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Patients’ toilet tap handle</td>
<td>45%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Ward phone</td>
<td>26%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Ward tap handle</td>
<td>5%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Bed frame</td>
<td>7%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Notes trolley</td>
<td>14%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Treatment trolley</td>
<td>9%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Patients’ toilet door handle</td>
<td>10%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Sluice handle</td>
<td>12%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Table 4.8.1.2 Failure rates of test surfaces after cleaning with specified method, as assessed by visual assessment (no soil visible from a distance of 60 cm)
4.8.2 Microbiological and ATP results
Microbiological and ATP test results are presented in Table 4.8.2.1 with their interpretation as pass or fail using the two proposed standards presented in Table 4.8.2.2.
Table 4.8.2.1 Microbial counts and ATP levels found on surfaces after the implementation of three different cleaning regimes

Mean and ranges (in italics) of sites sample with method and cleaning protocol used (n=14)

Microbiology shows cfus/cm² recovered, ATP shows RLUs

<table>
<thead>
<tr>
<th></th>
<th>Existing Cleaning using Detergent</th>
<th>Microbiology</th>
<th>Modified Cleaning with Detergent</th>
<th>Modified Cleaning with Sanitiser</th>
<th>ATP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ACC</td>
<td>Entero</td>
<td>Staph</td>
<td>ACC</td>
<td>Entero</td>
</tr>
<tr>
<td>Ward floor</td>
<td>5.6</td>
<td>&lt;1</td>
<td>2.0</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>0.6-25.0</td>
<td>0.6-25.0</td>
<td>0.7-8.6</td>
<td>0.3-7.0</td>
<td>0.2-0.4</td>
<td>0.1-0.3</td>
</tr>
<tr>
<td>Patients’ toilet tape handle</td>
<td>9.3</td>
<td>&lt;1</td>
<td>4.2</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>1.0-25.0</td>
<td>1.0-25.0</td>
<td>0.7-5.0</td>
<td>0.3-2.0</td>
<td>0.1-0.3</td>
<td>0.1-0.5</td>
</tr>
<tr>
<td>Ward phone</td>
<td>2.8</td>
<td>&lt;1</td>
<td>3.6</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Ward sink tap handle</td>
<td>1.6</td>
<td>&lt;1</td>
<td>1.5</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Bed frame</td>
<td>3.5</td>
<td>&lt;1</td>
<td>1.9</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Notes trolley</td>
<td>1.7</td>
<td>&lt;1</td>
<td>1.2</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Treatment trolley</td>
<td>4.1</td>
<td>&lt;1</td>
<td>3.0</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Patients’ toilet door handle</td>
<td>2-25.0</td>
<td>0.6-1.0</td>
<td>0.3-9.0</td>
<td>0.1-0.3</td>
<td>0.1-0.2</td>
</tr>
<tr>
<td>Sluice handle</td>
<td>7.2</td>
<td>&lt;1</td>
<td>4.0</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
<tr>
<td></td>
<td>0.1-3.4</td>
<td>0.8-2.3</td>
<td>0.6-0.6</td>
<td>0-0.1</td>
<td>0-0.3</td>
</tr>
</tbody>
</table>

Table 4.8.2.1 Microbial counts and ATP levels found on surfaces after the implementation of three different cleaning regimes

Mean and ranges (in italics) of sites sample with method and cleaning protocol used (n=14)

Microbiology shows cfus/cm² recovered, ATP shows RLUs

Not determined = not determined
<table>
<thead>
<tr>
<th></th>
<th>Existing cleaning with detergent</th>
<th>Modified cleaning with detergent</th>
<th>Modified cleaning with sanitiser</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Visual</td>
<td>ACC Std 1</td>
<td>ACC Std2</td>
</tr>
<tr>
<td>Ward floor</td>
<td>11%</td>
<td>21%</td>
<td>50%</td>
</tr>
<tr>
<td>Patients’ toilet tap</td>
<td>45%</td>
<td>57%</td>
<td>86%</td>
</tr>
<tr>
<td>handle</td>
<td>26%</td>
<td>29%</td>
<td>50%</td>
</tr>
<tr>
<td>Ward phone</td>
<td>5%</td>
<td>7%</td>
<td>14%</td>
</tr>
<tr>
<td>Ward sink tap handle</td>
<td>7%</td>
<td>7%</td>
<td>21%</td>
</tr>
<tr>
<td>Bed frame</td>
<td>14%</td>
<td>7%</td>
<td>21%</td>
</tr>
<tr>
<td>Notes trolley</td>
<td>19%</td>
<td>29%</td>
<td>36%</td>
</tr>
<tr>
<td>Treatment trolley</td>
<td>10%</td>
<td>29%</td>
<td>50%</td>
</tr>
<tr>
<td>Patients’ toilet door</td>
<td>12%</td>
<td>0%</td>
<td>7%</td>
</tr>
<tr>
<td>handle</td>
<td>12%</td>
<td>0%</td>
<td>7%</td>
</tr>
</tbody>
</table>

Table 4.8.2.2 Percentage failure rates for each site against proposed hygiene standards, after implementation of three cleaning regimes

Percentage failures by site, cleaning method and hygiene indicator. N=14

Std 1 from Dancer (2004). ACC <5 cfu/cm².
Std 2 from Malik et al., (2003). ACC <2.5 cfu/cm². ATP <500 RLU
Std 3 Proposed standard (Dancer, 2004) for indicator organism, staphylococci and enterobacteria <1 cfu/cm²
4.8.3 Existing cleaning regime

Using visual assessment found the site most often found to be unclean was the patient toilet’s tap handle (55% of occasions). The cleanest site by visual inspection was the taps handles of the ward sink (95% of occasions) (Table 4.8.1.2).

ACC yielded the highest overall mean counts for each site with four of the ten sites on occasions yielding 25 cfu/cm². Staphylococci were more frequently isolated than enterobacteriaceae even from toilet areas where higher counts of the latter may have been anticipated. Tap handles in the patients’ toilet were the most contaminated sites with a mean of 9.5 cfu/cm² for ACC, and 4.2 cfu/cm² for staphylococci. Other relatively contaminated sites were the ward floor, patients’ toilet door handles, bed frames and ward phone. The sluice handle had the least contamination. Inter sampling / day to day variation was high ranging from 1 to >25 cfu/cm². The ward phone, treatment trolley and patients’ toilet door and tap handles gave the highest mean and maximum staphylococcal counts. In total 2494 presumptive staphylococcal colonies were isolated from surfaces using Baird Parker selective media. Of these 1191 were identified as S. aureus on the basis of visual comparison with manufacturer’s instructions, although where large numbers of cells were present, differentiation on this basis was difficult. Three isolates of MRSA were found while using existing cleaning. The isolates were recovered from the sluice machine handle, the ward floor and from an air sample. No confirmed isolates of C. difficile, VRE or Salmonella were recovered.

Overall enterobacteriaceae levels were low with the patients’ toilet tap handle and treatment trolley giving the highest values, with maximum levels of 3.4 and 6.1 cfu/cm² respectively. Rapid testing using ATP bioluminescence indicated that the ward floor (mean and maximum values) was the site most likely to be contaminated with organic debris; the ward phone was the next highest with the maximum reading of the latter in excess of 68000 RLUs. The notes trolley also recorded a high mean value with a maximum in excess of 45000 RLUs.

4.8.4 Modified cleaning regime using non-ionic detergent

All sites were found to be visually clean after using the modified cleaning protocol with non-ionic detergent (Table 4.8.1.2). Aerobic colony counts were significantly lower for all but one site at P = 0.05, with some at P=0.01. Overall the mean and maximum microbiological counts were lower, with the treatment trolley having the highest mean ACC of 5.8 cfu/cm². Staphylococcal counts were also significantly reduced (Table 4.8.2.1).
MRSA was isolated from 7 samples taken in this phase of the study. Of these, 1 was found on the ward phone, and 6 were recovered from air samples.

Enterobacteriaceae counts, which were low using existing cleaning methods, were further reduced using modified cleaning with detergent, from 0.13 cfu/cm$^2$ to 0.024 cfu/cm$^2$, though this drop was not significant. In addition to reduced mean counts after modified cleaning, the range/spread of results and thus the variability in surface counts was also reduced. Mean ATP counts were significantly reduced with the highest mean and maximum values (243 RLU and 2289 RLU respectively) recorded from the tap handles of the ward sink. The maximum ATP count decreased from 163870 RLUs with existing cleaning regimes to 2289. Only 3 sites recorded a value over 500 RLUs with the modified regime.

4.8.5 Modified cleaning regime using a disinfectant

All sites were found to be visually clean after modified cleaning with the QAC disinfectant. Introducing a disinfectant and modifying the cleaning regime gave significantly lower microbiological and ATP readings compared to the existing regime. ACC counts fell from a mean of 4 cfu/cm$^2$ on the patient’s toilet door handle for existing cleaning to 0.17 cfu/cm$^2$ with modified disinfectant cleaning, and ATP levels dropped from 3842 RLUs to 109 on the same surface. However, results were not significantly lower than those after modified cleaning using the non-ionic detergent for surfaces. No MRSA, *C. difficile*, *Salmonella* or VRE were recovered while using modified cleaning with disinfectants.

4.8.6 Air counts

Air counts in the ward did not vary with any of the cleaning regimes. The existing cleaning methods showed a mean ACC of 26 cfu/100l of air with a range from 6-52 cfu/100l was. Staphylococcal counts had a mean of 10 cfu/100l, and 6 isolates were identified as MRSA. Enterobacteriaceae counts were lower, with a mean of less than 1 cfu/100l.

4.8.7 Characterisation of presumptive MRSA from ORSAB selective agar

Characterisation of the 182 presumptive MRSA isolated from the ORSAB selective agar showed that 10 were MRSA, being Gram positive coagulase-positive cocci, exhibiting oxacillin resistance and having both the *mecA* and *nuc* genes. In addition, they were identified as *S. aureus* by API Staph identification kits. Of the isolates found not to be MRSA, the predominant species was *S. haemolyticus*, with *S. epidermidis* and *S. xylosus* also recovered. Characterisation results are shown in Table 4.8.7.1.
<table>
<thead>
<tr>
<th>ORSAB +</th>
<th>Gram +</th>
<th>OxR by disc</th>
<th>Staphx</th>
<th>Coagulase</th>
<th>mec A</th>
<th>nuc</th>
<th>Identification API by Staph kits</th>
<th>Is isolate MRSA?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>identification API by Staph kits</td>
<td></td>
</tr>
<tr>
<td>Staphylococcus aureus</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>identification API by Staph kits</td>
<td></td>
</tr>
<tr>
<td>Staphylococcus aureus</td>
<td>No</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>identification API by Staph kits</td>
<td></td>
</tr>
<tr>
<td>Staphylococcus epidermidis</td>
<td>No</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>identification API by Staph kits</td>
<td></td>
</tr>
<tr>
<td>Staphylococcus haemolyticus</td>
<td>No</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>identification API by Staph kits</td>
<td></td>
</tr>
<tr>
<td>Staphylococcus hominis</td>
<td>No</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>identification API by Staph kits</td>
<td></td>
</tr>
<tr>
<td>Staphylococcus saprophyticus</td>
<td>No</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>identification API by Staph kits</td>
<td></td>
</tr>
<tr>
<td>Staphylococcus warneri</td>
<td>No</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>identification API by Staph kits</td>
<td></td>
</tr>
<tr>
<td>Staphylococcus xylosus</td>
<td>No</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>identification API by Staph kits</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.8.7.1 Synopsis of supplementary test results from of isolates recovered from ORSAB agar. A black square indicates a positive result for the test.

Testing with PFGE (examples shown in figures 4.8.7.1, 4.8.7.2 and 4.8.7.3) against the most common pulseotypes of EMRSA 15 (column e, Figure 4.8.7.1) and 16 (column f, Figure 4.8.7.1) found that 6 of these isolates were identical the most common pulsotype of EMRSA 15 (columns b, i and u, Figures 4.8.7.1, 4.8.7.2 and 4.8.7.3 respectively) and 4 were within a single band of the most common EMRSA-15 profile (column h, Figure 4.8.7.2). These figures are contained electronically in Appendix 2

![PFGE gel](image)

Figure 4.8.7.1 PFGE gel of suspected MRSA isolates recovered from ORSAB agar, isolates a to f
In addition to the isolates found to be MRSA, 2 isolates had EMRSA 15 pulseotypes, but lacked *mecA* and *nuc* genes according to PCR.

Of the 10 isolates MRSA found, 3 were recovered from surfaces during sampling after existing cleaning, 7 after modified cleaning with a detergent, and none were found after modified cleaning with a disinfectant. Of the 10 recovered, 6 were recovered from air samples and 4 from surfaces.
The performance of CHROMagar MRSA (Becton Dickinson, USA) chromogenic agar was tested using 173 of the 182 isolates recovered using ORSAB agar. Of these, 21 isolates were identified as MRSA. All 10 isolates shown to be MRSA by coagulase and PCR methods were detected, and 11 were false positives. This equates to a sensitivity of 100% and a specificity of 93.2%.

4.8.8 Assessment of standards used
Pass / fail levels in relation to the two different standards are presented in Table 4.8.2.2. One standard provides recommendations for a range of microorganisms including pathogens and indicator organisms, and propose a higher acceptable ACC level. The other had one microbiological recommendation (ACC) but suggested an equivalent ATP level found after routine cleaning using the CleanTrace test. Failure rates using the existing cleaning regime were higher with the more stringent of the two ACC recommended standards. Compared to both the ACC standards, using the existing regime, the sites most likely to fail were the patients’ toilet sink handles followed by the bed frame. Relatively few sites failed to pass the recommended enterobacteriaceae standards but failures rates were much higher with the staphylococcal standard. Failure rates using the ATP standard were high using routine cleaning. There was no correlation between the ATP and the ACC failures but the ATP failure rates were closer to those using the more stringent ACC standard.

Modifying the cleaning regime significantly reduced the number of failures but there was no significant difference in the number of failures when using a modified cleaning regime incorporating a sanitizer compared to the modified regime with non-ionic detergent (see Table 4.8.8.1). Details of comparisons are held in Appendix 3.
### Existing cleaning versus modified cleaning with disinfectant

<table>
<thead>
<tr>
<th></th>
<th>ACC</th>
<th>Staphylococci</th>
<th>ATP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing cleaning</td>
<td>Blue</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modified cleaning</td>
<td>Red</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No significant difference</td>
<td>Green</td>
<td>Green</td>
<td>Green</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Surface</th>
<th>ACC</th>
<th>Staphylococci</th>
<th>ATP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient's toilet sink handle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patient's telephone</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ward Sink</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bedframe</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Note trolley</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Treatment trolley</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patient's toilet door handle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sluice Handle</td>
<td></td>
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</tr>
</tbody>
</table>

Table 4.8.8.1 Site-by-site comparison of the effectiveness of existing cleaning and modified cleaning with disinfectant using 3 different hygiene indicators. Analysis by ANOVA with Tukey comparisons, P = 0.05

### Existing cleaning versus modified cleaning with detergent

<table>
<thead>
<tr>
<th></th>
<th>ACC</th>
<th>Staphylococci</th>
<th>ATP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing cleaning</td>
<td>Blue</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modified cleaning</td>
<td>Red</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No significant difference</td>
<td>Green</td>
<td>Green</td>
<td>Green</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Surface</th>
<th>ACC</th>
<th>Staphylococci</th>
<th>ATP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient's toilet sink handle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patient's telephone</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ward Sink</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bedframe</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Note trolley</td>
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<td></td>
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<tr>
<td>Treatment trolley</td>
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<td></td>
<td></td>
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<tr>
<td>Patient's toilet door handle</td>
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<td></td>
</tr>
<tr>
<td>Sluice Handle</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4.8.8.2 Site-by-site comparison of the effectiveness of existing cleaning and modified cleaning with detergent using 3 different hygiene indicators. Analysis by ANOVA with Tukey comparisons, P = 0.05
Modified cleaning with disinfectant versus modified cleaning with detergent

<table>
<thead>
<tr>
<th>Modified cleaning with disinfectant</th>
<th>Modified cleaning with detergent</th>
<th>No significant difference</th>
</tr>
</thead>
</table>

Table 4.8.8.3 Site-by-site comparison of the effectiveness of modified cleaning with disinfectant and modified cleaning with detergent using 3 different hygiene indicators. Analysis by ANOVA with Tukey comparisons, P = 0.05

4.9 Discussion

There is concern over the standards of cleanliness in hospitals (Dancer, 1999) yet few hospitals objectively assess the efficacy of cleaning in relation to cost or effectiveness and the implementation and management of cleaning has been criticized by some (NHS Wales, 2003). Components of effective cleaning management, as used in the food industry, include well designed and validated cleaning schedules, and monitoring of their effectiveness (Dillon & Griffith, 1999). Monitoring the cleanliness of surfaces is not routinely performed in hospitals, although various methods are available, including visual assessment.

4.9.1 Existing cleaning

4.9.1.1 Visual assessment

Visual assessment of cleanliness can overestimate cleaning efficacy, and an integrated approach to monitoring using visual, rapid (ATP) and microbiological methods has been recommended (Griffith et al., 2000). In this study, visual assessment gave fewer failures on most surfaces than ACC methods, except for the sluice handle and notes trolley. Failures with ATP methods were higher for every surface for existing cleaning. This is more relevant than ACC, as visual assessment is a test for residual soil rather than bacteria as is ATP assessment. Whilst many surfaces were visually clean, the results indicated that cleaners were prepared to leave a substantial number of surfaces visually dirty after cleaning. This could not happen with the modified cleaning protocols utilised in this study,
which incorporated a monitoring phase coupled with the need for corrective action if required.

4.9.1.2  *Specific pathogen counts*

Tests for specific pathogens, MRSA, *Salmonella* and *C. difficile* and VRE, yielded few isolates and no failures using the relevant proposed standard. No isolates of *Salmonella*, *C. difficile* or VRE were recovered, and only 3 isolates of MRSA were confirmed. The lack of failures against Dancer’s proposed standards could be expected as 1 square metre of surface could be contaminated with $10^5$ cfu of MRSA and still be considered acceptably clean for hospitals wards under these standards. For specific pathogens therefore, it might be better to consider the absence of that particular indicator organism from a specified area, for example 10 cm$^2$. A qualitative test could also include an enrichment step to increase sensitivity as the enumeration of bacteria would no longer be relevant.

4.9.1.3  *Indicator organism counts*

Enterobacteriaceae were infrequently recovered, even in bathroom and sluice sites where a significant presence could be expected. This could make enterobacteriaceae a suitable indicator organism, as a usually low number in the environment typically would make an increase in number much more indicative of recent contamination. However, it may be that the cause of an increase in environmental enterobacteriaceae, for example a patient with diarrhoea, will have already been noted by nursing staff and appropriate measures taken before the tests results are returned from the laboratory. The low numbers of enterobacteriaceae are in contrast to staphylococcal species which were found in higher numbers at all sites. As only 3 isolates of MRSA were found during the same period, staphylococci may be a poor indicator organism. As they survive well on surfaces and could be expected to be found in numbers on surfaces, it would be more appropriate to either test specifically for MRSA or generally for all bacteria, which would include staphylococci.

4.9.1.4  *General microbiology counts*

The bacterial sampling measure that produced most colonies was ACC. This could make it a more sensitive measure for cleaning effectiveness than testing for specific and indicator pathogens. Fewer failures were seen with either standard compared to staphylococci, implying that the proposed standard is harsher for ACC than for staphylococci.
4.9.1.5 ATP bioluminescence

On nearly every occasion where the existing cleaning regime was tested, the site failed against the ATP standard. The failure margin was often large, with the mean RLU reading for the patient’s phone being over 17 times the benchmark clean level. The lowest mean, for the patient’s toilet tap handle was 4.5 times the standard and the highest mean, for the ward floor, was over 55 times higher. The RLU standard was developed alongside the ACC standard of 2.5 cfu/cm$^2$ from results in the food industry, so it might be considered that the difference between the failure rates means that the standard is not appropriate. However it must be considered that the standard was not devised to measure levels of soil against each other, but as a maximum level of contamination that was allowable after a thorough clean. In addition, microbiological testing may or may not correlate with ATP readings as the two techniques measure different parameters and much will depend upon the type of soil likely to be present on the surfaces. ATP bioluminescence can be regarded more as a measure of cleanliness as it detects residual organic soiling (microbial and non microbial ATP). Due to the sensitivity of the test, and the speed of results, ATP bioluminescence is a good method for testing cleaning effectiveness.

4.9.2 Effectiveness of existing cleaning

The results clearly indicate that the hygiene standards in this hospital ward did not satisfy the standards used. The tests were carried out within 15 minutes of the completion of morning cleaning, so it was expected to be the cleanest point of the day. The results of this aspect of the study are similar to those in Cooper et al. (2007), where a ‘before and after’ study of cleaning showed little improvement in the bacterial counts and ATP levels. This is a clear indication that the cleaning performed each day was not effective at removing either microorganisms or residual dirt. It may be that dirt and bacteria picked up from surface are deposited on the next, as the potential for contaminated cleaning materials to contaminate other areas has been demonstrated (Dharan et al., 1999). Surfaces were assessed as being visually clean on 83.2% of occasions, a failure rate of 16.8%. Even though visual assessment is a generous method of assessing cleanliness, existing cleaning methods could not reliably achieve the standards required. The resources put into the cleaning are therefore, at least in part, wasted, and the possibility of a heightened risk to patients from environmental pathogens exists. In addition, because this method overestimates cleanliness, when results derived from it are released, there may be a tendency to underestimate the problem.
4.9.3 Approaches to improve cleaning

In December 2004, NHS Estates published ‘Revised Guidance on Contracting for Cleaning’ (NHS Estates, 2004b) on to the internet, attempting to “assist the NHS in ensuring that contracts for cleaning are driven by quality rather than price”. While this could be interpreted as a tacit acknowledgement that this has not always been the case, the document makes recommendations that contracts should include performance measures so that attainment levels could be monitored. The document did not give advice on the nature of the type of measures that should be implemented, only that they be audited with a risk-dependant frequency. One conclusion is that an opportunity to ensure that hospital cleaning was carried out effectively was missed, even though it does provide a mechanism to ensure the implementation of future changes.

Another government scheme is to give ‘matrons’ a say in what is cleaned, how frequently, expedite emergency cleaning, and recommend to that payment be withheld where cleaning is poor, has been devised (NHS Estates 2004c). By giving responsibility for cleaning to a senior and specific individual with powers to influence payment, one mechanism to improve practice was generated. However there are notable pitfalls in this approach too. The results of this chapter show that the method of cleaning (for example, rinsing and drying) are important factors in a successful clean, and the matron would not have influence over these matters. In addition, ‘poor performance’ remains undefined. If it is determined by visual assessment, it is a qualitative assessment and subject to interpretation. The potential contractual difficulties in withholding payments by subjective criteria may preclude any authority that this measure promised. Without defined standards and methods to test with (as in Chapter 3), this mechanism of control could prove too difficult to use as intended.

4.9.4 Modified cleaning methods

4.9.4.1 Visual assessment

Using visual assessment, no surfaces were recorded as dirty with either modified cleaning protocol. Fewer failures were found with other methods when using modified methods, but visual assessment still overestimated the cleanliness of surfaces, following the pattern seen with existing cleaning methods, and in other studies.

4.9.4.2 Specific pathogen counts

Sampling after modified cleaning with detergent found a single MRSA isolate on a surface (the ward floor) but no other specific pathogens were found on surfaces with either modified method. Combined with the results for existing cleaning, the frequency of recovery of
specific pathogens suggest that routine sampling for specific pathogens is unlikely to be an effective measure to assess cleaning effectiveness.

4.9.4.3 Indicator organism counts
As with existing cleaning, enterobacteriaceae may be a better indicator for the presence of enteric pathogens than staphylococci is for MRSA, due to the relatively poor survivability of many of these organisms. A high enterobacteriaceae count would therefore indicate recent contamination, perhaps as a result of a recent gastrointestinal infection. A high staphylococcal count would be a better measure of cleaning effectiveness rather than of immediate risk, as these high counts could be the result solely of touch actions and persistence.

4.9.4.4 General microbiology counts
The general microbiology counts were a good measure of the changes in cleaning effectiveness achieved when using the modified cleaning methods. In addition for the potential for this method to be used to monitor cleaning, it would also be of value as a technique in the design and validation of other cleaning approaches and methodologies.

4.9.4.5 ATP bioluminescence
As with general microbiology, ATP was a good indicator of cleaning effectiveness and could also be useful in validating cleaning programmes.

4.9.5 Modified cleaning effectiveness
The modified cleaning produced significant reductions in all bacterial indicators and ATP levels at nearly all sites tested. This suggests that relatively simple improvements (Table 4.7.3.1) to the cleaning regime could achieve significantly better results, i.e. lower levels of residual soil and bacteria. This reduction applied to both mean values and to the spread of results. Reducing variability and improving the consistency of the results is a measure of how well cleaning is controlled and managed (Dillon & Griffith, 1999). Changes to the existing protocols were relatively minor but require a clean cloth for each surface, and incorporate a rinsing and drying stage. A clean cloth would prevent bacteria picked up from one surface during cleaning being transferred to another surface. It has been found that contaminated detergent solution can seed other surfaces with bacteria (Dharan et al., 1999), and the same could occur with a cloth. The study reported that using a detergent actually resulted in an increase in bacterial numbers, though that study did not appear to have used a
rinse step. Rinsing surfaces after use of a detergent helps to remove detached bacteria, preventing them from re-deposition. Barker, investigating removal of Norovirus from a surface found that detergent cleaning alone was not enough to remove virus particles, and that the rinsing of fomites was not an option (Barker et al., 2004). Hence disinfection was inferred to be appropriate. This study shows that the incorporation of a rinsing step to handles or toilet seats is possible if handheld sprays are used, although practicality in routine use must be examined. Although no attempt to measure virus contamination was made here, it may be the case that a rinse step would improve the removal of virus particles from a surface. While feasible, cleaning with the express purpose of removing Norovirus would normally occur during an outbreak situation, where the use of disinfectants would be justified by infection control procedures.

Incorporating a drying stage further helps to remove organisms as well as reducing transfer rates (Rusin et al., 2002). Rinsing and drying steps may also help to alleviate any cross contamination by previously used cloths, as transferred bacteria would be unlikely to have firmly attached before this was carried out.

Although the improvements to the cleaning schedules were relatively simple, they would require an increased input of resources, in terms of materials and cleaning hours. In addition, regular monitoring of results would require further expenditure. The other side of the balance sheet is that the cost of HCAI is huge, both in financial terms for treatment and additional length of stay, at an estimated £1 billion pounds a year (National Audit Office, 2000). Social costs of HCAI must also be examined. Patients may be wary of hospital treatment for fear of HCAI, and the high profile of HCAI damages confidence in the health care system as a whole. Losses in productivity in the wider economy can not be ignored.

4.9.6 The effectiveness of detergents and disinfectants

There has been debate about whether a detergent or disinfectant is more appropriate for routine ward cleaning, where the advantage of a disinfectant’s anti-microbial action is offset by concerns over prolonged exposure and also aesthetic appeal.

For detergents, the results from the modified cleaning protocol using the existing detergent product were much improved, and routine incorporation of a quaternary ammonium compound as a disinfectant offered little advantage. The reduction of bacterial numbers to background levels using detergents suggests that detergents are suitable for routine cleaning, when the cleaning is carried out properly. However, some pathogens can be difficult to remove from surfaces during routine cleaning using existing NHS recommended protocols.
(Barker et al., 2004). Disinfectants should therefore be used to control outbreaks and where increased infection risk is indicated, as per current recommendations (Pratt et al., 2007). High staphylococcal counts were noted when using the existing cleaning regime and there is some evidence to suggest epidemiological strains of MRSA have greater survival abilities than non epidemiological strains (Vagenvoort, 2000b).

4.9.7 Characterisation of MRSA isolates

Although more specific than using a general agar for sampling surfaces for MRSA, the poor specificity of ORSAB agar for MRSA found in this study could preclude its routine use. A large number of presumptive MRSA (94%) isolates proved to be coagulase negative staphylococci when more fully characterised. The ORSAB agar is designed to develop a deep royal blue colour when mannitol fermenting bacteria lower the pH of the medium, allowing identification of mannitol fermenters such as S. aureus. While this may be effective for screening clinical samples, it is less successful for environmental samples where other flora and surface residue may make it harder to identify genuine MRSA colonies. Poor performance of ORSAB agar for use in sampling surfaces has been noted previously (Manning et al., 2004; Chapter 3), and certainly rely on characteristic colonies alone is not advised. Although chromogenic agars with claims for improved specificity for MRSA have been made, there must be doubts over their suitability for sampling surfaces (Chapter 3), and it seems likely that, at this time, any recovered colonies with any medium would require further characterisation. When testing isolates recovered in this study on chromogenic agar, false positives were recorded for 52% of isolates. Comparisons with the performance of ORSAB agar are not valid, as this figure was not for surface sampling. However, if this ‘best case scenario’ figure could be replicated for surface sampling, it may be possible to use such an approach for routinely sampling for surfaces for MRSA, if subsequent processing costs could be kept low. For example, if a latex agglutination test applied to bacteria taken directly from the chromogenic agar proved highly specific, then additional costs would be low.

PFGE results showed that amongst the confirmed MRSA isolates recovered some had a pulotyptpe that matched EMRSA-15, a strain often found associated with HCAI. This finding shows that HCAI with MRSA was a present risk within the hospital.
4.9.8 Assessment of standards and tests used

4.9.8.1 Visual assessment

Visual assessment overestimated the cleanliness of surfaces for all cleaning methods compared to general microbiology, a finding frequently reported. In spite of its deficiencies, the HIS guidelines require visually clean surfaces, and hospitals are marked on the appearance of ward areas in the UK governments grading system, via the PEAT process (PEAT, 2007). The PEAT process requires hospital to self-assess their wards in terms of a number of factors. The PEAT report relies on the word ‘cleanliness’ and results are expressed in this manner. However, ‘general environment’ or ‘patient experience’ may be a better expression to convey the intention of the report, because waiting areas, external appearance, and from 2006 assessments of privacy and dignity by segregation of male/female sleeping and toilet areas are included (Pratt et al., 2007). The survey requires no microbiological sampling of any kind, and assessment of cleanliness is limited to visual inspections. The assessment form does not delineate between either surfaces or areas that pose varying cross contamination or infection risks, with ‘beverage bays’ in corridors given equal standing with ‘patient equipment’ in emergency departments. Relying on visual assessment can lead to an overestimation of cleanliness. Year on year figures from PEAT have been used to claim improvements, and blanket assertions such as “over 80% of trusts scoring excellent or good” (National Patient Safety Agency, 2006). Unfortunately, due to national differences, the hospital assessed in this study is not included in the PEAT results, so a comparison can not be made. However, no issues likely to cause concern on the PEAT assessment were observed.

The value of such an approach seems to be in influencing public perception that the NHS is seen to be doing something about hospital cleaning, rather than the prevention of HCAI. This conclusion is illustrated by Green et al. (2006), who compared MRSA bacteraemia rates with the Patient Environment Action Team results between 2001 and 2003 in 173 hospitals, with a view to drawing conclusions about the role of hospital cleanliness in MRSA HCAI. No correlation was found, and so a conclusion that it is not helpful to link MRSA infection rates with cleanliness standards was derived. This does not seem to be a valid deduction because an attempt to correlate MRSA and cleanliness would require that the PEAT assessment of cleanliness would bear some relation to the level of MRSA contamination in the environment. The present study, and others, shows that visual
assessment is poor indicator of cleanliness, and Green acknowledges that PEAT results are subjective, and lack microbiologic data. If the issue of hospital cleanliness is to be more than simply an aesthetic exercise, then improvements in cleaning practice of the sort described in this chapter need to be implemented, and their effectiveness must be monitored.

4.9.8.2 Specific pathogen counts

The detection of specific pathogens was not found to be a successful approach to assessing cleanliness, with few isolates recovered. Only a limited number of MRSA and no confirmed isolates of VRE, Salmonella or C. difficile were recovered. It is likely that the environmental contamination of these organisms remains infrequent except at times of outbreak, so that recovering a positive isolate from a limited number of tests at a specific moment in time is unlikely. Many of the MRSA isolates found in this study were recovered in air samples. MRSA has been found regularly in air samples in other studies (Jeanes et al., 2005). This represents a possible method of movement and dispersal, but the low numbers recovered make air an unlikely source of cross-infection.

4.9.8.3 Indicator organism counts

This study found staphylococci could be present in the environment in significant numbers, without MRSA being present. Such ubiquity makes staphylococci a poor indicator for MRSA or other pathogens (except staphylococci themselves). Enterobacteriaceae are a better indicator of risk, as they were rarely found in the environment. Their appearance in the environment could indicate recent contamination with an organism causing gastrointestinal symptoms. The proposed standard of 5 cfu/cm² would indicate significant recent contamination. However, it is possible that nursing staff might be aware of an enteric infection already, and cleaning and disinfection measures immediately implemented as part of infection control strategies. Therefore, although this standard could be applicable, its real-world use may be limited.

4.9.8.4 General microbiology counts

ACC would seem to offer the best indicator of bacterial contamination of surfaces, judging on the observations made. A wide range of species are likely to contribute to a positive test, which is a distinct advantage where the predominant species are not known. One of the standards used allowed twice as many bacteria to be present as the other, but when modified cleaning was used, the more stringent standard was still met on 89% of occasions. The more
A stringent standard is based on data on achievable cleaning results (Griffith 2005, Griffith et al., 2001). Which is the more appropriate standard for implementation depends on the objectives behind its introduction. If ensuring the best possible cleaning practice is the aim, then a standard of <2.5 cfu/cm² is more appropriate. However, if a reduction in risk to patients is required, then further work must be carried out in order to assess the contamination levels at which risk is heightened.

4.9.8.5 ATP bioluminescence

ATP bioluminescence is acknowledged as a good measure of cleaning effectiveness, and the speed with which results are returned means that problems can be swiftly rectified. Bacterial isolation requires at least 24 hours, so the chance of rectifying a problem swiftly is lost. The magnitude of the advantage of the rapidity of ATP testing will depend on the frequency and urgency of monitoring. If monitoring is carried out at spaced intervals, for example as a monthly audit, the speed of results is less important. However, for daily or time critical processes (for example, those described in Chapter 2), the speedy supply of data is essential. The ATP bioluminescence technology used here (and others available) is designed to be straightforward and easy to use, requiring no technical skills or knowledge. This method, therefore, would be suitable for non-technical staff to use and would not require the services of a microbiology department. Its use, in combination with microbiological testing could help to provide a more scientific approach to managing, validating and monitoring the effectiveness of hospital cleaning.

4.10 The value of surface sampling in hospitals

Routine environmental sampling of the hospital environment is not recommended by HCAI prevention guidelines, nor by NHS cleaning guidelines. Babb (2000) states that “a ward surface that is physically clean and dry is unlikely to represent an appreciable infection risk”; in the same book Ayliffe (2000) regards routine assessment of cleaning as rarely indicated. This study shows that surfaces can look clean and dry while still harbouring bacteria, and that routine sampling can identify such surfaces.

Existing cleaning methods used in hospitals have been shown to be ineffective, but also that they can be improved by some relatively simple changes. Often studies on the benefits of cleaning have equated more cleaning with better cleaning, but this can not be assumed. Cleaning programmes must be validated and monitored to ensure they are having the desired effect of contamination levels, and environmental sampling is therefore an essential
component of any concerted action to improve cleanliness. Cleaning needs to be cost effective, and give value for money. Money spent on poor or ineffective cleaning is money wasted. Money spent on sampling to ensure cleaning effectiveness may be recovered by improving value for money in better cleaning. In addition, given the expense incurred to hospitals by HCAIs, there are potentially significant monetary savings that could be made by any reduction in HCAI. Certainly, the money saved when increased cleaning, combined with environmental sampling, brought an MRSA outbreak to an end was four times greater than the cost of the extra cleaning (Rampling et al., 2001), purely in financial terms.

Further work is needed to try to determine if there is a link between surface hygiene and infection rates, but this needs to be based on validated and monitored improvements to cleaning and considered in relation to hand hygiene practices and patient / ward dynamics.
5 Use of notational analysis for assessing transfer and spread of bacteria in hospital wards

In Chapter 4, the effectiveness of cleaning at removing pathogens from hospital surfaces was examined. When pathogens persist on surfaces, a risk exists that they are transferred to other surfaces, staff and patients. This process is known as cross contamination.

5.1 Cross contamination in hospital wards

The transfer of bacteria from and to patients and surfaces has been recorded in several studies. Sexton and colleagues (2006) found evidence that strains of pathogens can be transferred from patients to their immediate environment, as MRSA was isolated from patients during routine screening that were very similar to those recovered from isolation rooms after the rooms had undergone terminal cleaning. A similar study, (Hardy et al., 2006) found that strains isolated from patients and their immediate environment were indistinguishable on 35% of occasions, and deduced that at least 3 of the 26 patients studied had become colonised with MRSA from the environment. McBryde and colleagues (2004) investigated cross contamination between healthcare workers after contact with MRSA colonised patients or their local environment. It was found that 17% of previously uncolonised healthcare workers became colonised with MRSA, and that transfer of organisms by hands was a significant factor. Duckro et al., (2005) found that 10.6% of sites that had previously been tested and found to be free of VRE became contaminated after a HCW worked touched them having previously touched a site contaminated with VRE. HCWs who are colonised with MRSA have been found to have contaminated home environments (Kniehl et al., 2005), indicating that contamination can be spread wider even than ward surfaces.

MRSA colonised patients do not all distribute MRSA to the environment at the same rate. People shed scales of skin at different rates, and those that release the scales at a higher rate are known as ‘heavy shedders’. If colonised with MRSA, such heavy shedders can contribute to contamination of the environment, to the extent that some NHS trusts raise the possibility of isolating MRSA colonised patients who suffer from eczema or psoriasis (Northamptonshire NHS Trust, 2005; Dumfries and Galloway NHS Trust, 2005). One outbreak was curtailed when a room was designated for the treatment of two MRSA colonised heavy shedding patients, removing them from the main ward (Boswell & Fox, 2006). The presence of a heavy shedder might explain the increased number of MRSA recovered from air samples during microbial sampling in a ward (Chapter 4) that could not be explained by a cleaning modification.
5.2 Bacteria on hands

The chance and rate of cross contamination is unlikely to be a fixed constant, but rather is affected by a multitude of factors. In order to better understand cross contamination in hospitals, it is necessary to address and evaluate these factors.

From Semmelweis’s 1846 recognition that infectious particles could be carried on hands, to the present day, there has been evidence to show that hands can carry and transfer pathogens (Whitby et al., 2007). The skin can not be considered as just another surface however, but could be considered as a selective growth medium (Lowbury, 1961), with a high salt concentration and few nutrients. Bacteria on the skin are usually divided into two groups, transient and resident (Kampf & Kramer, 2005). Resident species could be considered to be permanent, well adapted, members of the skin flora. As well as living on the skin surface, they can also be found subdermally, making them hard to remove through washing. Through competition, their ability to grow under these relatively demanding conditions may help to reduce the opportunity for pathogens to become established. Although some species are sometimes considered commensal because of their suppression of more harmful species, they can cause serious infection in immunocompromised individuals. Coagulase-negative staphylococci were the third most common causative organism in ICU-acquired infection, with *S. aureus* being the most common (Spencer, 1996). An analysis of bloodstream infections in the US found that 31% were caused by coagulase-negative staphylococci, greater than the 20% were caused by *S. aureus* (Wisplinghoff et al., 2004). Many coagulase negative staphylococci can exhibit multiple resistances to antibiotics, up to 64.3% of *S. epidermidis* showed oxacillin resistance in one study (Lee et al., 1994). Indeed, it has been suggested that the MecA gene that confers methicillin resistance to MRSA may have been recruited from the distantly related coagulase-negative *S. sciuri* (Wu et al., 2001).

Transient species are those that may be found on the skin, but can not exist there permanently. The low water availability selects against most Gram negative bacteria, and some pathogens are ‘killed by unsaturated fatty acids of the sebaceous secretions’ (Lowbury, 1961). Transient bacteria can include pathogens picked up from the hospital environment (Lowbury, 1961). Even though these bacteria will eventually be lost from the skin, the duration of their stay on hands can be long enough to allow transfer elsewhere. *S. aureus* and *Acinetobacter* have been shown to remain on hands in excess of two and a half hours (Ayliffe, 1988) and VRE for up to 60 minutes (Noskin et al., 1995). During this period, especially in a busy ward, multiple surfaces or patients could have been touched. Bacteria can be acquired from surfaces by touch (Bhalla et al., 2004), and also deposited on
to surfaces by touch (Harrison et al., 2003). This indicates that the transfer of microbes to distant surfaces by hands within a hospital, ward is possible

### 5.3 Bacterial survival and persistence on surfaces

While effective cleaning can reduce bacterial numbers on a surface to low levels, and monitoring ensure that this is achieved, surfaces will become recontaminated post-cleaning. Depending on the cleaning schedule, these microbes could remain on the surface for an extended period. Some bacteria, virus particles and fungal species can survive well on surfaces and their persistence could increase the chance of cross contamination. Many significant HCAI causing pathogens exhibit persistence from days to many months (Kramer et al., 2006) (Table 5.3.1). The persistence of MRSA on surfaces has been observed for as long as 7 months (Kramer et al., 2006). Clearly, this allows ample time for any transfer between the surface and hands or another surface to occur.

<table>
<thead>
<tr>
<th>Species</th>
<th>Range of reported persistence</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Acinetobacter</em> spp.</td>
<td>3 days to 5 months</td>
</tr>
<tr>
<td><em>C. difficile</em> (spores)</td>
<td>5 months</td>
</tr>
<tr>
<td><em>Escherichia coli</em></td>
<td>1.5 hours – 16 months</td>
</tr>
<tr>
<td><em>Enterococcus</em> spp. Inc. VRE</td>
<td>5 days</td>
</tr>
<tr>
<td><em>Haemophilus influenzae</em></td>
<td>12 days</td>
</tr>
<tr>
<td><em>Proteus vulgaris</em></td>
<td>1 – 2 days</td>
</tr>
<tr>
<td><em>Ps. aeruginosa</em></td>
<td>6 hours – 16 months</td>
</tr>
<tr>
<td><em>Serratia marcescens</em></td>
<td>3 days – 2 months</td>
</tr>
<tr>
<td><em>S. aureus</em> inc. MRSA</td>
<td>7 days – 7 months</td>
</tr>
<tr>
<td><em>Streptococcus pneumoniae</em></td>
<td>1 – 20 days</td>
</tr>
<tr>
<td><em>Streptococcus pyogenes</em></td>
<td>3 days – 6.5 months</td>
</tr>
</tbody>
</table>

Table 5.3.1 The reported persistence of several pathogens on surfaces (adapted from Kramer et al., 2006)

### 5.4 Transfer rates between hands and surfaces

The transfer of bacteria between hands and a surface is key for cross contamination to occur, but not all bacteria will be transferred by a touch action. The transfer rate between hands and surfaces has been examined by several authors. Rusin and colleagues (2002) examined the transfer of Gram-positive and negative bacteria from common hand-contact surfaces during activities such as turning on a tap or food preparation. For hard surfaces, bacteria were transferred at a rate of between 27.5% and 65.8%, and for porous surfaces below 0.01%. These figures are at odds with those reported in another study where the transfer rates of bacteria between hands and paper towel dispensers was measured (Harrison et al., 2003). For dispensers to hand, the rate was between 12.1 and 13.1%. From hand to
dispenser, the rate was lower with a maximum of 0.64%. Investigating transfer rates in food service, Chen and colleagues (2001) found transfer rates ranging from 0.05% to 100%. These studies used different methodologies, different tasks and different organisms, and indicated that transfer rates depend on a variety of factors. Although not specifically related to cross contamination in healthcare, the studies described above showed transfer of pathogens between hands to surfaces; there is little doubt touch actions that occur within a ward can widely distribute infectious agents in a zigzag manner. Even with the lowest recorded transfer rates, the number of bacteria on hands and surfaces, combined with the frequency of touches, means the potential for spread may be significant.

5.5 Handwashing to reduce the spread of bacteria

As discussed previously, Semmelweiss discovered that the organisms carrying puerperal fever were carried on the hands of medical students from cadavers to pregnant women. By instituting a hand disinfection policy, the mortality rate was significantly cut. Today, handwashing is still considered central to controlling HCAI (Pittet et al., 2006; Kampf & Kramer, 2004). It is an essential part of the preparation for surgery, and is required by medical staff before patient contact on the wards. Clean hands will transfer fewer bacteria on to a surface that is touched. The most obvious method to reduce the level of hand-mediated cross contamination is therefore effective cleaning of the hands. An effective handwash comprises several steps (Figure 5.5.1).
Figure 5.5.1 Graphical description of all the steps required for an effective hand wash (Health Protection Agency, 2005b)

Performed correctly, handwashing can be effective at reducing contamination on hands, with up to a log $3_{10}$ reduction of transient bacteria reported when using soap, although the minimum reduction observed was $0.5 \log_{10}$ reduction (Kampf & Kramer, 2004). The use of alcohol-based gel disinfectants is also now widespread, and can be more effective than soaps when used correctly (Kampf & Kramer, 2004) and was an important component of the approach that was effective in lowering HCAI in a Swiss hospital (Pittet et al., 2000). However, alcohol based gels are disinfectants rather than detergents, and may not act as effectively if hands and nails have high level of organic soil (Michaels et al., 2003). However, despite the well-known importance of handwashing and its inclusion in rules and practice guidelines, compliance rates have been shown to vary from 16% to 80% (Pittet, et al., 2000). A range of factors influences handwashing behaviour, including
knowledge and risk (Redmond & Griffith, 2003).

Some educational and promotional campaigns to promote hand hygiene did not have a prolonged effect in increasing compliance (Naikoba & Hayward, 2001), although Pittet and colleagues (2000) did find that an increase in handwashing compliance was associated with an improvement in HCAI rate, suggesting that cross contamination due to the carriage of infectious agents carried on hands is an important factor in HCAI.

5.6 Improved surface hygiene to reduce the spread of bacteria

Another potential method of reducing the frequency or quantity of bacterial cross contamination is through the reduction in the number of bacteria available to be picked up from potential contact sites. This circumvents the good persistence of some HCAI associated bacteria on surfaces. A low surface contamination level means that fewer bacteria are available to be picked up. However, as seen in Chapter 4, cleaning is rarely performed effectively. In addition, the data presented were taken shortly after cleaning had occurred, so that this could be a ‘best case’ scenario. As it stands, hospital cleaning may be entirely ineffective at preventing cross contamination, and the potential for contaminated cleaning cloths to transfer infectious particle means cleaning efforts may actually contribute to cross contamination.

The same cost pressures that may lead to potential understaffing and subsequent poor handwashing compliance may also adversely affect investment in infection control and cleaning. However, with the increasing financial accountability given to hospitals, and competitive pressure applied through government policy, along with a desire for lowered infection rates, there may be in future greater emphasis placed on spending money on infection control because it has been shown that this has a cost benefit in reducing in costs incurred in treating HCAI (Laupland et al., 2006). It may be that funding to improve hospital cleaning across the board is not forthcoming, and it may be advantageous to maximise the impact of cleaning environmental surfaces by targeting those surfaces that may pose the greatest risk for cross contamination.

5.7 Determining the ‘risk’ posed by surfaces

To determine which surfaces are the most important in cross contamination, two factors must be known. These are the likelihood of a surface being touched, and the potential severity of impact if it is. The severity of impact can be determined in terms of the number and type of bacteria on that surface. Likelihood and severity are the two components that make up risk, and must be considered together. An extremely high severity, with an
extremely low likelihood may be less of a risk that a moderate severity with a moderate likelihood. The severity of the consequences of a surface laden with Ebola virus being touched is potentially much greater than a surface harbouring a few cells of *S. epidermidis* being touched.

5.8 Determining the ‘severity’ posed by surfaces
Data about the number and type of pathogens present on surfaces can be gathered, as demonstrated in Chapter 3. By sampling surfaces and recording what was on them, some information on the severity of possible consequences of a touch action can be gathered. Factors such as the survival of the species on hands or surfaces and the minimum infective dose of a pathogen by any applicable infection routes must also be considered. Another aspect in determining the severity of consequence of a touch action is what happens subsequently. If a surface with low levels of *S. aureus* is touched, and immediately following that, a wound is touched, the severity of consequence is raised. However if a touch is likely to be followed by hand decontamination, the severity of consequence of that surface being touched is reduced. For example, touching the activation button or lever of an alcohol gel dispenser may transfer pathogens to the hand, but as touching this surface is usually a precursor to a decontamination activity that will reduce microbial load on the hand, the severity is lowered.

Determining the likelihood of a surface being touched is straightforward in principle; the more frequently a surface is touched, the more likely the transfer of pathogens between hand and surface. However, objective data on the frequency and patterns of touch actions in hospital wards has not been gathered previously.

5.9 Determining frequency of touches on a surface
Predictions of which surfaces are touched most frequently could be sought by questioning healthcare workers, patients and visitors. However, these would be neither objective nor accurate. Responses could be skewed by existing beliefs about ward hygiene, individual’s roles and responsibilities, and would almost certainly be shaped by recent experiences. Certainly, in areas of practice such as handwashing, beliefs about practice do not measure up to the actuality (O’Boyle *et al.*, 2001). However, the importance of collecting data on the frequency and sequence of touch actions has been recognised and employed in other studies (Clayton 2004; Harrison *et al.*, 2001). These studies have used notational analysis to gather quantitative data.
5.10 Notational analysis

Notational analysis is a technique that was first developed in the 1960s and is a widely used method of scientifically and objectively analysing actions in sport (Hughes & Franks, 1997). In essence, the tool is as simple as a method for breaking down complex patterns into constituent parts by recording actions using simple notation. By recording actions and outcomes, assessments could be made on strategy and tactics, in order to gain a competitive advantage. For example, the types of shots utilised by elite squash players and their effectiveness at winning points in order to assess the strategies employed at the highest level of the sport have been analysed (Hong et al., 1996). It was concluded that a pressure and attacking game was important, and identified the most productive strokes, so that these could be prioritised for training. Similarly, it could be used to identify patterns of play that led to the scoring of goals in football, thereby allowing coaches to work on either producing or defending such patterns.

5.11 Notational analysis in cross contamination studies for food safety

The principles of notational analysis have been applied to food safety studies, in order to assess the patterns of behaviour relating to hygiene (Harrison et al., 2001). Items (such as knives, containers and cupboard handles) within the kitchen were given code designations. Activity within the kitchen was watched and observed, and actions were recorded sequentially using the coded designations. The collected data could then be analysed to identify patterns of actions that led to cross contamination actions. An example would be a knife that had been used to cut raw chicken subsequently being used to prepare salad, without being decontaminated in between.

However, this method of analysis was applied to participants who were using a known and predetermined recipe, where the actions and likely preparation actions were predicted (Clayton, 2004). Knowing such factors simplifies both defining the notational code and recording actions. Examining patterns of behaviour in a hospital would be analogous to the examining food handlers in situations where their subsequent actions are not known, and where unspecified interactions with other food handlers or customers may occur. Clayton (2004) carried out such a notational study on the actions of food handlers in eight nursing homes and restaurants, and found it to be a good instrument for recording and assessing actions that could prevent cross contamination. It was concluded that notational analysis demonstrated an improvement over approaches that did not allow sequential recording of actions that may have lead to cross contamination, and provided a more accurate tool for assessing the potential cross contamination in catering businesses.
5.12 Notational analysis in hospitals

The notational analysis approach could therefore be successfully applied to hospital wards although it has not been carried out previously. While numbers of bacteria on surfaces can be estimated, the actions that lead to bacteria being transferred to patients or other surfaces are not identified. By identifying types and patterns of actions that lead to cross contamination, efforts to prevent them can be closely targeted. In addition, this would indicate which surfaces were most frequently involved in such patterns, so that decontamination efforts could be focussed on the most important surfaces. Such an approach, used in conjunction with information on bacterial load begins to introduce risk-management into the area of HCAI.

5.13 Aims

This study therefore, aims to employ notational analysis to elucidate possible cross contamination routes within hospitals. The following objectives were identified in order to achieve this aim:

To identify which surfaces are most commonly touched by groups using the ward, and to evaluate their relative importance in cross contamination.
To identify any regular patterns of touch actions.
To make recommendations about medical practice based on the observations.
To assess the applicability of notational analysis for use in hospitals, and make recommendations for any future work.

5.14 Methods

5.14.1 Study design considerations

A provisional protocol for observation was drawn up based on previous experience of working in hospital wards and discussion with researchers who had used notational analysis in other settings. Although kitchens have a wide variety of surfaces (to the extent that a redesignation of codes after the completion of a pilot was study was required by Clayton (2004)), hospitals wards have an even greater number of different objects and surfaces to consider. Furthermore, for ethical and reasons of patient privacy not all activities can be observed in a ward. This especially applies to doctors’ examinations of patients on wards; such events are often short and at irregular intervals. In addition, the medical personnel may object to being watched and having their actions recorded. Therefore, it would be important for the work to gain acceptance amongst staff on a professional, but also on a personal level. In addition, the question of observer bias and the effect of observation affecting behaviour (known as the Hawthorne effect (Clayton, 2004) ) needed to be addressed and
acknowledged.

5.14.2 Pilot study

A pilot study was arranged with a Welsh 500-bed general hospital. A coding system based on previous experience in hospital wards was drawn up and memorised. Recording sheets, based on previous studies were created (Table 5.14.2.1).

<table>
<thead>
<tr>
<th>Object</th>
<th>Control</th>
<th>Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>Control</td>
<td>Problems</td>
</tr>
<tr>
<td>Sequence 1</td>
<td>Sequence 2</td>
<td>Notes</td>
</tr>
<tr>
<td>11:00</td>
<td>H</td>
<td>P</td>
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<td>H</td>
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<td>WSH</td>
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Table 5.14.2.1 Sample from recording sheet used in notational analysis pilot study showing data and table structure. Touch actions are recorded in the ‘Sequence column’, actions such as hand or surface cleaning are recorded in ‘Control’ column. Key: H – Hands; P – Patient; BF – Bedframe; N- Nurse; BST – Bedside table; WSH – Hand wash

The purpose of the study was discussed with the ward sister and staff nurses to assure them that data would not be attributable to any individual and was not an assessment of professional competence. The pilot study did not have a single defined methodology, but instead a variety of approaches were tried for approximately half an hour each.

a) Watching an individual surface, and recording what touched it
b) Watching an individual for a defined time period and recording what was touched
c) Watching an individual for a defined number of actions and recording what was touched
d) Taking a position in the ward and attempting to watch and record every action.

Of these, (a) was discarded because touch actions were too infrequent and (d) proved too difficult achieve effectively. However, (b) and (c) were achievable, but defining specific length of time or number of actions was problematic as the person watched could leave the ward or otherwise become unobservable.

5.14.3 Study design

It was decided that a minimum of 10 actions by the observed had to be recorded for those observation to be valid. This figure was based upon data that showed that bacteria could be transferred from a touched surface for up to 7 surfaces (Barker et al., 2004), with an additional 3 surfaces to add some leeway in measurement to ensure better representative data.
The pilot study identified that the recording sheets initially created (Table 5.14.2.1) were too complicated to use on the hospital ward. These were simplified into a format that gave a From – To structure (Table 5.14.3.1). Control actions would be recorded in this table.

<table>
<thead>
<tr>
<th>Patient</th>
</tr>
</thead>
<tbody>
<tr>
<td>hands</td>
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<td>hands</td>
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<td>hands</td>
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</tbody>
</table>

Table 5.14.3.1 Example of sequential touch actions, recorded in the format used in full notational analysis study. Key: ptdh – patient’s toilet door handle; ptsh – patient’s toilet sink handle; ns – nurse’s station; bs – bedside.

Many more surfaces were touched during the pilot than codes could be easily remembered, and there was no way of ensuring that an enlarged coding system would encompass all actions and surfaces when the full study began. In addition, the convention used in previous studies of identifying individual surfaces (bedside table 1, bedside table 2, bedside table 3 and bedside table 4, for example) would not be practical given the number of surfaces. For example, there were some 28 bedside tables within the ward. It was decided that codification would only be used for common actions and frequently touched surfaces, and others would be written in full. Different instances of the same surfaces would be grouped together.

Simultaneous observation of the same sequence was planned (Clayton, 2004), so that results could be compared to ensure that recording was accurately carried out. However, this was felt by hospital staff to be too intrusive and could be perceived as too judgemental. All data collected during the trial period was discarded.

Initially, the staff response to the proposed study was not negative, but it was discovered that in order to comply with the hospital’s research policy, and to ensure that the study
obtained the support of the hospital management, the study had to be discussed with the nursing directorate and the consultant for the ward in question. This discussion focussed on the acceptability of the study to staff and patients in terms of intrusion into routine practice and the length of the study. In addition, the proposal was required to go through the formal research procedure and gain approval from the hospital trust. This was duly achieved and a temporary honorary contract was awarded (Appendix 4) to the observer to carry out the agreed research programme, which helped to gain the acceptance of the study from the ward staff.

Following the definition of the study through the hospital research process, the nature and purpose of the audit was again discussed and explained to the ward sister and senior nurses in order to allay fears that their professionalism was being assessed or called into question, and that any data collected could not be personally identified. Any questions from nurses or patients were answered fully, and any objections from patients to being observed led to discontinued observation of that patient. Requests to view observations recorded were accepted.

**5.14.4 Study schedule**

Observation was carried out over a four week period, three days a week and for between 1.5 and 2 hours a day. The observation covered the period from 7am to 9pm (Figure 5.14.4.1) in a general surgery ward of a 500-bed general hospital. In order to reduce the Hawthorne effect, no observations were recorded in the first 10 minutes, and efforts were made to put the staff at ease through personal interaction.

<table>
<thead>
<tr>
<th>Schedule for observational audit.</th>
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<tbody>
<tr>
<td><strong>Monday</strong></td>
</tr>
<tr>
<td>Week 1 7am - 8.30am</td>
</tr>
<tr>
<td>Week 2</td>
</tr>
<tr>
<td>Week 3 2pm - 3.30pm</td>
</tr>
<tr>
<td>Week 4 5.30pm - 7pm</td>
</tr>
</tbody>
</table>

Figure 5.14.4.1 Study schedule, showing the days and times that observational analysis was planned to occur. Shaded areas indicate non-observation periods.
5.14.5 Study implementation

An unobtrusive position in the ward was taken up by the observer and an individual person was selected for observation. Where observation was difficult from this position, a closer position was taken up, with care taken to avoid interference in the activity in progress. Choice of individual for observation was dictated by opportunity. Efforts were made to ensure that the four groups (doctors, nurses, patients and visitors) received observation proportional to the time spent on the ward.

Actions were sequentially recorded in the form ‘From – To’ in a simple grid (Figure 5.14.3.1). Where less than 10 sequential observations were recorded for an individual, that observation sequence was discarded. Observations were ceased at a ‘natural’ point, for example on leaving the ward, examining a patient behind screens, lunch breaks, or in the case of patients, falling asleep. Because of the number of possible surfaces, a true notation, where each surface is designated a code, was not possible as the complete code would be too difficult to recall during observation. However, frequently touched surfaces (determined during pilot study and previous time on wards) were given codes, for example H for hands, N for notes, BS for bedside, PTSH for patient’s toilet sink handle, BP for blood pressure and P for patient.

5.14.6 Digitisation of collected observations

On completion of a period of observation, the data were transferred from paper grids into Microsoft Excel. Codified observations were returned to plain text in order to aid clarity. The data were then normalised to ensure that observations from different days could be compared. Normalisation involved checking the collected data to ensure consistency with data collected previously. For example, that ‘bedframe’ was recorded, rather than ‘bed frame’. This was important as the volume of data collected meant that some analysis would have to be carried out by computer, and differences such as the above could adversely affect the accuracy of these calculations.

5.14.7 Analysis of observations

Once the observation schedule had been completed, the frequency of each touch action was calculated in Excel. Some consolidation of data was required for analysis as Excel sheets are limited in size to 255 columns. For example, actions involving newspapers and magazines were combined to newspapers alone. In order to assess the patterns as well as the frequencies of touch actions, a Visual Basic for Applications programme was written in MS Excel (Appendix 5). The programme assessed how frequently after touching a specific
surface, other surfaces was touched, within 3 subsequent touch actions. For example, using the sample data (Figure 5.14.3.1), after each ptdh (patient toilet door handle) touch, the surfaces touched within 3 subsequent are lock (twice), flush, patient toilet sink handle, nurses station surface and bedside table.

5.15 Results

In total, 2573 touch actions were recorded. For actions carried out by nursing staff 1489 actions recorded, by doctors 185, by patients 519 and by visitors 380 (these numbers include object to object touches recorded while observing the above group. Such touches are described separately below).

5.15.1 Nurses

Hand – object touches 1185

The most common touch action for nurses was the handling of notes (174 instances), most commonly the notes at the foot of the patient’s bed and often in conjunction with dispensing of drugs or taking blood pressure readings. Blood pressure cuffs (61 instances) and trolley (51) were also frequently touched, as part of the routine ward rounds and admission of new patients. Sites around the patient’s bedside (excluding notes, drug administration and patient’s personal effects) accounted for 17% of all nurse hand touch actions, with the bedside table being the most frequent of these (45 times).

Patients were touched on 76 occasions, gel use was observed on 32 occasions, effective handwashing on 9 occasions and ineffective handwashing on 10 occasions. It must be remembered that due to patient privacy, observations were not made when the curtains were drawn across the bed bay – during these times it is likely that patient touch actions and use of gel may have occurred, as well as further touch actions.

5.15.2 Doctors

Hand - object touches 159

Doctors hand touch actions were more often focussed around the nurse station area where computers and patient’s medical records resided. The most commonly touched items by doctors when on the ward were patient notes/medical record (53 instances) and the notes trolley (17). Pager/phones were touched on 8 occasions. Similar to nurses, hand touches by doctors were common around the patient’s bedside (21 in total). Nine patient touches were recorded, although in some instances these were due to the patient shaking the doctors hand. Again, observation was sometimes prevented by screening a bay off with curtains.
5.15.3 Patients
Hand object actions 461
The focus of patient touch actions was the bed itself (Bedclothes 44 touches, bedframe/bed rails 38 touches) and the furniture around the bed (bedside table 45 touches, bedside chair 22 touches). Patients were often observed touching wound dressing or the wound itself (22 occasions), or inserted medical devices.

5.15.4 Visitors
Hand object touches 350
Visitors recorded frequent patient touches (39 instances) and sometimes touched the patient’s dressings or wound (5 occasions). The bulk of visitor hand actions were around the bedside area (198 touches).

5.15.5 Object – Object touches
In total, 418 object to object touches were recorded. Some of the most frequent object to object touch actions were those where an object was applied to a patient. These include blood pressure cuff (15), ear thermometer (19) and oxygen saturation/pulse device (14). Placing these items into their holder or on their trolleys was also relatively frequent. Placing patient notes on objects around the patient’s bedside was commonly observed, with the bedside folder (30) and bedclothes (22) being the most frequent locations. The movement of notes accounted for 89 observations in total.

5.15.6 Patterns of touch actions – within 3 previous touches prior to patient contact
The most frequently touched area by all groups prior to patient contact were the bedclothes (25 touches), followed by patient notes (24 instances). Bedside furniture, such as chairs (18 touches) and tables (16 touches) were also common. Blood pressure cuffs and trolleys were often touched prior to patients (21 and 7 touches respectively). Gel was used within 3 touch actions of patient contact on 8 occasions, and a hand wash was performed twice.

Following patient contact, a similar range of surfaces were touched with 3 touch actions. Bedside tables (12) and chairs (29) were frequently touched, as were bedframes (13) and bedclothes (20). Notes (21), the note trolley (10) were also touched after patient contact.

Frequent sequences were often found where things were located in close proximity to each other; for example, actions in the nurses station were often within 3 actions of another action.
within the nurses’ station area. This pattern was also seen with actions that occurred close to the patient’s bedside area. Other sequences reflected typical ward activities, examining notes and handling drugs for example.

5.16 Discussion

By examining the type and patterns of touch actions within a hospital ward, and recording them in an objective codified form known as notational analysis, it is possible to assess actions and patterns of actions that contribute to cross contamination and movement of bacteria around a hospital ward.

5.16.1 Main area of activity – the bedside area

The main focus of activity for all four groups of ward users was the area immediately around the patient bed. This is not surprising, as the patient is at the centre of attention, is the main focus of the medical staff and visitor’s activity, and is the area closest to the patient. Due to the levels of contamination that have been demonstrated on these surfaces, their proximity to the patient, their frequency of contact and their use as a resting place for other objects makes them an important fomite. Indeed, the area could be considered as a ‘crossroads’ or hub in zigzag cross contamination models (Block, 1991), as a place where any of the groups observed could potentially pick up microbes from any of the other groups. Visitors and patients could deposit pathogens picked up from outside of the hospital, including CA-MRSA and medical staff could transfer species from other wards, including other specialisations.

5.16.2 Zigzag cross contamination and hand decontamination

Touching surfaces in this area can circumvent hand hygiene procedures. If hands are decontaminated effectively, but pathogens are picked up from the bedside area prior to patient contact, then cross contamination can occur. Post-decontamination, pre-patient contact touches in this area seemed to be inevitable, and previous studies (Chapter 4; Cooper et al., 2007) have found pathogenic bacteria in these areas. Acinetobacter (Wang et al., 2003) and VRE (Mayer et al., 2003) have been found on bedside table and on bed rails. Even bedside curtains have been found to be contaminated with MRSA (Palmer, 1999). The risk posed by a surface for cross contamination is defined by the likelihood of it being touched, and the severity of consequence if it is. This study has shown that the likelihood of surfaces in the patient’s environment being touched is high. The severity, indicated by the number and type of bacteria, could be relatively high for surfaces in the patient’s
environment, as seen in other studies. Combining these two factors suggests that patient environmental surfaces pose a heightened risk for cross contamination. The two elements that serve to minimise cross contamination risk are not fully effective for these surfaces – cleaning through poor implementation, and hand decontamination through recontamination when touching bedside surfaces. It is therefore recommended that more attention is given to cleaning in these areas, perhaps using the cleaning protocol described in Chapter 4. Following the study described in Chapter 4, an improved routine cleaning system was implemented into routine cleaning at a hospital in England, (Lewis et al., 2008). Environmental sampling showed that improvements in surface hygiene, similar to those found in Chapter 4, were achievable outside of the confines of academic study.

5.16.3 Bedclothes
Although bedclothes have a low level of contamination after cleaning (Bureau-chalot et al., 2004), their contact with the patient’s skin combined with regular touches by other people on the ward and objects means that they may readily acquire bacteria. Contamination of domestic bed linen by MRSA colonised HCW was been demonstrated (Kniehl et al., 2005), suggesting that hospital bed linen maybe similarly at risk. Although numbers of bacteria may be low, because contact will be prolonged and over large areas of patient’s skin, the potential for transfer is increased. Additionally, bedclothes will be in contact with IV and drain tubing as well as dressings. These items are inherently close to where the integrity of the skin is compromised, and consequently more vulnerable to infection. A simple solution to this could be more frequent changes of bedding, but this would require significant increases in financial resources and nursing time to wash and to change the bedding. In the case of morbid patients, who may be at more risk from infection, more frequent bedding changes maybe difficult to achieve, and the disturbance to the patient could have clinical implications.

5.16.4 Blood pressure cuffs, ear thermometers and oxygen saturation equipment
One of the most commonly observed activities on the ward was the routine taking of blood pressure, temperature and blood oxygen saturation level. The trolley carrying this equipment was moved from patient to patient. The blood pressure cuff, typically made from neoprene or nylon, was a reused item. It directly contacted the skin of a patient allowing bacterial transfer, especially during the period where pressure is applied. The cuff then was applied to successive patients, presenting an obvious avenue for cross contamination. Blood pressure cuffs have been previously implicated in HCAI (Layton, et al., 1993) and one more
recent study found high bacterial levels on pressure cuffs (Walker et al., 2006), including pathogenic species. The oxygen saturation measuring device is placed directly on to a patient’s finger, and thus could be a vector for cross contamination in the same manner as the blood pressure cuff. Under the Spaulding classification, these items are rated as non-critical, requiring solely cleaning with detergent. However, their cleaning or disinfection was not part of the routine cleaning schedule for the domestic staff, meaning that it is the responsibility of the nursing staff. Discussions with nurses found that no specific responsibility or rota was set, similar to the finding of Walker et al., (2006). The allocation of specific cleaning responsibilities to nursing staff was found to be helpful in ending an outbreak of MRSA (Rampling et al., 2001), and would ensure that these items are not neglected.

5.16.5 Disposable equipment to reduce cross contamination

Unlike the blood pressure cuff and oxygen saturation device, the ear thermometer included a disposable tip that was replaced with fresh tip between patients, while the old tip was discarded. The tip replacement was performed without fail, eliminating the chance of cross contamination between patients with this device. As the hygiene issues have evidently been considered and acted upon in this similar context, it seems strange that they have not been addressed for the blood pressure cuff, especially as a role in HCAI has been previously demonstrated. The use of absorbent cloth fabrics to cover the cuff means that cleaning (if performed at all) is rendered less effective. Using non-porous materials and implementing a cleaning rota or responsibilities for the item would lead to significant reduction in the bacterial load, and consequently decreased risk of cross contamination between patients. Disposable cuffs have been presented as a means to prevent cross contamination previously (Dodd et al., 1990; Alpert & Cohen, 1996), but were not in use at the hospital examined. While these would remove the cross contamination risk if used properly, it is likely that financial constraints would prevent implementation. However, they could be used for high-risk patients (Alpert & Cohen, 1996), for example those colonised with MRSA, in order to reduce the possibility of cross contamination.

5.16.6 Patient notes

One study reported that in surgical wards 24.7% of patient notes were contaminated with pathogenic bacteria (1.1% with MRSA), and 85.2% in intensive care units (6.8% with MRSA) (Panhotra et al., 2005), and isolates often had the same pattern of antibiotic resistance as those isolated from respective patients. This suggests that these bedside notes (which are unlikely to have begun life precontaminated with bacteria) may well have been
contaminated by hand, or perhaps through being placed on contaminated surfaces. Dealing with notes and medical records was one of the most frequent activities undertaken by nurses and doctors, and was often followed by patient contact, whether to administer drugs, take readings or to perform examinations. Therefore, handling notes before patient contact could pose cross contamination risks and circumvent hand decontamination. The above study recommended good hand hygiene procedures after handling notes. However, examining notes, performing hand decontamination and then examining the patient may pose difficulties, not least the problems of referring to notes during the procedure.

The problem with paper-based notes is somewhat intractable, but moves towards electronic notes may hold advantages. According to a consultant microbiologist at the University College London Hospitals NHS Trust, there will be a move towards electronic patient records available at the patient bedside (BBC, 2006). While this would remove the cross contamination potential of notes, care must be taken to ensure that computer mice and keyboards do not replace them as focal points for cross contamination, especially as existing keyboards have been found to harbour pathogens (Simmons, 2006; Rutala et al., 2006).

5.16.7 Contributions of visitors to the spread of bacteria
Visitors were seen touching the wound or dressing of the patient, presumably out of curiosity or concern for the patient. As visitors did not have a medical reason for these actions and often did not decontaminate their hands, this represents an unnecessary cross contamination risk. In general, visitors did not seem to be aware or concerned about the possible cross contamination risks that they present. For example, despite being banned from the wards, mobile phones were observed being passed from visitor to patient. Visitors also placed items on bedside furniture or bedclothes, or giving the patient small children to hold. Other studies have found that compliance with infection control procedures was low (Afif et al., 2002). Although some notices asking visitors to decontaminate their hands on entering and leaving the ward were displayed, no further advice was given on safe conduct within the ward. However, in one instance, a nurse asked a visitor to refrain from sitting on the patient’s bed for reasons of hygiene. This intervention was undermined subsequently, when a doctor doing her rounds sat on the bed when talking to the same patient. It is therefore recommended that greater efforts are made to alert visitors to their own responsibilities in reducing cross contamination in the interests of the patient, through intervention by both visual display and by ward staff. This may also have the effect of making medical staff more aware of their responsibilities towards in infection control.
5.16.8 Hand decontamination compliance
The prevalence of handwashing before patient contact was low. Hand decontaminations were observed on 43 occasions (effective, ineffective and gel use) compared to 85 patient touches by medical staff, about 50%. Only on 17 occasions did hand decontamination occur in the 5 previous actions of patient contact, so that the opportunity exists for decontaminated hands to become recontaminated following the decontamination. This represents a 20% compliance rate, at the lower end of the ranges seen in other studies (Kramer & Kampf, 2004).

5.16.9 Limitations of the study
Due to the requirement to protect patient privacy, actions that occurred where the bed was screened off behind a curtain could not be observed. These sequences are likely to represent significant patient contact, including examinations and use of medical devices. Therefore important data, potentially containing critical patterns leading to cross contamination cannot be observed. The low compliance rate could suggest that the Hawthorne effect, where behaviour is modified under observation, did not affect the results to a large extent, as an increase in handwashing compliance might otherwise have been expected. However, gel use before patient contact could have occurred behind the screens and would not have been observed by this study.

5.16.10 Use of notational analysis in hospitals
This study describes what is believed to be the first use of notational analysis in a hospital. It proved to be a useful tool for objectively analysing possible routes of cross contamination in the ward, but it was not without drawbacks. Compared to previous sport and food hygiene studies, the hospital ward is a uncontrolled environment. Action sequences do not occur in a defined area, such as a squash court or a kitchen, but can range over several locales, or even off the ward entirely. This was especially the case with doctors, who would frequently come on to a ward, visit a patient and leave again. This makes viewing the actions occasionally difficult. In other situations, video cameras have been used to record footage that can be analysed frame by frame at a later date. This would represent an excellent solution for notational analysis on hospital wards, but is unlikely to be practical. With the exception of neonatal wards (where cameras may be fitted for security reasons), closed circuit television cameras are not fitted, making the process expensive. Several cameras would be needed to film all action, and dovetailing action between them could be problematic. In addition, there could be problems in gaining acceptance from staff on the ward. If cameras are being used with the express purpose of
filming their actions in order to produce information that might have impact on HCAI, the staff would be unlikely to accept their presence. For this study, several levels of hospital staff and bureaucracy had to be negotiated, from the Nursing Directorate to nursing staff, and initial plans were scaled back due to concerns over staff acceptance.

However, it may be possible that such a project could be implemented by the hospital, with the finance to install cameras, several staff to record actions from the video footage and through management enthusiasm, have a greater acceptance of the study by staff on the wards. Even so, using cameras to record actions that occurred while patients were screened off would problematic. Either actions behind the screen would have to excluded, or patient consent would have to be forthcoming. In addition, the expense of individual camera for each bed and the extra data analysis could prove prohibitive.

Nevertheless, notational analysis has a place in risk management for hospital wards. The data collected, although imperfect in terms of what could be observed and possible psychological effects, represents an objective view of the interactions behind those who use the ward, between objects and surfaces between the ward, and also between those two groups. The need for objectivity is paramount, in order to help sate the needs of evidence-based practise. The data collected can be used in various ways, for example to identify cross contamination risks or to identify areas that could be prioritised for cleaning. The data could also be used for modelling cross contamination around the ward.
6 The use of event trees for examining the spread and transfer of bacteria in hospital wards.

In Chapter 5, the patterns of touch actions around a ward were examined. Such touch actions are a central element in models of the spread and transfer of bacteria (Pittet et al., 2006; Block, 1991), as they inform on the probability of various actions and patterns occurring. The data gathered in Chapter 5 can therefore be used to insert numbers within the conceptual models, and could be combined with data on surface contamination such as that gathered in Chapter 4, to create tools that could be used to predict the spread of bacteria. Knowledge of the spread of bacteria could inform on exposure routes by which bacteria are transferred to patient. In turn, this information could be used in risk assessment.

Models of disease transmission and epidemiology are not new. The origins of geographical epidemiology can be traced back to John Snow who used data on the location of cholera deaths in 1854 to locate the fomite of infection to a single water pump on Broad Street (Newsom, 2006). Epidemiology to assess the spread of infectious disease using a more mathematical approach was accomplished by Ross in 1911, who determined “a threshold value for the density of the mosquito vectors, below which the transmission of malaria could not be maintained” (Matthews & Woolhouse, 2005). The findings of this study were distilled into a form where the threshold value was defined as the basic reproduction ratio, or $R_0$. In situations where $R_0$ was greater than 1, new infections were predicted to increase, and where it was less than one, the number of new infections was predicted to shrink (Matthews & Woolhouse, 2005). The theories underlying this modelling approach are the basis for many infection control strategies and principles, such as vaccination procedures, outbreak control and herd-immunity. Such models work on a deterministic basis; using mathematical formulae to reproduce the effects seen. They could also be used to assess the spread of bacteria in a hospital ward and could provide data for use in risk assessments. One aspect of risk assessment is the determination of the exposure routes, which describe the pathways by which pathogens might arrive at the patient.

6.1 Deterministic modelling in the hospital ward

An example of a deterministic model for modelling the movement of pathogens around the ward was created by Sebille and colleagues (1997). Here, 13 factors were identified that could be involved in the spread of pathogens, including the proportions of patients colonised by antibiotic sensitive or resistant strains of a bacteria and the mean annual number of staff
colonised by a patient (and visa versa). These factors were combined in a computerised model. The values for each factor were fixed each time the model was run, and varied to other defined values for other runs to investigate various scenarios. This report produced a number of interesting findings, for example that increased handwashing would attenuate the outbreak but would not stop it.

Lipstitch and colleagues (2000) used mathematical models to investigate the epidemiology of antibiotic resistance in hospitals, deriving a series of differential equations based on the numbers of uncolonised patients, patients colonised with antibiotic sensitive strains and patients colonised with antibiotic resistant strains, together with the effectiveness of two drug treatments. By assessing the change in each of the populations over time, the effects of different interventions were assessed. The model was used to predict that a decrease in within-hospital transmission would reduce the prevalence of resistant bacteria, and would do so relatively rapidly.

6.2 Drawbacks of deterministic modelling

While deterministic models have been widely utilised, they are not without criticism for ward settings. Outbreaks and the spread of disease are often fundamentally altered by single significant effects that can impact on the overall results. In very large populations, the effects of chance can be minimised or adsorbed in the average, but in hospital wards where the population is smaller, chance effects will play a larger part in determining outcomes (Cooper et al., 1999). For example, the presence of so-called ‘shedders’, (individuals who release a significantly higher level of bacteria into the environment) can have an influence on the contamination in a ward (Boswell & Fox, 2006) but the random nature of such factors can not be taken into account in a deterministic model such as that created by Sebille and colleagues (1997). Although a factor such as ‘mean number of shedders’ can be incorporated into a deterministic model, the figure is an absolute for each iteration of the model, and will produce a single theoretically perfect, but realistically incorrect, result.

One difficulty in deterministic modelling is deciding what values to use for variables. Although a range of values for some variables can be collected, for example the mean, minimum and maximum values, problems arise where multiple factors are used in the model. Representing all factors by the minimum or maximum value found could lead to significant under or over estimations in results, and thus a misleading interpretation of the risk. For example, if standards are based upon a model where several factors in a model were set at their minimum recorded values, then actual implementation of the standard would be extremely difficult to achieve, to the point where the value of the standards would
be undermined. On the other hand, if they are set at maximum values, it would represent a situation that would only occur extremely infrequent, if ever, in practice. Using only mean values could miss nuances in the distribution of factors within the model.

6.3 Stochastic modelling

Where chance factors are important in spread, such as the presence of shedders, or ‘super-spreaders’ in the case of dissemination of the SARS virus (Matthews & Woolhouse, 2005), or where numerous factors are involved, models may more accurately simulate their target by using stochastic modelling. The stochastic approach has been considered more appropriate for hospital wards because the low number of staff and patients mean that stochastic effects are more important (Austin et al., 1999). Stochastic modelling is not a new technique, but being more complex and involved, it has been boosted by cheap computing power and also by the further development of statistical methodology (Matthew & Woolhouse, 2005). Pelupessy and colleagues (2002) used a stochastic model to assess the importance of different colonisation routes within a hospital ward. Using distributions, (rather than absolute values) for factors such as colonisation levels, discharge rates and cross and endogenous contamination, this study included graphs and contour plots that supported, amongst other things, the separation of colonised patients to reduce spread. In addition, an interesting finding was that the $R_0$ value for the model was below a value previously discovered, indicating that over time that the organisms tested would not persist solely by person to person transmission and that additional patients, already colonised, would need to be admitted to maintain presence of the pathogen. This would suggest that pre-admission screening, isolation, or clearing their colonisation, would result in a decreased prevalence of the pathogen in the ward.

6.4 Stochastic modelling and cross contamination

The divide between deterministic and stochastic modelling is as relevant for models of the spread of bacteria in the hospital environment as for the epidemiology of SARS. Many factors are involved in the spread of bacteria around hospital wards, including the number of bacteria on a surface, the frequency that a surface is touched, the transfer rate of bacteria to hand from surfaces and what is touched subsequently. While all of these factors can be computed and determined in terms of descriptive statistics, for any individual occasion examined, the actual situation will be different from the descriptive statistics. The value of a stochastic approach in these situations is that the ‘outlier’ events are not lost, while ‘average’ results are retained. For example, a surface may have a low number of bacteria on the vast majority of occasions and any touch actions followed by hand decontamination.
Occasionally, it may be highly contaminated, and occasionally the following touch action could be to a much more frequently touched object. This newly-contaminated object could then contribute extensively to cross contamination. The impact on the spread of pathogens of the first surface could be lost in a deterministic model. Such chance events may play an important role in the transfer of bacteria to susceptible individuals, as super-spreaders did for SARS (Matthews & Woolhouse, 2005). As many unknown factors contribute to the outcome of such a model, a Monte Carlo simulation could be used.

6.5 Monte Carlo simulation

Despite the name, Monte Carlo simulation was not developed as a tool for modelling gambling. Instead, the first practical use was for investigating the random collisions of neutrons within fissionable material (Metropolis, 1987). In this scenario, a neutron would be given a random velocity and position. Such variables would vary from neutron to neutron in a real situation, so could be considered as ‘unknown’ when examining a single neutron. The next decision is where the first collision occurs, and the nature of that collision. As nuclear fission relies on the splitting of atomic nuclei by neutrons, more neutrons may emerge from the split nucleus, and their paths would be modelled in the same way. This simulation can be run as many times in order to simulate outcomes for many starting neutrons. In this way, the process of nuclear fusion can be modelled without having to resort to rather expensive and dangerous practical testing.

A feature of this technique is that rather than just take random numbers, the random numbers can be taken from a distribution. For example, if the velocities of the neutron with the fissionable material are known to follow a normal distribution with known mean and standard deviation, then the randomly selected numbers would be representative of their likelihood as defined by the distribution. Running the model many times gives a picture of all possible outcomes including where unusual inputs occur. This allows complex probabilities to be stored and generated easily, and this approach becomes exponentially more important as the number of factors (each with their own distribution) included within the model is increased. In this way, rather than using an average to represent the number of bacteria on a surface in a cross contamination study, a distribution based on gathered data could be used. Each time the model is run, a figure is sampled from within the relevant defined distributions. By running the model many times, so that figures from the ‘tails’ of a distribution are included as well as the ‘body’, a full picture of the extent of the possibilities can be gathered, including the instances where two unlikely events coincide.
Although Monte Carlo sampling overcomes the problem of ‘unknown’ values for hospital environmental surfaces and other factors, alone it does not constitute a model. There needs to be a connection between surfaces, and this could be represented by the recorded touch actions of hospital staff, patients and visitors. By using their touch actions as a basis to determine the frequency and patterns of links between surfaces, and using stochastic sampling for the contamination of those surfaces, a model for cross contamination can be begin to be developed, and run as a Monte Carlo type simulation.

6.6 Event trees

While notational analysis produces a great deal of information and data about touch actions, and patterns, drawing the disparate threads of actions together into organised and intelligible format is difficult. One approach that has been used was to translate the collected data into an event tree (Harrison et al., 2001), also known as a decision tree. Event trees are multichotomous branching pathways, where each branch represents an event from which one option or another is chosen (Figure 6.6.1). This simple event tree concerns the probabilities of a purchaser choosing a particular floor covering material based on previous significant events. The figures within this example model are not based on observed values.

The circle ‘junctions’ in figure 6.6.1 are called ‘nodes’, and the probabilities obtained from techniques such observational analysis can be assigned to the paths leading from the nodes. This model gives example probabilities that a buyer chooses any particular floor covering, and the decisions that must be made to arrive at any of the possibilities. For example, the chance of choosing a carpet is 75%, compared to the 25% chance of a wood-type covering. The model allows that where an identical decision is to be taken under different circumstances, the results of previous decisions can affect the probability of the decision in question. In the model, the likelihood of the purchaser buying a stain guard product for their carpet changes depending on whether a synthetic or wool carpet has been chosen. This sort of data is analogous to that which was collected by notational analysis in Chapter 5, where the probabilities of individual actions and patterns of behaviour were collected.

In addition, figure 6.6.1 has figures attached to some decisions, so that the financial implications of each choice can be monitored. These can also be combined with possibilities so that an overall average expenditure can be gathered. For example, the chance of a light coloured wool carpet without stain guard being selected is 3%, and would cost £100 pounds. The average cost at each node is also displayed, based upon price and chance. If carpet is chosen, the price at the ‘material’ node shows that on average the cost outcome of this path is £60.86. The average cost regardless of any event is £66.65.
Figure 6.6.1 Example event tree model showing the decisions and associated probabilities involved in choosing a particular type of floor covering, and associated costs. No figures within this example model are derived from actual observation.

In this model, the figures applied are absolutes, but in reality a variety of prices for floor coverings are available. They could vary with geographical location of seller, quality and discounts, amongst many other factors. It is here that Monte Carlo simulation can be applied to stochastic sampling event trees, by applying appropriate distributions rather than absolute values. If a survey of prices paid found that laminate flooring followed a normal distribution with a mean of £50, with a standard deviation of £5, with a minimum of £35 and maximum of £85, this could be inputted instead.

Event trees combined with Monte Carlo simulation could provide a manageable structure with stochastic probabilities that could be used as a tool to model the transfer and spread of bacteria in a hospital ward. By using the model to determine the transfer of bacteria to patients, a suitable event model could be used for assessing exposure routes, an important
component of the risk assessment techniques that have been examined for use in healthcare (Griffith, 2006). A similar process has been utilised to assess exposure routes in domestic kitchens (Harrison et al., 2001). This study performed notational analysis in domestic kitchen in order to record activities that would lead to a ‘high-risk’ of ready to eat foods becoming contaminated. These data were then combined with information on the number of pathogens on certain surfaces or foods within an event tree model. This model was then used to generate potential exposure to pathogens via the foodstuffs examined. The importance of various factors in the exposure levels was also examined, and the level of contamination of raw food was found to be the most significant. Such an approach could be used in hospital wards, but has not been previously attempted, and could prove very useful in prioritising the use of scarce resources. The branched structure may also help to untangle the relationship between surfaces and hand hygiene in the transfer of bacteria to patients.

6.7 Aims
The aim of this study was to model possible exposure pathways which contribute to the exposure of patients on hospital wards to potential pathogens, and to investigate the interactions and effect of control measures. The following objectives were identified:

To devise an event tree model, incorporating Monte Carlo simulation and stochastic sampling incorporating data gathered in previous work into the study
To model the importance of exposure routes of patients to bacteria
To use the model to assess the importance of surface contamination levels with a variety of levels of cleaning effectiveness and hand decontamination frequencies
To evaluate the use of such a model for this area of study, and make recommendations for future work.
To investigate the relationship between environmental surfaces, hand hygiene and patient contact

6.8 Methods

6.8.1 Software used
Computer software capable of running the proposed model was reviewed and examined for suitability. The ‘Decision Tools Suite’ (Palisade Corporation, USA) was selected as it had the required functionality, would run on the available hardware, and had been used previously for a similar purpose with success (Harrison et al., 2001).
6.8.2 Considerations for surface inclusion

The notational analysis data collected in Chapter 5 were examined to determine how it might best be fitted into an event tree. The number of surfaces and interactions found during notational analysis was so large that many had to be grouped together (for example, newspapers and magazines were considered analogous for the purpose of that study). Even then, well over 100 individual surfaces and some 250 interactions were considered. This number of surfaces was too large for the software to handle, with 30 branches from each node being the maximum. Such a large number of branches could defeat the desire to have a model that was easily intelligible. In addition, because each touch on each surface could be followed by a touch on any other surface, each of the 30 initial branches would require 30 branches coming from it. Within a short space of time, such a structure would become unworkable.

Unlike the outcomes in the example model above (Figure 6.6.1), cross contamination within the ward does not finish when a particular decision is made or activity performed. Having touched a surface, it would be possible for a surface to be retouched immediately, or later. This means that a model should have several layers of the same options so that re-contamination could occur, and to utilise notational data on patterns of actions. However, if more layers to the model are included, exponentially more nodes and outcomes are also required.

6.8.3 Surfaces included in model

Observational analysis had shown that actions tended to be clustered in certain areas or groups. Rather than model individual surfaces, it was decided that groups of surfaces should be considered together. This would prevent the exclusion of individual surfaces from the model, and allow more depth to the model. For example, if 30 surfaces were included in the first layer, then 30*30 would be needed for a second, and 30*30*30 for a third. Assessing the outcomes for 27,000 would not be practical, and in addition, the time required to run such models would increase exponentially. Thus a balance between number of layers in the model and number of surfaces included had to be struck.

In total, 4 areas or groups of surfaces were identified. These were:

- Group A: Patient’s bedside area
- Group B: Medical equipment and instruments
- Group C: Nurses’ station area
- Group D: General ward environmental surfaces
In addition, 2 further events were included. These were ‘patient touch’ and hand decontamination.

A model was the constructed using the ‘Precision Tree’ module of the Decision Tools software, 3 layers deeps, giving a total of 216 possible outcomes. In full, it is 10 pages long, so a contracted version is shown in Figure 6.8.3.1. This figure shows the 6 possible outcomes where surface group A is touched first followed surface group B. In the full model (Appendix 6) the pattern seen here is present for all nodes currently contracted. The outcomes shown are: hand decontamination occurs; a patient is touched; a surface in group A is touched; a surface in group B is touched; a surface in group C is touched; a surface in group D is touched, in that order.

![Event Tree Diagram](image)

Figure 6.8.3.1 Contracted version of the created event tree, showing a selected route through the model. The route shows a surface in group A being touched, followed by a surface group B, ending with the probabilities of any of the groups being touched, hand decontamination occurring, or a patient being touched. No figures for microbial contamination are included as these are selected randomly from a distribution and would not be representative if displayed singly.
### 6.8.4 Frequency and patterns of touch actions

Surface touches recorded in Chapter 5 were arranged into the groups decided above, and the frequency of touches was determined (Table 6.8.4.1).

<table>
<thead>
<tr>
<th>Group</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A</td>
<td>56.7%</td>
</tr>
<tr>
<td>Group B</td>
<td>16.6%</td>
</tr>
<tr>
<td>Group C</td>
<td>5.3%</td>
</tr>
<tr>
<td>Group D</td>
<td>9.2%</td>
</tr>
<tr>
<td>Patient touch</td>
<td>9.4%</td>
</tr>
<tr>
<td>Hand decon.</td>
<td>2.8%</td>
</tr>
</tbody>
</table>

**Table 6.8.4.1** Frequency of any group of surfaces being touched, or of an action being performed, as derived from notational analysis data

This set of raw frequencies was inputted into the first level of the model, in order to represent the likelihood of a starting point for an exposure route.

The data was then re-examined to determine how frequently after one of the group was touched another group followed by another (Table 6.8.4.2). This data gave the patterns of behaviour and links between surfaces groups.

<table>
<thead>
<tr>
<th></th>
<th>Group A</th>
<th>Group B</th>
<th>Group C</th>
<th>Group D</th>
<th>Patient touch</th>
<th>Hand decon.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A</td>
<td>64.2%</td>
<td>11.6%</td>
<td>4.3%</td>
<td>7.5%</td>
<td>9.6%</td>
<td>2.7%</td>
</tr>
<tr>
<td>Group B</td>
<td>38.2%</td>
<td>36.5%</td>
<td>3.5%</td>
<td>6.6%</td>
<td>12.7%</td>
<td>2.5%</td>
</tr>
<tr>
<td>Group C</td>
<td>43.3%</td>
<td>6.4%</td>
<td>35.1%</td>
<td>5.0%</td>
<td>5.0%</td>
<td>5.3%</td>
</tr>
<tr>
<td>Group D</td>
<td>44.7%</td>
<td>13.8%</td>
<td>4.6%</td>
<td>29.5%</td>
<td>5.1%</td>
<td>2.4%</td>
</tr>
<tr>
<td>Patient touch</td>
<td>61.2%</td>
<td>18.7%</td>
<td>3.0%</td>
<td>4.9%</td>
<td>9.8%</td>
<td>2.3%</td>
</tr>
<tr>
<td>Hand decon.</td>
<td>49.7%</td>
<td>22.2%</td>
<td>10.5%</td>
<td>6.5%</td>
<td>8.5%</td>
<td>2.6%</td>
</tr>
</tbody>
</table>

**Table 6.8.4.2** Patterns of touch actions, as derived from notational analysis data. Where a group on left column was touched, the probability that a group on the top row was touched next is displayed. For example, after a group B touch, the chance of a patient touch was 12.7%.

This set of data was inputted for subsequent layers of the model to represent the clustering and patterns seen in touch actions.
6.8.5 Surface contamination distributions, mean and standard deviation

It was decided to model the spread and exposure to staphylococci. These were chosen as the measure of exposure as they are found regularly on all surfaces (Chapter 4), are associated with significant levels of HCAI (Kampf & Kramer, 2004; Wisplinghoff et al., 2004), and permanent members of skin flora (Evans & Stevens, 1976). This is in contrast to S. aureus, which was found in smaller numbers on surfaces, and may only be present on 36% of doctors hands (Kampf & Kramer, 2004). The use of a specific pathogen, such as MRSA was considered, but was found to be impractical for this model. The number of MRSA cells on surfaces can be low and sporadic (Chapter 4) in wards, and although significant numbers of MRSA have been found during outbreaks, reports have used percentage of surfaces contaminated rather than cell densities, and different sampling and recovery methodologies prevent comparison between studies.

Data from studies that used similar methodologies to determine the surface contamination of hospital surfaces was taken (Cooper et al., 2007; Chapter 4) and analysed with the ‘BestFit’ function of the Decision Tools suite. This reported that the two distributions that best matched the data were ‘Pareto’ and ‘Lognormal’. The lognormal distribution has previously been suggested for use surface contamination (Montville & Schaffner, 2004), and was thus selected for this model.

The log normal distribution requires a mean value and a standard deviation, but as the groups were a collection of different surfaces, a single figure was not available. In addition, as highlighted in Chapter 3, the different methodologies used by the various studies could produce widely variable results from the same surfaces. Staphylococcal count data from a study by Cooper and colleagues (2007) on the contamination of hospital environmental surfaces was combined with data from Chapter 4. These data was collected with similar methods, and so was comparable.

The data from these studies was searched for surfaces in each group. These figures were then multiplied by frequencies that the surface was touched, in order that both contamination and frequency were reflected in that surfaces contribution to the group’s weighted mean value (Table 6.8.5.1).
<table>
<thead>
<tr>
<th>Group</th>
<th>CFU/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A</td>
<td>6.7</td>
</tr>
<tr>
<td>Group B</td>
<td>3.9</td>
</tr>
<tr>
<td>Group C</td>
<td>1.9</td>
</tr>
<tr>
<td>Group D</td>
<td>1.9</td>
</tr>
</tbody>
</table>

Table 6.8.5.1 Weighted mean staphylococci contamination on groups of surfaces, derived from hospital hygiene studies and notational analysis

As a number of surfaces were included, the standard deviation was derived from the BestFit distribution analysis, as diverse surfaces were included here. The standard deviation was found to be 1.855 times, so this figure was used to find the standard deviation for each group of surfaces.

6.8.6 Number of bacteria on hands

The initial number of bacteria on hands was likely to be an important factor in the number of bacteria transferred to patients later in the model. However, there are various different estimates, obtained with a variety of methods, for the number of staphylococci on hands, or part of hands. Evans & Stevens (1976) found an average of 281 gram-positive cocci per cm² from hand palms. While this does not exclude Micrococcus and other gram-positive species, the majority of these are likely to have been staphylococci. This figure is used in the model as a base number of staphylococci for an undetaminated hand. Numbers of staphylococci on hands would be expected to vary between individuals but this value was left as an absolute, rather than a distribution. This was because as the number of staphylococci transferred to patients was the outcome being measured, and variations in this initial figure would make determining the effects of the various factors involved in the spread of bacteria more difficult. Other assumptions had to be made for the model (Table 6.8.9.1).

6.8.7 Hand decontamination

The range of hand decontamination effectiveness (measured as log₁₀ reductions) has been reported from 0.5 to 3.0 with soap, and 2.6 to 4.5 with ethanol (Kampf & Kramer, 2004). Distribution of decontamination effectiveness within those ranges was not available, nor data on any synergistic effects of combining decontamination methods. A value of a 4 log₁₀ reduction was chosen to represent a effective hand decontamination that would have a significant effect on hand carriage. Staphylococci are often found sub-dermally and their numbers can recover after hand decontamination, as cells are forced to the surface by sweating. This aspect is not included in the model.
6.8.8 Hand size

The size of a ‘dermal contact area’ has been said to be 840 cm$^2$ for the purposes of chemical exposure risk analysis (NICNAS, 2005). For the purpose of this study, a touch action represents the palm and digits of a single hand coming into contact with a surface. From the above figure of 840 cm$^2$ for the total area of two hands, a figure of 210 cm$^2$ for the palm and digits of a single hand was assumed. The contaminations levels per cm$^2$ for both surface contamination and hand decontamination figures were then multiplied by this factor for use in the model.

6.8.9 Transfer rates

Transfer rates between hands and surfaces have been reported as being anywhere between 0 and 100% depending on conditions (Harrison et al., 2003; Chen et al., 2001). This uncertainty could be included in the model, but may have an unduly large effect. This factor is included in most calculations and every layer of the model. In addition, because no information on the distribution of transfer rates was available, a uniform distribution would need to be used. Effectively, if the model is run for sufficient time, a uniform distribution between 0 and 100% becomes equivalent to a constant of 50%. Evidence exists that the transfer rate between hand and skin is higher than for hand to hard surfaces (Rusin et al., 2002), so transfer rate was included at two constant rates, one for hand to surface transfer 0.36 and another for hand to patient transfer 0.43. These figures were derived as means from the work of Rusin and colleagues (2002).

<table>
<thead>
<tr>
<th>Bacteria on surfaces</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groups of surfaces used rather than individual surfaces</td>
</tr>
<tr>
<td>Growth/death of bacteria on surfaces does not occur</td>
</tr>
<tr>
<td>Cleaning interventions did not occur</td>
</tr>
<tr>
<td>Bacteria on hands</td>
</tr>
<tr>
<td>Number of bacteria on hands initially is the same</td>
</tr>
<tr>
<td>Number of bacteria on hand does not change, except where due to hand decontamination</td>
</tr>
<tr>
<td>Cross contamination between HCW hands did not occur</td>
</tr>
<tr>
<td>Hand decontamination</td>
</tr>
<tr>
<td>The effectiveness of hand decontamination remains constant once set</td>
</tr>
<tr>
<td>Transfer between hands and surfaces</td>
</tr>
<tr>
<td>Contact area between hand and surface is constant</td>
</tr>
<tr>
<td>Transfer rates remain constant</td>
</tr>
<tr>
<td>General</td>
</tr>
<tr>
<td>Exposure routes data only collected when patient touched as third action</td>
</tr>
<tr>
<td>All actions occur immediately after each other</td>
</tr>
</tbody>
</table>

Table 6.8.9.1 Showing general assumptions that were made in the creation and running of the model.
6.8.10 Scenarios tested
In order to determine the import of factors within the model, a variety of factors within the model were changed.

6.8.11 Contamination levels on surfaces
Evidence collected in Chapter 4 suggested that improved cleaning could reliably reduce surface contamination to below 1 cfu/cm² with a reduced standard deviation. The average staphylococcal count on environmental surfaces with improved cleaning was found to be 0.4 cfu/cm², and a standard deviation of 1.36 times the mean. These figures were changed in the model to assess the impact of improved cleaning.

6.8.12 Hand decontamination effectiveness
As described above, the effectiveness of hand decontamination has been reported to vary widely, with factors such as time spent washing, agents used, compliance with requisite step and adequate drying affecting success. To model the importance of handwashing, values of handwashing effectiveness between 0.5 and 5 (log₁₀ reductions) were tried, either side of the figure used for a hand decontamination of average effectiveness. In addition, the model was also run with hand decontamination set to be entirely ineffective. These changes were applied to the number of staphylococci on hands used initially in the model, as well any handwashing events within the model.

6.8.13 Patterns of activity
An important component of the model is the pattern in which touches are made. If activities in a ward were altered in order to reduce the frequency of touches on certain groups of surface, this could reduce the spread of bacteria. In order to assess this, the frequencies of the touch actions to groups were reduced. The probability of touching the relevant group of surfaces initially was reduced by 20%, as was the chance of it being touched as part of a pattern. The modelling software requires that the sum total of probabilities of branches from each node is 1, and adjusts the probability of each branch accordingly if this is not the case. While reducing the probability of one action, the others probabilities were increased in proportion to their initial size in order to keep the overall probability at each node as 1. In these modifications, the frequency of hand decontamination and patient touch was kept constant.
6.8.14 Reducing frequency of patient touches
As the recorded outcome in the model, the frequency of patient touch will be factor in contamination. If unnecessary touches can be excluded, then contamination of the patient may be lowered. The touch frequencies and patterns involving patient touch was reduced by 20%, and surface touches increased as described above. Frequency of hand decontamination was unchanged in this scenario.

6.8.15 Increasing hand decontamination frequency
Hand decontamination compliance is regarded as a key component in preventing the spread of infection, and may also help to prevent cross contamination as part of zigzag model. Frequency of hand decontamination was doubled in one scenario and tripled in another, in order to assess its importance exposure values and bacterial spread. As above, the possibility of touching other groups of surfaces was altered proportionally, but the probability of patient touch actions was not altered in this process.

6.8.16 Model set up
For each investigation carried out, the model was run 10000 times (10000 iterations), the maximum allowed by the modelling software. Outputs from the third layer of the model that ended in a patient touch were recorded for each iteration by the modelling software. The mean and maximum figures for each scenario were recorded for each outcome, and these figures were totalled for each scenario. Unlike the models seen in Figure 6.6.1, the numerical outputs in this study are affected by differential transfer rates, and the probability of each route through the model must be accounted for. As there are endpoints in the study that do not end with patient touch, these ‘dilute’ the values for patient touch. Therefore, the numbers of bacteria on routes through the model that end with a patient touch are inevitability an underestimate, and can be used comparatively rather than as an absolute assessment of transfer of bacteria to patients. This can not be related to leading to colonisation or an infectious dose, as the interactions are complex, and dependant on many issues. For example, the number of MRSA required to produce pus is 1000 times lower for damaged skin compared to healthy skin (IFH, 2006).
6.9 Results

The model was successfully created (Appendix 6)

6.9.1 Initial hand decontamination implemented

If hands were not decontaminated at the beginning of the model, the mean number of staphylococci a patient was exposed to was 1852, with a maximum of 2788 (Table 6.9.1.1). If they had been decontaminated, the mean fell to 24.6 cells, and the maximum fell to 690 cells. This is equivalent to the mean dropping 75 fold, and the maximum falling 4 fold.

<table>
<thead>
<tr>
<th>Staph on hands initially</th>
<th>Hand wash effectiveness (log10 reduction)</th>
<th>Mean staphylococci on a surface group (cfu)</th>
<th>Standard deviation factor (as multiple of mean)</th>
<th>Mean transfer of cells</th>
<th>Max. transfer of cells</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
</tr>
<tr>
<td>59010</td>
<td>4</td>
<td>1316</td>
<td>772</td>
<td>388</td>
<td>372</td>
</tr>
<tr>
<td>5.9</td>
<td>4</td>
<td>1316</td>
<td>772</td>
<td>388</td>
<td>372</td>
</tr>
<tr>
<td>59010</td>
<td>4</td>
<td>80</td>
<td>80</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>59010</td>
<td>4</td>
<td>80</td>
<td>772</td>
<td>388</td>
<td>372</td>
</tr>
<tr>
<td>59010</td>
<td>4</td>
<td>1316</td>
<td>80</td>
<td>388</td>
<td>372</td>
</tr>
<tr>
<td>59010</td>
<td>4</td>
<td>1316</td>
<td>772</td>
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<td>372</td>
</tr>
<tr>
<td>5.9</td>
<td>4</td>
<td>80</td>
<td>80</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>5.9</td>
<td>4</td>
<td>80</td>
<td>772</td>
<td>388</td>
<td>372</td>
</tr>
<tr>
<td>5.9</td>
<td>4</td>
<td>1316</td>
<td>80</td>
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</tr>
<tr>
<td>5.9</td>
<td>4</td>
<td>1316</td>
<td>772</td>
<td>80</td>
<td>372</td>
</tr>
<tr>
<td>0.59</td>
<td>5</td>
<td>1316</td>
<td>772</td>
<td>388</td>
<td>372</td>
</tr>
<tr>
<td>18660</td>
<td>0.5</td>
<td>1316</td>
<td>772</td>
<td>388</td>
<td>372</td>
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<tr>
<td>591.1</td>
<td>3</td>
<td>1316</td>
<td>772</td>
<td>388</td>
<td>372</td>
</tr>
<tr>
<td>591</td>
<td>2</td>
<td>1316</td>
<td>772</td>
<td>388</td>
<td>372</td>
</tr>
<tr>
<td>5910</td>
<td>1</td>
<td>1316</td>
<td>772</td>
<td>388</td>
<td>372</td>
</tr>
<tr>
<td>59010</td>
<td>0</td>
<td>1316</td>
<td>772</td>
<td>388</td>
<td>372</td>
</tr>
</tbody>
</table>

Table 6.9.1.1 Effects on the mean and maximum number of staphylococci transferred to patients by altering surface contamination, initial hand contamination and hand decontamination effectiveness.
6.9.2 Reduction of surface contamination where initial hand decontamination was not implemented

Reducing the number of bacteria on the various groups of surfaces to 0.4 cfu/cm² reduced the mean contamination of patients from 1852 to 1830 cfu, and the maximum from 2788 to 1866 cfu. When the contamination of groups was reduced individually, reductions to group A had the largest effect, with alterations to groups B, C and D having little impact.

6.9.3 Reduction of surface contamination where initial hand decontamination was implemented

Reducing the contamination on all surfaces had a significant effect on the number of staphylococci transferred to patients if hand had been decontaminated initially, with only 8% as many cells being transferred compared to normal levels of surface contamination. The maximum number of cells transferred was reduced to 2.9% of the initial level.

6.9.4 Effectiveness of hand decontamination

Increasing the effectiveness of hand decontamination reduced the number of staphylococci that patients were exposed to. A 3 log₁₀ reduction was almost as effective as a 5 log₁₀ reduction in terms of mean bacteria transferred, but had higher maximum values. A 2 log₁₀ reduction caused an increase in mean transfer to 43.5 cfu from 26.6 cfu for a 3 log₁₀ reduction. A 0.5 log₁₀ reduction by hand decontamination resulted in an exposure of 615 cfu, and completely ineffective decontamination, 1978 cfu.

6.9.5 Patterns of activity

When starting with decontaminated hands, reducing the frequency of touches to group A surfaces, while increasing them for other groups produced a small reduction in the mean exposure of patients to staphylococci (Table 6.9.5.1). The alterations to the groups of surfaces touched, and consequent effect of patterns of touch actions are displayed in Table 6.9.5.2. Decreasing frequency of touch for groups B, C and D did not produce any effect in the mean exposure of patients to staphylococci. When hands were not decontaminated initially, altering the touch probabilities for groups provided no significant change in the mean or maximum bacterial transfer.
<table>
<thead>
<tr>
<th>Ref. number</th>
<th>Staph. initially on hands</th>
<th>Hand washing effectiveness (log10)</th>
<th>Mean staph. transfer</th>
<th>Max. staph. transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>59010</td>
<td>4</td>
<td>22.3</td>
<td>1193.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.9</td>
<td>4</td>
<td>1819.9</td>
</tr>
<tr>
<td>2</td>
<td>59010</td>
<td>4</td>
<td>25.3</td>
<td>1470.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.9</td>
<td>4</td>
<td>1821.0</td>
</tr>
<tr>
<td>3</td>
<td>59010</td>
<td>4</td>
<td>24.4</td>
<td>1551.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.9</td>
<td>4</td>
<td>1870.7</td>
</tr>
<tr>
<td>4</td>
<td>59010</td>
<td>4</td>
<td>25.3</td>
<td>1022.1</td>
</tr>
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<td></td>
<td>5.9</td>
<td>4</td>
<td>1878.1</td>
</tr>
<tr>
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<td>59010</td>
<td>4</td>
<td>24.2</td>
<td>1455.5</td>
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<tr>
<td></td>
<td></td>
<td>5.9</td>
<td>4</td>
<td>1759.0</td>
</tr>
<tr>
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<td>59010</td>
<td>4</td>
<td>22.5</td>
<td>1094.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.9</td>
<td>4</td>
<td>1626.4</td>
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<td>59010</td>
<td>4</td>
<td>20.8</td>
<td>915.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.9</td>
<td>4</td>
<td>1549.5</td>
</tr>
</tbody>
</table>

Table 6.9.5.1 The effect on mean and maximum exposure of patients to staphylococci of altering the frequency and patterns of touch actions. The details of the changes to frequency and patterns are cross-referenced in Table 6.9.5.2
Table 6.9.5.2 Alterations made to frequency and patterns of touch actions, as cross referenced to table 6.9.5.1. The left side table represents the altered initial probabilities, and right table shows the altered pattern probabilities used within the model. Table is continued overleaf

<table>
<thead>
<tr>
<th>Ref. 1</th>
<th>20% Reduction in touches to group A</th>
<th>Group A</th>
<th>Group B</th>
<th>Group C</th>
<th>Group D</th>
<th>Patient touch</th>
<th>Hand decon.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A</td>
<td>45.4%</td>
<td>51.4%</td>
<td>18.0%</td>
<td>6.7%</td>
<td>9.2%</td>
<td>9.6%</td>
<td>2.7%</td>
</tr>
<tr>
<td>Group B</td>
<td>22.6%</td>
<td>30.6%</td>
<td>42.5%</td>
<td>4.1%</td>
<td>7.6%</td>
<td>12.7%</td>
<td>2.5%</td>
</tr>
<tr>
<td>Group C</td>
<td>7.2%</td>
<td>34.6%</td>
<td>7.6%</td>
<td>41.6%</td>
<td>5.9%</td>
<td>5.0%</td>
<td>5.3%</td>
</tr>
<tr>
<td>Group D</td>
<td>12.0%</td>
<td>35.7%</td>
<td>16.3%</td>
<td>5.4%</td>
<td>35.0%</td>
<td>5.1%</td>
<td>2.4%</td>
</tr>
<tr>
<td>Patient touch</td>
<td>9.4%</td>
<td>49.0%</td>
<td>27.3%</td>
<td>4.4%</td>
<td>7.2%</td>
<td>9.8%</td>
<td>2.3%</td>
</tr>
<tr>
<td>Hand decon.</td>
<td>2.8%</td>
<td>39.7%</td>
<td>27.9%</td>
<td>13.1%</td>
<td>8.2%</td>
<td>8.5%</td>
<td>2.6%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ref. 2</th>
<th>20% Reduction in touches to group B</th>
<th>Group A</th>
<th>Group B</th>
<th>Group C</th>
<th>Group D</th>
<th>Patient touch</th>
<th>Hand decon.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A</td>
<td>59.4%</td>
<td>66.2%</td>
<td>9.3%</td>
<td>4.5%</td>
<td>7.8%</td>
<td>9.6%</td>
<td>2.7%</td>
</tr>
<tr>
<td>Group B</td>
<td>13.3%</td>
<td>44.0%</td>
<td>29.2%</td>
<td>4.1%</td>
<td>7.6%</td>
<td>12.7%</td>
<td>2.5%</td>
</tr>
<tr>
<td>Group C</td>
<td>5.5%</td>
<td>43.9%</td>
<td>5.1%</td>
<td>35.6%</td>
<td>5.0%</td>
<td>5.0%</td>
<td>5.3%</td>
</tr>
<tr>
<td>Group D</td>
<td>9.6%</td>
<td>46.2%</td>
<td>11.0%</td>
<td>4.7%</td>
<td>30.5%</td>
<td>5.1%</td>
<td>2.4%</td>
</tr>
<tr>
<td>Patient touch</td>
<td>9.4%</td>
<td>64.5%</td>
<td>15.0%</td>
<td>3.2%</td>
<td>5.2%</td>
<td>9.8%</td>
<td>2.3%</td>
</tr>
<tr>
<td>Hand decon.</td>
<td>2.8%</td>
<td>53.0%</td>
<td>17.8%</td>
<td>11.2%</td>
<td>7.0%</td>
<td>8.5%</td>
<td>2.6%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ref. 3</th>
<th>20% Reduction in touches to group C</th>
<th>Group A</th>
<th>Group B</th>
<th>Group C</th>
<th>Group D</th>
<th>Patient touch</th>
<th>Hand decon.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A</td>
<td>57.4%</td>
<td>64.9%</td>
<td>11.8%</td>
<td>3.5%</td>
<td>7.6%</td>
<td>9.6%</td>
<td>2.7%</td>
</tr>
<tr>
<td>Group B</td>
<td>16.8%</td>
<td>38.5%</td>
<td>36.8%</td>
<td>2.8%</td>
<td>6.6%</td>
<td>12.7%</td>
<td>2.5%</td>
</tr>
<tr>
<td>Group C</td>
<td>4.2%</td>
<td>48.8%</td>
<td>7.2%</td>
<td>28.1%</td>
<td>5.6%</td>
<td>5.0%</td>
<td>5.3%</td>
</tr>
<tr>
<td>Group D</td>
<td>9.3%</td>
<td>45.2%</td>
<td>13.9%</td>
<td>3.7%</td>
<td>29.8%</td>
<td>5.1%</td>
<td>2.4%</td>
</tr>
<tr>
<td>Patient touch</td>
<td>9.4%</td>
<td>61.7%</td>
<td>18.8%</td>
<td>2.4%</td>
<td>4.9%</td>
<td>9.8%</td>
<td>2.3%</td>
</tr>
<tr>
<td>Hand decon.</td>
<td>2.8%</td>
<td>51.0%</td>
<td>22.8%</td>
<td>8.4%</td>
<td>6.7%</td>
<td>8.5%</td>
<td>2.6%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ref. 4</th>
<th>20% Reduction in touches to group D</th>
<th>Group A</th>
<th>Group B</th>
<th>Group C</th>
<th>Group D</th>
<th>Patient touch</th>
<th>Hand decon.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A</td>
<td>58.0%</td>
<td>65.4%</td>
<td>11.8%</td>
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<td>6.0%</td>
<td>9.6%</td>
<td>2.7%</td>
</tr>
<tr>
<td>Group B</td>
<td>17.0%</td>
<td>38.8%</td>
<td>37.1%</td>
<td>3.6%</td>
<td>5.2%</td>
<td>12.7%</td>
<td>2.5%</td>
</tr>
<tr>
<td>Group C</td>
<td>5.4%</td>
<td>43.8%</td>
<td>6.5%</td>
<td>35.5%</td>
<td>4.0%</td>
<td>5.0%</td>
<td>5.3%</td>
</tr>
<tr>
<td>Group D</td>
<td>7.4%</td>
<td>48.9%</td>
<td>15.1%</td>
<td>5.0%</td>
<td>23.6%</td>
<td>5.1%</td>
<td>2.4%</td>
</tr>
<tr>
<td>Patient touch</td>
<td>9.4%</td>
<td>61.9%</td>
<td>18.9%</td>
<td>3.1%</td>
<td>3.9%</td>
<td>9.8%</td>
<td>2.3%</td>
</tr>
<tr>
<td>Hand decon.</td>
<td>2.8%</td>
<td>50.5%</td>
<td>22.6%</td>
<td>10.6%</td>
<td>5.2%</td>
<td>8.5%</td>
<td>2.6%</td>
</tr>
</tbody>
</table>
Table 6.9.5.2 continued from previous page. Alterations made to frequency and patterns of touch actions, as cross referenced to table 6.9.5.1. The left side table represents the altered initial probabilities, and right table shows the altered pattern probabilities used within the model.

### 6.9.6 Reducing frequency of patient touches

A reduction in the chance of patients being touched by 20% reduced the mean and maximum number exposure of patients to staphylococci, whether the model was begun with a decontaminated or undecontaminated hand. Where hands were initially decontaminated reduction in mean transfer of 15.8% was seen, and where hands started undecontaminated, mean cells transferred was lowered by 16.4%.

### 6.9.7 Increasing hand decontamination frequency

Doubling the frequency of hand decontamination had little effect on transfer of bacteria to patients when hand decontamination had occurred at the beginning of the model. Where hand decontamination had not previously been carried out, a small reduction in mean transfer (5%) was recorded, from 1852 cfu to 1759 cfu. A tripling the frequency of hand decontamination had a larger effect on exposure of the patient to bacteria, with an 8.6% reduction when starting with undecontaminated hands, and a larger reduction of 12.2% with decontaminated hands.
6.10 Discussion

Although some models of the spread and transfer of bacteria in the hospital environment have been created, none have combined event trees with stochastic sampling, an approach that has been used for exposure assessment exposure in catering and the home (Harrison et al., 2001). Determining exposure route is part of the risk assessment approach been investigated for use in healthcare (Griffith, 2006).

6.10.1 Model creation

The creation of the model was successfully completed, but this process was not without its difficulties and several assumptions had to be made (Table 6.8.9.1). Most models include simplifications in order to make the modelling process intelligible and manageable. For Lipsitch et al., it was assumed that an uncolonised patient could only become colonised with a new type of bacteria (so that colonisation with two or more strains could not occur). Austin et al. (1999) used a Ross type model to examine transmission dynamics of VRE in a hospital ward, but specifically excluded the influence of any environmental transmission for simplicity’s sake, an assumption shared by Cooper and colleagues (1999), although the environment is known to be a factor in VRE transmission (Weber & Rutala, 1997). Most similar models exclude the role of cross contamination, and cross contamination has been described as ‘the Achilles heel of risk modelling’ (Paoli G, personal communication). This model takes account of cross contamination to model exposure routes of patients to staphylococci.

6.10.2 Presence of an initial hand decontamination step

The single largest factor in the exposure of patients to staphylococci was whether hands were decontaminated at the start of the series of actions at the beginning of the model. This is entirely consistent with accepted infection control practice (Pittet et al., 2006), and underlines the importance of hand decontamination as a tool for prevention of HCAI. Although the mean exposure value for decontaminated hands was 75 times lower than for undecontaminated, the maximum value was only half. This implies that although the initial decontamination decreases exposure to staphylococci, it is not a panacea, as large numbers of cells can sometimes be transferred.

6.10.3 Reduction in surface contamination on all surfaces

When hands were not initially decontaminated, reducing the surface contamination had little effect on transfer of bacteria to patients. However, when hands were decontaminated, a reduction was observed, suggesting that surfaces are of limited importance in increasing
exposure when hands are not decontaminated. However, the maximum number of cells transferred decreased sharply with the lowered surface contamination. This finding suggests that poorly cleaned surfaces can provide a large ‘spike’ in the exposure of the patient to staphylococci.

This is echoed by the impact of better surface hygiene on exposure when hands were decontaminated initially. The mean number of cells patients were exposed to was reduced by more than 92%, and the maximum number was reduced by 97%. The reduction in the maximum is perhaps the more significant of these effects. As described above, a decontaminated hand can still transfer a large number of bacteria, and this is due to touching a surface with an unusually large number of bacteria on it. High densities of cells on surfaces have been recorded (Chapter 4), so this possibility exists in the real world. However, the model shows that if the surfaces are cleaned more effectively, then the possibilities of this ‘spike’ are vastly reduced, which in turn greatly reduces the chance of a patient becoming colonised or infected as the result of cross contamination. Therefore cleaning surfaces to a high standard could have an impact on contamination of patients by bacteria.

### 6.10.4 Reduction of contamination on specific groups of surfaces

Reducing the number of bacteria on individual groups of surfaces had broadly the same effect as reducing it for all surfaces, but to a lesser extent. Little effect on the mean exposure was seen for hands that were not initially decontaminated, which would be expected as none was seen for the more extensive reduction in surface contamination. Reduced maximum exposure values were seen when contamination on groups A and B was reduced, but not for groups C and D. This effect is likely due to the elevated probabilities that groups A and B were touched, and consequently more likely to contribute more to the maximum figure. As C and D were touched less frequently, the effects on patient’s exposure to bacteria via cross contamination from groups C and D will be smaller (Table 6.9.1.1).

Where hands were initially decontaminated, only a reduction in surface contamination at group A had a large effect on exposure, which underlines the importance of this group of surfaces. As predicted by the zigzag model, this model demonstrates that a conscientious HCW who washes their hands thoroughly could recontaminate their hands on group A surfaces when preparing to examine the patient.

Therefore, if additional resources are available for improved cleaning are limited, they should be targeted at surfaces around the patient’s bedside. Many of the studies that have found no link between environmental hygiene and HCAI have focussed on the cleanliness of
the floor, but this study suggests that it would be more appropriate to look at those areas close to patients.

Improvements in the cleanliness of medical instrumentation could also reduce the exposure of patient to pathogens, and this maybe simple to achieve. As highlighted by Rampling and colleagues (2001), simply allocating specific cleaning responsibilities and rotas for decontaminating medical equipment may be an effective measure.

### 6.10.5 Altering hand decontamination effectiveness

The effectiveness of hand decontamination was found to have a dominant effect on the exposure of patients to staphylococci. This finding fits in with the principle that hand hygiene is critical in preventing HCAI. The lowest decontamination effectiveness recorded by Kampf and Kramer (2004) was a 0.5 log_{10} reduction in bacteria on hands. Although this level of reduction did offer a significant reduction in transfer, it was not enough to reduce this to background levels. This finding reiterates the importance of thoroughness in hand decontamination.

It was also found that while increasingly poor decontamination led to more cells being transferred, additional beneficial effects of hand washing were not seen above a 3 log_{10} reduction. As this model can only show relative exposure by changing factors, this does not mean that this holds true for all individuals, because some may have higher counts of staphylococci on their hands. However it does show that a highly effective handwash following all the required steps and/or disinfection with an alcohol gel can be compromised if surfaces are touched before the patient, as no reduction in the maximum values was observed.

### 6.10.6 Altering patterns of activity

Only reducing the frequency of touches to the surfaces in group A (patient’s bedside area) had the effect of reducing exposure values. As discussed previously, group A was the most frequently touched and harboured the most contamination, so that the biggest reduction was seen here would be expected. Decreasing the frequency of touches of other groups did not affect exposure. This is because of the inherent limitations of this model structure. Decreasing the frequency of one branch requires the increase of another as the sum probability of all choices at a node must be 1. This would inherently lead to the increase in frequency of touch to the more highly contaminated group A. Decreasing touches to other surfaces is therefore counter-productive in the model, whereas a real world situation any reduction in surface touches would be expected to lead to a decrease in cross contamination.
6.10.7 Increasing hand hygiene frequency
In this model, hand hygiene frequency is not directly analogous to hand hygiene compliance, although an increase in the first would indirectly produce an increase in the second. Doubling and tripling the frequency of hand washing produced a reduction in the transfer of bacteria, but as these can not be tied to a specific patient touches within the model, they may not reflect a real-world improvement. However, the importance of hand washing is emphasised by these results.

6.10.8 Decreasing frequency of patient touches
Avoiding touching the patient unless necessary is an obvious method to reduce transfer of bacteria to patients. During Chapter 5, it was observed that this may not always be at the HCWs discretion, as some patients initiated contact, wanting to shake hands with their surgeon for example. Nevertheless, a reduction in patient contact resulted in lower exposure as fewer bacteria were transferred. This would be a method of reducing the possibilities of causing the patient to become colonised with bacteria without incurring additional expense (as cleaning might) or time (a commonly given reason for poor hand hygiene compliance).

6.11 Conclusions

6.11.1 The importance of hand hygiene
A confounding factor in determining the importance of surface hygiene on HCAI has been untangling the relationship between bacteria on hands initially and those picked up from surfaces. This work provides some evidence into the relative contributions of each to the spread and transfer of bacteria. Effective hand hygiene, performed before touching a patient, was found to the most effective way to reduce the transfer of bacteria to patients. This supports the general opinion that hand hygiene is critical in preventing HCAI. However, actually improving compliance has attempted many times, and few have been successful in producing a lasting effect. Pittet and colleagues (2000) achieved improvement to 70% compliance, with a consequent fall in infection rates, but even this did not achieve full compliance or a zero infection rate.

6.11.2 The importance of surface contamination
This model demonstrated that the positive effect of effective hand decontamination could be undone with two touches of decontaminated surfaces, as predicted by the zigzag cross contamination model. Therefore, as greater success is achieved in increasing hand hygiene compliance, as achieved by Pittet and colleagues (2000), surface hygiene compliance
increases in importance if the benefits of improved hand hygiene are not to be undermined. If hand decontamination is not effectively implemented when indicated, then surface contamination does not affect cross contamination to any great extent, as the number of bacteria on hands already is very large.

While a touching a surface that was grossly contaminated might be a rare event individually, the number of touches performed in a ward as a whole means that it would not be exceptional with the existing level of contamination. Achieving the improvement in surface contamination levels shown to be possible in Chapter 4 almost eliminated the chance of a high number of cells finding their way on to a patient by an unexpectedly high number on a touched surface. This was a product mostly of the decreased mean contamination in the lognormal distribution, but the lowered standard deviation also reduces the chance of a surface being highly contaminated. This represents a reduction in the impact of stochastic effects, which have previously been found to be important in the spread of pathogens (Matthews & Woolhouse, 2005)

6.11.3 Risk assessment
The exposure route assessment performed here does not directly inform on the likelihood of the patient contracting an HCAI, or even becoming colonised with a pathogen. These interactions are complex and beyond the scope of this study. However, the number of cells a patient is exposed to could be a factor in the likelihood of either colonisation occurring or an infection developing. The analysis performed here could therefore form part of the risk characterisation process that underpins risk analysis. Risk analysis and assessment of the role of the environment would allow more informed and rational discussion of the issue. In addition, a risk assessment would allow proposed changes or interventions to be tested. As described in Chapter 2 with reference to EBM, thoroughly testing the effectiveness of interventions designed to prevent HCAI is a long-winded and resource intensive process. A risk model would help to screen suggested changes to practice to reduce the chance that anything tried would be a failure. In addition, such risk modelling allows the effect of changes to be examined, so that interventions can be prioritised according to need. For example, if cleaning resources are scarce, the most cost-effective intervention can be introduced first.

6.11.4 Assessment of the event tree model and modelling exposure routes
The event tree model structure was not well suited for the task it was employed for in this study. Hospital wards have a great many surfaces, perhaps thousands, and the branching
nature of event trees mean that the number of endpoints increases exponentially with each iteration of the model, and this prevented a complete evaluation of individual surfaces.

The notion of an ‘endpoint’ for a contamination route runs counter to the zigzag model. Any bacteria transferred to a patient or surface in this model was ‘lost’ once each cycle of the model had been completed, whereas in a ward a patient might go on to contaminate other surfaces or colonise fellow patients. Where cross contamination in a real ward could be considered to be an on-going web of interactions in a state of flux over time, the model used here represented a number of linear paths, replicated 10000 times. This allows the model to take a ‘snapshot’, but it can not considered the entire ‘landscape’ of cross contamination within the ward has been captured.

Nevertheless, the model used here was successfully used to make exposure assessments, and it could be expanded and improved to capture more information and provide better data. However, it should be recognised that the model needed to obviate the problems above is a much more complex entity, both in terms of construction and of computing power needed to run the model.

Other software packages exist that might be able to marry the stochastic sampling and individual events that are central to this model, with modelling elements that allow for a more dynamic simulation with changes over time to be included. One such software package is GoldSim (GoldSim Technology Group, USA), which has been used to model the transmission of infectious disease between the hands of healthcare workers and patients. Potentially, such models could be expanded to include the contribution of environmental surfaces, which this study shows to be a contributory factor in bacterial transmission. However, the inclusion of all these factors may result in a model too complex for simulation on a single office computer, and could exceed the provisions of a piece of software not specifically designed for it. One solution might be to custom write an application designed specifically for modelling cross contamination. This could then be run on a distributed computing framework, spreading the task between many computers.
7 Synoptic discussion, conclusions and recommendations

7.1 Introduction
In the UK, there has been considerable public concern over the number of HCAI in hospitals, which have been widely blamed by the general public on falling standards of ward hygiene (Dancer, 1999). Many government initiatives and campaigns have been launched to improve both HCAI rate and cleaning standards (National Audit Office, 2004), evidence-based practice guidelines for infection control have assessed the importance of environmental cleanliness (Pratt et al., 2007), and a yearly reporting system for hospital environments has been implemented (Green et al., 2006). Despite this attention, quantitative data is lacking on many aspects of cleaning, as assessment of hospital hygiene is performed qualitatively, and no link between surface hygiene and HCAI has been conclusively proven. This is in part due to the complexities of conducting research within the confines of EBM, and also in determining the contributions of different factors to the spread of bacteria in a ward.

The overall aim of this thesis was to explore relationships between environmental surfaces and the transmission of pathogens to patients. The present study has examined the management of cleaning together with and its implementation on surfaces and medical instruments using novel and traditional methods, against existing and proposed quantitative standards. In addition, this study has considered the mechanisms by which environmental hygiene could contribute to cross contamination and exposure of the patient to potential pathogens using techniques not previously used in the hospital environment. The study does not attempt to directly link surface contamination levels to HCAI rates. The complexity of the interactions between the many surfaces in wards and intricate web of hand contact actions, combined with the difficulty in unpicking the relationships between bacterial carriage, colonisation and infection, means that finding an direct link is extremely difficult.

7.2 Review of chapters
The aims of Chapter 2 were to evaluate the decontamination of endoscopes and the management of the process, in order to assess situations where the importance of effective decontamination was known and accepted, and where well established procedures existed. The effectiveness of decontamination was generally good, but some aspects of the process
presented cross-contamination risks that could result in an elevated risk of HCAI. Management of decontamination, a known factor in endoscopy-related infection, was poor in some instances. Improvements in this area, combined with routine monitoring of decontamination using rapid methods, have the potential to lead to a reduction in the potential for endoscopy patients to acquire HCAI.

In Chapter 3 the aims were to investigate a variety of sampling methods and growth media for the recovery of different clinical isolates of MRSA from surfaces because little information was available on the relative performance and merits of different approaches. Furthermore it had been demonstrated in Chapter 2 that routine monitoring of hygiene may be advantageous, and so available methods had to be evaluated. Contact methods provided the best rates of recovery of bacteria, though they utilised a small surface area. Selective media had some advantages and, when used with contact methods, did not suffer a loss of sensitivity. It was concluded that the methods tested in this chapter could be utilised to investigate microbial contamination of hospital surfaces, and could form the basis for standard operating procedures for surface sampling since none currently exist within the NHS. Reliable and sensitive methods for assessing the number of bacteria on a surface are essential in the construction and validation of cleaning schedules, and in the on-going management of hospital cleaning.

In Chapter 4, the aims were to evaluate routine hospital environmental cleaning and to assess available methods and proposed standards, using protocols developed in Chapter 3. Existing routine cleaning was found to be ineffective, and the qualitative standards currently in use in the NHS seemed to underestimate the amount of residual soil compared to quantitative standards. It was found that significant improvements in cleaning effectiveness could be achieved with small changes to cleaning practices, and that these were equally effective whether disinfectants or detergents were used for routine cleaning. This is relevant to the debate over whether routine disinfection of surfaces is required. The introduction of validated cleaning protocols, as used here, would help to improve the management of ward cleaning, and would achieve a reduction in surface contamination.

In light of the considerable contamination on ward surfaces reported in Chapter 4, the aims of Chapter 5 were to employ notational analysis to elucidate possible cross contamination routes within hospitals. It was found that the most frequently touched areas were the surfaces around the patient’s bedside, and that touches here were often followed by patient
contact. Routinely used medical equipment was found to pose a potential cross contamination risk, especially where it was used on several patients sequentially.

The aims of Chapter 6 were to use collected data (from Chapters 4, 5, and from published studies) to model possible exposure pathways which contribute to the exposure of patients to potential pathogens, and to investigate the effect of control measures. This was achieved using data. The created model had some limitations, but provided useful information on exposure routes in the ward setting. It was found that by reducing contamination levels to those achieved by improved cleaning in Chapter 4, the number of bacteria transferred to a patient was reduced. This was especially pronounced if an HCW had decontaminated their hands.

### 7.3 Thesis themes

In addition to the specific aims of each chapter, further themes running through the research were identified.

#### 7.3.1 Management of cleaning

Although the effectiveness of endoscope decontamination observed in this study was generally good, the management of the process in one of the units examined was not good. Poor management and deviation from cleaning protocols has been reported in many of the recorded outbreaks of endoscopy related HCAI, and the absence of monitoring for some important steps in the decontamination process has exposed patients to heightened risk of acquiring HCAI. This thesis has shown that the management of the decontamination of endoscopes can be limited (Chapter 2), and that the routine cleaning of ward surfaces is poor (Chapter 4), with perhaps only a general schedule to determine frequency of cleaning (Appendix 1). Unlike endoscopy, poor cleaning management in wards has not been shown to be directly responsible for HCAI, but improvements in its management could reduce the transfer of bacteria to patients (Chapter 6). The importance of management in decontamination was shown in an independent review into endoscope decontamination in Northern Ireland, where many shortcomings where identified.

To some extent, the NHS has begun to recognise the importance of management in infection control with the introduction of The Health Act (Department of Health, 2006). This document charges NHS bodies with responsibility to have in place arrangements for infection prevention and control. Such bodies are also required to publish both cleaning frequencies and cleaning standards. The decontamination of medical instruments, such as
endoscopes, must be monitored although the document makes no recommendation to use monitoring methods that allow corrective action to be carried out before the instrument is reused.

While this document represents a step forward in some ways, it is a missed opportunity in others. Three factors important in the good management of cleaning were identified in this study and these were the monitoring of cleaning, ensuring the effectiveness of cleaning through validated protocols and the use of standards against which to assess cleaning. The Health Act does not appear to require that cleaning is monitored, nor that cleaning schedules are validated to ensure they are effective. While the Health Act does insist on standards for cleaning being used, no recommendation is made for what these standards should be, and it is likely therefore that NHS bodies will adhere to the visual standards that have repeatedly found to be inadequate in assessing microbial contamination.

7.3.1.1 Monitoring of cleaning

This thesis attempted to monitor the effectiveness of cleaning in different decontamination situations in hospitals using new methods of assessment (Chapter 2; Chapter 4). As part of a managed approach to cleaning it is essential that monitoring is carried out as you can not manage what you can not measure. ATP bioluminescence was found to be a useful tool for assessing hygiene in hospitals, as it is an indication poor cleaning generally, rather than bacteriological sampling which excludes any virus and fungal contamination. This makes the technique especially useful if a particular organism is not sought. Using specific pathogens as a measure of routine cleaning effectiveness was not found to be useful approach, as contamination was sporadic.

In order to allow cleaning to be better managed, and for corrective action to be applied promptly, data on cleaning effectiveness must be generated rapidly. ATP bioluminescence allowed this, but traditional microbiology did not. More rapid microbiological methods, such as real-time PCR are available and may have applications, although are not without drawbacks.

It was demonstrated clearly in Chapter 3 that some of the common methodologies used to monitor pathogen numbers on surfaces would produce widely varying results. Choosing one method over another could lead to an underestimation of pathogen numbers in the order of several thousand. There are at least two methods of sampling endoscope channels in use, brushing the channels, or flushing the channels. Data on which of these is more effective at dislodging bacteria is lacking at present, and this could have similar impact on monitoring of hygiene in this scenario.
7.3.1.2 Standards to assess cleaning

While standards are essential to properly manage cleaning, this thesis has shown that not all standards used or proposed for assessing cleaning in hospital are valid (Chapter 4), and the methods used to monitor them are critically important (Chapter 3). The existing standard of visual cleanliness has again been shown to bear little relationship to the contamination on the surface (Chapter 4). While standards based on bacterial numbers may offer advantages, the sampling method used is critical as their effectiveness at recovering bacteria can vary by a factor of hundreds (Chapter 3).

Of the standards examined in this study, some were more applicable than others. The Spaulding classification of semi-critical was found to be well adapted for endoscopes (Chapter 2), but some of the proposed standards for surface hygiene were less so. Proposed standards for the number of specific pathogens or some indicator organisms were found to be unlikely to achieve their purpose, and this study emphasises the importance of testing and validating standards for surface hygiene. However, standards based on achievable levels of bacteria were shown to be good at assessing cleaning effectiveness, and would require fewer resources to process.

7.3.1.3 Effectiveness of cleaning

Poor or ineffective cleaning has been implicated in some HCAI related to endoscopy, and some outbreaks in wards. This thesis provides evidence that achieving a significant improvement in surface hygiene standards through routine need not be expensive or complex, and provides a basis for the improvement of cleaning effectiveness. In addition, it has shown that existing cleaning materials, better applied, can reduce bacterial counts to background levels.

While the adequate decontamination of endoscopes to a defined standard is essential to prevent endoscopy related HCAI, routinely monitoring the success of decontamination is not required in UK hospitals, and microbiological results may only become available after the endoscope has been reused (Chapter 2). Evaluations of the endoscope decontamination showed that it was carried out effectively, in contrast to routine surface cleaning seen in hospitals (Chapter 4) despite endoscopes being more difficult to clean. Improvements in cleaning made in Chapter 4 were found to be able to reduce contamination on surfaces to levels similar to those recorded for endoscopes. The difference in results achieved may be due to the existence of good guidelines for endoscope decontamination, which, coupled with
recognition of the consequences of failure may increase awareness of the importance of doing a thorough job.

A feature of many studies that provide evidence for the role of cleaning in HCAI is that cleaning is improved as part of a suite of measures to combat outbreaks of HCAI. Deficiencies in cleaning effectiveness are found and remedied, cleaning hours are increased, responsibility for cleaning some items is allocated by rota and high-level management groups may be formed. It could be said that the importance of routine cleaning as anything other than an aesthetic nicety is only fully considered at times of an HCAI outbreak. It could therefore be advantageous to consider good routine cleaning as a measure that would help in the prevention of outbreaks, rather than solely in their ‘cure’, as is the case in endoscope decontamination.

7.3.2 Zigzag cross contamination

The Dutch ‘seek and destroy’ approach is perhaps the most successful infection control policy in Europe for the prevention of MRSA bacteraemia. Comprising patient screening with isolation, staff cohorting and good environmental hygiene, it is this approach that many reported responses to HCAI outbreaks mimic, unwittingly or not. Reports on the successful control of HCAI outbreaks often have similar features.

In addition to the improvement in cleaning (Chapter 4), these include allocation of cleaning responsibilities, surveillance of staff and patients, isolation and cohorting. Many of these interventions act to prevent zigzag cross contamination by targeting the interactions found between many surfaces, staff and patients. In itself, this provides some evidence that zigzag cross contamination is a factor in HCAI outbreaks, but as the same techniques are used in the Dutch method to prevent MRSA infections generally, it suggests that zigzag transmission is a factor in sporadic HCAI as well. As surface hygiene is an essential component in the zigzag cross contamination model, it would appear that it is important in both the prevention and control of HCAI. The potential for zigzag cross contamination was also found in endoscope decontamination (Chapter 2) where it was found that an impeccable decontamination of an endoscope could be undermined if the scope later acquired bacteria from environmental surfaces or hands.

This thesis found extensive evidence of the potential for, and actuality of, zigzag cross contamination. Links between surfaces, HCW and patients were observed and characterised in Chapter 5, demonstrating that the zigzags did occur and were concentrated around the patient’s bedside area. The role of zigzag cross contamination was demonstrated in Chapter
where exposure through the spread of staphylococci via zigzag transmission was assessed. In addition, results from the model created in Chapter 6 showed that surface hygiene, especially around the patient’s bedside played a significant role in zigzag contamination and that reducing it reduced patient exposure to opportunistic pathogens. This thesis therefore provides supporting evidence for the hypothesis that poor surface cleanliness is a contributory factor for HCAI.

### 7.4 Recommendations

It is recommended that hospital cleaning is improved, and is achieved through improved management. Improving management should take the form of implementing validated cleaning schedules and routinely monitoring cleaning against standards. Such an improvement will reduce the exposure of patients to potential pathogens.

Unified methods for sampling surfaces for various pathogens, indicator organisms, general microbiology and other indicators should be introduced across the NHS. This will aid investigation into the role of the environment in HCAI.

Decontamination of both endoscopes and ward surfaces should be monitored to ensure that decontamination to the required standard has been successful, ideally with methods rapid enough to allow corrective actions to be taken promptly. This recommendation should be extended to other situations where cleaning is more than an aesthetic issue.

Visual assessment should not be used as a measure of cleaning effectiveness as it has been repeatedly demonstrated to be a poor indicator of surface contamination.

Quantitative standards for cleaning should be introduced wherever cleaning is important for safety reasons. Ideally, these standards should be risk based, but if this is not possible, they should be based upon levels of cleanliness that are achievable with good practice. Quantitative standards could be used as performance measures where cleaning is contracted out to external service suppliers, and for internal NHS inspections.

Priority should be given to improving decontamination of sites around the patient’s bedside. These were the sites that were both frequently contaminated and frequently touched, thereby making them important in the transfer of bacteria to patients.
Shared equipment and facilities offer a high chance of cross contamination and improved and regular cleaning of these should be considered. This is especially the case for blood pressure monitoring equipment, where the cuff should be either single-use or easily decontaminated.

Due to zigzag cross contamination, the spread and transfer should be considered holistically, rather than separate components being considered individually. The importance placed on hand hygiene before patient contact is well judged, as this is critical in determining the number of bacteria transferred to patients. Attempts to achieve sustained improvement through campaigns similar to Pittet and colleagues (2000) are recommended.

The dangers of cross contamination should be made clear to HCW, visitors and patients alike. Visitors should be made aware that a smear of alcohol gel at the beginning of a visit will not prevent any bacteria being transferred to the patient for the duration of their visit, and that it is for the patient’s protection, not theirs. Patients should be discouraged from examining wounds or touching drips and catheters to prevent cross or auto infection. While the complete exclusion of these activities is probably not possible, any reduction will have beneficial results.

Ideally, consideration or allowance would be given to the difficulties in producing direct evidence for the role of the environment in HCAI in EBM, as it is unlikely that the required studies will be implemented given their expected size, complexity and duration. The recent addition of homeopathic medicine to the NHS, with little supporting clinical evidence, shows that exceptions can be made in EBM where there is sufficient will to do so.

### 7.5 Further work

Work carried out Chapter 3 on the performance characteristics of various methods of recovering MRSA from hospital surfaces should be extended to include other methodologies, and other pathogens. Without insight into the relative merits of different methods, assessing the significance of published studies is rendered difficult.

Further studies on routine cleaning should be carried out in order to determine how best to improve it in practice, and should investigate material, methods and frequencies. Such studies will help focus attention on the quality of cleaning, rather than hours spent cleaning.
Notational analysis (Chapter 5) was hampered by difficulties posed by an external researcher carrying out the work. This limited the length of time that observations could be carried out and what could be observed. A more complete understanding of patterns of activity on a ward would be achieved by a more comprehensive study.

The modelling of exposure attempted in Chapter 6 showed enough promise to make an extension of the size and scope of the model a useful addition to knowledge on this subject. Including more surfaces and individuals and designing the model to run over time would create a useful tool that would allow interventions to reduce patient exposure to bacteria to be simulated.

An expanded and improved could allow risk analysis to be performed, which could be used to perform cost benefit analysis. In addition, the spread of other organisms could be investigated. These should include Norovirus or \textit{C. difficile}, so that approaches to dealing with outbreaks of pathogens where the environment is an accepted factor can be investigated.
8 References


Boswell TC & Fox PC (2006). Reduction in MRSA environmental contamination with a portable HEPA-filtration unit. Journal of Hospital Infection, 63, 47-54

Boyce JM, Potter-Bynoe G, Chenevert C, King T (1997). Environmental contamination due to methicillin-resistant *Staphylococcus aureus*: possible infection control implications. Infection Control and Hospital Epidemiology, 18, 622-627


Buchan (1769). Domestic Medicine. Edinburgh: Balfour


CDR Weekly (2006a) Hospital-associated transmission of Panton-Valentine leukocidin (PVL) positive community-associated MRSA in the West Midlands. CDR Weekly, 16(50)


Cooper RA, Molan PC, Harding KG (2002). The sensitivity to honey of Gram-positive cocci of clinical significance isolated from wounds. Journal of Applied Microbiology, 93, 857-863


Eckstein BC, Adams DA, Eckstein EC, Rao A, Sethi AK, Yadavalli GK & Donskey CJ. Reduction of Clostridium Difficile and vancomycin-resistant Enterococcus contamination of environmental surfaces after an intervention to improve cleaning methods. BMC Infectious Diseases, 7:61


Hardy KJ, Oppenheim BA, Gossain S, Gao F & Hawkey PM (2006). A study of the relationship between environmental contamination with methicillin-resistant *Staphylococcus aureus* (MRSA) and patients' acquisition of MRSA. Infection Control and Hospital Epidemiology. 27, 127-132


Hawkyard C & Bignardi GE (2006). Has the severity of *Clostridium difficile* infections increased? Journal of Hospital Infection 61, 111-112


Health Protection Agency (2005b). Hand washing is the single most important method of reducing the spread of infection. 


Hong Y, Robinson PD, Chan WK, Clark CR & Choi T (1996). Notational analysis on game strategy used by the world's top male squash players in international competition. Australian Journal of Science and Medicine in Sport, 28, 28-23


Jackson FW & Ball MD (1997). Correction of deficiencies in flexible fiberoptic sigmoidoscope cleaning and disinfection technique in family practice and internal medicine office. Archives of Family Medicine, 6, 578-582


Kampf G & Kramer A (2004). Epidemiologic background of hand hygiene and evaluation of the most important agents for scrubs and rubs. Clinical Microbiology Reviews, 17, 863-893

Kampf G, Bloss R & Martiny H (2004), Surface fixation of dried blood by glutaraldehyde and peracetic acid. Journal of Hospital Infection, 57, 139-143


Kirby WM (1944) Extraction of highly potent penicillin inactivator from penicillin resistant staphylococci. Science, 99, 452


Mayfield JL, Leet T, Miller J & Mundy LM (2000). Environmental control to reduce transmission of *Clostridium difficile*. Clinical Infectious Diseases, 31, 995-1000


Metropolis N (1987). The beginning of the Monte Carlo method. Los Alamos Science, Special Issue, 125-130


Muscarella LF (2002). Application of environmental sampling to flexible endoscope reprocessing: the importance of monitoring the rinse water. Infection Control and Hospital Epidemiology, 23, 285-289

Valentine leukocidin in a French university hospital. Journal of Hospital Infection, 61, 321-329


Newsom SWB (2006). Pioneers in infection control: John Snow, Henry Whitehead, the Broad Street pumps and the beginnings of geographical epidemiology. Journal of Hospital Infection, 64, 210-216


Pearman JW (2004). Lowbury Lecture: the Western Australian experience with vancomycin-resistant enterococci - from disaster to ongoing control. Journal of Hospital Infection, 63, 14-26


Rutala WA & Weber DJ (2001). Surface disinfection: should we do it? Journal of Hospital Infection, 48, S64-S68


Sciortino CV, Xia EL & Mozee RN (2004). Assessment of a novel approach to evaluate the outcome of endoscope reprocessing. Infection Control and Hospital Epidemiology, 25, 1-7


Smith A (2005). Outbreak of *Clostridium difficile* infection in an English hospital linked to hypertoxin-producing strains in Canada and the US. Eurosurveillance Weekly Release, 10(6)


The Guardian (2005). One to another. Tuesday January 25, 2005


Wagenvoort JHT (2000a). Dutch measures to control MRSA and the expanding European Union. Eurosurveillance, 5, 26-28


Weber DJ & Rutala WA (1997). Role of environmental contamination in the transmission of vancomycin-resistant enterococci. Infection Control and Hospital Epidemiology, 18, 306-309


Wu SW, de Lencastre H & Tomasz A (2001). Recruitment of the mecA gene homologue of *Staphylococcus sciuri* into a resistance determinant and expression of the resistant phenotype in *Staphylococcus aureus*. Journal of Bacteriology, 183, 2417-2424