The chain of infection transmission in the home and everyday life settings, and the role of hygiene in reducing the risk of infection

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Other data, more recently published, on the chain of infection transmission in the domestic home and everyday life settings, and the role of hygiene in reducing the risk of infection can be found in the IFH Library of Recent Publications, Topic 2 Infection transmission. This library is updated every 6 months with new publications related to home hygiene. These papers can be found at: http://www.ifh-homehygiene.org/IntegratedCRD.nsf/IFH_Topic_Infection_Transmission?OpenForm


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SECTION 1. INTRODUCTION – AIMS AND OBJECTIVES OF THE REVIEW

The evidence presented in the 2009 IFH review on the global burden of hygiene-related diseases\(^1\) shows that infection outbreaks in the domestic home and everyday life settings, particularly gastrointestinal (GI) infections (also called infectious intestinal disease (IID)), respiratory infections (RT), and skin, wound and eye infections, continue to exact a heavy toll on the health and prosperity of the global community. The evidence indicates that a significant proportion of these infections are preventable by getting people to practice better hygiene in their own homes and in everyday life. This includes food and respiratory hygiene, and better hand, surface and laundry hygiene practices coupled with other practices such as safe disposal of refuse and wastewater. In communities that lack access to adequate sanitation and clean water, this may also involve ensuring water treatment and safe storage and the safe disposal of faeces.

As reported in the 2009 IFH Review\(^1\) in recent years a number of events or trends have prompted a need for greater investment in hygiene promotion:

- **Food-related, waterborne, and non food-related infectious intestinal diseases** (e.g. many norovirus infections) remain at unacceptably high levels, much of this infection occurring in or being related to practices in people’s homes.
- **Evidence now suggests** that respiratory hygiene plays a significant part in limiting the spread of respiratory infections such as cold and influenza.
- **New pathogens** (including antimicrobial resistant strains) are continually emerging. In the event of a pandemic, hygiene is seen as an important first line of defence.
- **Alongside prudent antibiotic prescribing**, hygiene is now seen as a key strategy for reducing the impact of antibiotic resistance. Resistant strains traditionally regarded as causing Healthcare–Associated infections are emerging in the community such as CA-MRSA, and ESBL and NDM-1-producing gram negative strains. As persistent nasal or bowel carriage of these strains in the healthy population increases, this increases the risk of infection with these strains in both hospitals and the community. Hygiene provides a means to reduce this “silent epidemic”.
- **In developing countries**, there is increasing realisation that integrating hygiene education and hygiene promotion into water and sanitation programmes is key to reducing the burden of diarrhoeal diseases.

At the same time:

- **Social and demographic changes** mean that people who have more or less reduced immunity to infection make up an increasing proportion of the population (currently up to 20%). The largest proportion is the elderly. It also includes the very young, patients discharged from hospital, or home-based patients taking immuno-suppressive drugs or using invasive systems, etc.
- **Infectious diseases** can act as co-factors in other diseases that manifest at a later date, such as cancer and chronic degenerative diseases, or as triggers for allergic diseases such as asthma.
- **Globally, there is an inequitable distribution** of disease. Populations with a low education level, income level or occupational class are at a higher risk of infection. This initiates a “vicious cycle” of infection predisposing to malnutrition and growth faltering, which in turn leads to increased risk for further infection.

These changes demand new containment strategies, increasingly involving the community as a whole. A number of interrelated factors should be considered:

- Although it is often assumed that respiratory and foodborne infections are a minor concern, the burden in terms of absence from work and school is considerable.
• Community and hospital care for at-risk groups who become seriously ill, or develop ongoing sequelae are further adding to the healthcare costs.
• Technological and policy changes (for example, use of less water and lower temperatures for laundering) are being introduced in order to reduce costs and/or environmental/ecological impacts without regard to the importance of a balanced approach in which the need to reduce disease risks is also considered.

Governments, under pressure to fund the level of healthcare that people expect, are looking at prevention strategies as a means to reduce health spending. Hygiene is recognised as a cost effective means to reduce the infectious disease burden. Increased homecare is one approach to reducing health spending, but gains are likely to be undermined by inadequate infection control at home.

Although hygiene practice is now acknowledged universally as a cost effective means to reduce the burden of infectious diseases, in developing countries, the overriding priority for most governments is still the provision of clean drinking water, safe sanitation (excreta disposal) and environmental issues (control of waste water, disposal of refuse etc). According to a 2012 report by UNICEF and WHO, in the developing countries, 2.5 billion still lack access to sanitation services. Even though 1.8 billion people have gained access to improved sanitation since 1990, the world remains off track for the Millenium Development Goals sanitation target. Since 1990, although more than 2 billion people have gained access to improved drinking water sources, there are still 780 million people without access to an improved drinking water source. If we take into account the problems of chemical/microbial quality, and those associated with collection/storage/handling of water in the home, the figure would be much higher. As such any discussion on prevention of infection in homes of the developing countries must be contextual to these realities. According to a World Bank report, inadequate water, sanitation and hygiene account for a large part of the burden of illnesses (4 billion cases of diarrhea including 2.2 million deaths and 62.5 million DALYS (Disability-adjusted life years), intestinal worms infect 10% of the developing country population, 6 million people are blind from Trachoma, 300 million suffer from malaria, 200 million people are infected with schistomiosis). It is pertinent to note that, of the total number of deaths globally attributable to poor water supply, sanitation and hygiene, 99.9% occurs in developing countries. For total DALYS, the corresponding percentage is 99.8.

The International Scientific Forum on Home Hygiene (IFH) is a global, professional, non-government organisation which was established in 1997 to meet a growing need to develop and promote an effective approach to home hygiene based on sound scientific principles. To achieve this, IFH has drawn on the expanding volume of scientific data, to formulate a risk-based approach to home hygiene. Applied to the home, it has come to be known as “targeted hygiene”.

The aim of targeted hygiene is to maximise protection against infectious diseases by breaking the chain of infection transmission at critical points before infectious agents can spread further.

The principles of targeted hygiene are reviewed in Section 2. The major objectives of this report are:
• To assess the strength of the causal link between hygiene practice and infectious disease (see section 3).
• To review the validity and applicability of the IFH risk-based approach to hygiene in home and everyday life settings (see section 4).
• To review the key factors to be considered in applying targeted hygiene as part of hygiene promotion programmes (see section 5).
These aspects are discussed in the following sections. The database of scientific material used for developing the concepts outlined in Sections 3-5 is detailed in the appendices to this review. This includes microbiological studies (laboratory and field-based), data on how and to what extent pathogenic organisms enter the home and how they survive and are spread around the home environment. This is reviewed together with data on the extent to which we are exposed to these agents in our daily lives, and what is known about their infectivity (infectious doses). Data from epidemiological (intervention and observational studies) and data generated by quantitative microbial risk assessment is also reviewed.

This review is based on a previous review, prepared by the IFH in 2002, which has been updated to contain material from the peer-reviewed literature accumulated by IFH since 2002 (the “new” material can be found in the reading rooms of the IFH website Library of Recent Publications), together with contributions (published scientific literature) from the knowledge base of the authors. These data are also addressed in some of our other IFH reviews on specific issues including hand hygiene, household water treatment and safe storage, viral and fungal infections, and on MRSA, *Clostridium difficile* and ESBL-producing *Escherichia coli*. Evidence assessing the role and effectiveness of hygiene procedures in breaking the chain of infection is reviewed in detail in another IFH review “Hygiene procedures in the home and their effectiveness: a review of the evidence base”.

The focus of this review is infection prevention in the home and in everyday life, including that part of primary healthcare which occurs in the home. It is not intended to cover other primary care settings including residential facilities, although much of the data is also relevant to these settings.

We anticipate that readers will sometimes use this review as a reference source for individual issues. For this reason, we have tried to make sections as internally comprehensive as possible; thus readers may find some repetition in the material presented.

**SECTION 2. INTRODUCTION – THE IFH TARGETED APPROACH TO HOME HYGIENE**

**2.1 A RISK-BASED APPROACH TO HOME AND EVERYDAY LIFE HYGIENE – BASIC PRINCIPLES**

The aim of using a risk-based (targeted) approach to hygiene is to maximise protection especially against infectious diseases by breaking the chain of infection transmission and addressing other risk factors. As specified by Aiello and Larson, although a single factor (or control point) such as the hands may be a “sufficient cause” of infection transmission, spread of infection frequently involves a number of interdependent “component causes” which act together or independently to determine the overall risk. The interdependent roles of the hands and environmental sites and surfaces etc in the chain of infection transmission can be understood by mapping the potential routes of spread of GI, RT and skin infections in the home as shown in Figure 1. This suggests that, for all 3 groups, the hands are probably the single most important transmission route because, in all cases they come into direct contact with the known portals of entry for pathogens (the mouth, nose and conjunctiva of the eyes), and are thus the key last line of defence. Figure 1 shows that, although, in some cases, the hands alone may be “sufficient cause” for transmission of an infection (e.g., from an MRSA carrier, to hands, to the wound of a recipient), in other cases transmission involves a number of component causes (e.g., from contaminated food, to a food contact surface, to hands, to the mouth of a recipient).
There is considerable debate regarding the extent to which respiratory viruses such as cold and flu viruses, and enteric viruses such as norovirus are transmitted via surfaces as opposed to via aerosols droplets. The data on this aspect is reviewed in appendix 1.2. It is also noted that, although people and domestic animals are the primary reservoirs of GI infections, in situations where sanitation is inadequate, faeces are a key vehicle for transmission of pathogens to hands and surfaces.

The criteria (and methodology) for assessing causal inference of a link between hygiene practices and infectious disease risk reduction have been reviewed by Aiello, Larson and co-workers. They postulate that establishing the health impact of a hygiene intervention requires evaluation of a range of criteria including the strength, consistency, specificity and temporality (cause and effect) of the association, together with data on plausibility (microbiological or behavioural). Other factors include time dependency (did the outcome occur after the cause?), biological gradient (is there a relationship between the number of infectious agents to which the population is exposed and occurrence of infection?) and consistency of the association (has the same association between a hygiene practice and a health-related outcome, been shown among different populations, at different times and in different geographical locations?).

**Figure 1 – Routes of transmission of infection in the home**
One of the problems in making the case for hygiene as a cost-effective means to reduce the burden of infectious disease has always been the lack of quantitative data (intervention studies, randomized controlled trials etc.) indicating the extent to which infections result from poor hygiene relative to other causes. Although epidemiological studies have been used to assess the impact of hand hygiene, household water treatment and safe disposal of faeces, relatively few studies have directly assessed the health impact of procedures such as surface hygiene, cleaning cloth hygiene or laundry hygiene. Even for hand hygiene, where intervention or case-control studies have been performed, most of these have involved settings such as schools or day-care centres rather than the home and everyday life settings.

Assessing the health impact of practices, such as surface and cleaning cloth hygiene, either in combination with or separate from that of practices such as hand hygiene or household water treatment, is particularly difficult because of the multiplicity and close interdependence of the routes of infection transmission which make it difficult to determine the separate effects of different interventions, and the difficulties in controlling variables. It also stems from the large population sizes required to produce a significant result which makes the cost of such studies prohibitive. The impact may also vary from one community or even one household to another, according to a range of factors such as the types of pathogens prevalent within that community, their modes of transmission and the social conditions and domestic habits of the study population. In developing codes of hygiene practice for the home, this makes it difficult to assign values to the relative importance of different procedures e.g., hand hygiene relative to surface hygiene.

Relative to intervention and observational study data, there is now a large body of microbiological data which shows the extent to which infectious disease agents enter the home, how they survive and are spread, the extent to which we are exposed to these agents in our daily lives, and what is known about their infectivity. A limiting factor is that the majority of these data come from homes in developed countries, with advanced systems of water and sanitation. Although laboratory tests and field data can be used to quantify the impact of hygiene procedures on transmission of infectious agents, they give no assessment of how microbiological contamination reduction correlates with reduction in disease burden. Risk modelling techniques now offer the possibility to perform such assessments but this approach is also open to challenge.

Currently, there is still a tendency to demand that data from intervention studies should take precedence over data from other sources in formulating public health policy. Although there are those who still adhere to this, it is increasingly accepted that, since transmission of pathogens is so complex, infection control policies and guidelines must be based on the totality of evidence including microbiological as well as epidemiological data. This is particularly important for home hygiene, for which little or no intervention data is available and where it is virtually impossible to isolate the effects of specific hygiene procedures (handwashing, surface hygiene, laundry, washing and bathing etc.). This shift of opinion is reflected in a 2005 document produced by the UK Health Development Agency which concluded that “Although the randomised controlled trial (RCT) has the highest internal validity and, where feasible, is the research design of choice when evaluating effectiveness, however, many commentators felt the RCT may be too restrictive for some public health interventions, particularly community-based programmes. In addition, supplementing data from quantitative studies with the results of qualitative research is regarded as key to the successful replication and ultimate effectiveness of interventions”.

In the following section, the IFH targeted approach to home hygiene is outlined. The development of this approach has been based on a consideration of the totality of data.
which ranges from microbiological studies (laboratory and field-based), to investigations of outbreaks, data from intervention and observational, and data generated by quantitative microbial risk assessment. These data are summarised in Appendices 1-6.

2.2. DEVELOPING THE IFH TARGETED APPROACH TO HOME HYGIENE

As outlined in the introduction, in devising a strategy for home hygiene and producing hygiene practice advice, the IFH has developed an approach based on risk management which involves identifying the “critical control points” for preventing the spread of infectious disease. Risk management is now the standard approach for controlling microbial risks in food and other manufacturing environments, and is becoming accepted as the optimum means to prevent such risks in home and healthcare settings.11,14,15

The key feature of the IFH approach is that it recognises the need to look at hygiene from the point of view of the family and the total range of problems that they faces in order to reduce infectious disease risks. This includes risks related to poor food and water hygiene, poor personal hygiene (particularly hand hygiene), hygiene related to clothing and household linens, and hygiene related to the general environment (toilets, baths, hand basins, surfaces etc.), to domestic animals, and to family members at increased risk of infection. Other factors include unsafe disposal of faeces and refuse. Adopting a holistic approach makes sense, since all these issues are interdependent and based on the same underlying microbiological principles. A risk assessment approach also forms the basis for developing an approach to home hygiene which can be adapted to meet differing needs in differing communities across the world. Indeed, it is only by adopting such a holistic approach that the causal link between hands and infection transmission in the home can be addressed properly, since hand hygiene is a central component to all of these issues.

The IFH risk approach starts from the principle that pathogens are introduced continually into the home, by people (who may be ill or infected even without apparent symptoms), food and domestic animals, but also sometimes in water, via insects, or via the air. People, food, water, animals etc. as sources of infection in the home are reviewed in Appendices 1.1.1, 1.2.1 and 1.3.1. Household pets as a source of infection has also recently been reviewed by Chomel and Sun (2011).16 Additionally, sites where stagnant water accumulates such as sinks, toilets, waste pipes, or items such as cleaning or face cloths readily support microbial growth and can become primary reservoirs of infection; although species are mostly those which represent a risk to vulnerable groups, primary pathogens can also be present. Damp conditions such as the tiling and other surfaces in kitchens and bathrooms readily support the growth of fungi, but sites of fungal growth also include carpets and soft furnishings.17 Fungi found on these surfaces are mostly opportunistic species that cause infection in the immuno-compromised community living at home.

As long as there are people, animals and food in the home, there will always be a risk of exposure to pathogens. In many homes, there will also be at least one family member who is more susceptible to infection for one reason or another.

Reducing the spread of infection in homes and everyday life is achieved in 2 ways:

- To some extent we can control the spread of infection by controlling potential infection sources/reservoirs e.g. preventing the growth of mould and fungi, safe storage of food etc.
- By controlling the vectors (e.g. insects) and vehicles (e.g. hands and surfaces) which serve as transmitters of pathogens.
Within the home (as in other environments) there is a chain of events, as described in Figure 2 that results in transmission of an infection from its original source to a new recipient such that when circumstances combine, people become infected.

![Figure 2 – The chain of infection transmission in the home](image)

The risk-based approach to home hygiene has previously been outlined in a number of IFH publications.18,19 To carry out a risk assessment, sites and surfaces in the home are categorised into six groups: reservoir sites, reservoir/disseminators, hands, hand and food contact surfaces, clothing and household linens, and other surfaces. Risk assessment is based on assessing the frequency of occurrence of pathogenic contamination at that site, together with the probability of transfer from that site such that family members may be exposed. This means that, even if a particular environmental site is highly likely to be contaminated, unless there is a probability of transfer from that site, the risk of infection transmission is low. From this, the “critical control points” for preventing spread of infection can be determined.

The development of this risk-based approach has been based largely on consideration of the available microbiological data as detailed in the Appendices, including assessments of:

- frequency of occurrence of sources of pathogens in the home;
- rate of "shed" from an infected source into the environment;
- rate of die away on hands and surfaces etc.;
- rate of transfer via the hands to the mouth, nose, conjunctiva etc. or to ready-to-eat foods;
- the infectious dose. A key factor which determines the infection risk is the number of particles to which the recipient is exposed, their immune status and the route by which they are infected. The “infectious dose” varies for different pathogens and is usually lower for people who are immuno-compromised than for healthy household members.

Overall these data suggest that:

- For reservoir sites such as the sink, waste pipes or toilets, although the probability of significant contamination (i.e., with potentially pathogenic bacteria, fungi or viruses) is high, the risk of transfer is relatively limited, unless there is a particular risk situation (e.g., a family member with enteric infection and fluid diarrhoea, when toilet flushing can produce splashing or aerosol formation that can be inhaled or come into contact with the eyes or nose, or can settle on contact surfaces around the toilet).
• For reservoir sites such as wet cleaning cloths, not only is there a high probability of significant contamination, but, by the very nature of their usage, they carry a high risk of disseminating contamination to other surfaces and to the hands.

• For hands, and hand contact and food preparation surfaces, although the probability of significant contamination is, in relative terms, less, it is still significant, for example, particularly following contact with contaminated food, people, pets or other contaminated surfaces such as door, tap (faucet) and toilet-flush handles. Since there is a constant risk of spread from these surfaces, hygiene measures are important for these surfaces.

• For clothing and household linens, although the probability of significant contamination is less than for hands, hand and food contact surfaces and cleaning utensils, the microbiological data suggests it is still significant, particularly following contact with an infected source (people, raw contaminated food, domestic animals). Since there is a risk of spread from these surfaces, it is important that, for items that come into direct contact with body surfaces, laundry processes should be used which eliminate contamination.

• For other surfaces (floors, walls, furniture etc.), risks are mainly due to pathogens such as *S. aureus* and *C. difficile* that survive dry conditions. Because the risks of transfer and exposure are relatively low, these surfaces are considered low risk, but where there is known contamination, (e.g., floors soiled by pets) crawling infants may be at risk. Cleaning can also re-circulate dust-borne pathogens onto hand and food contact surfaces. However, damp surfaces e.g. tiled bathroom or shower surfaces can support the growth of fungi/moulds which can be spread by hand, feet or body contact or by airborne dispersal of spores.

Overall, this approach allows us to rank sites and surfaces (Figure 3) according to the level of risk. This indicates that the “critical control points” or “component causes” of infection transmission in the home are the hands, together with hand and food contact surfaces and cleaning cloths. Although, in some cases, the hands alone may be “sufficient cause” for transmission of an infection (e.g., from an MRSA carrier, to hands, to the wound of a recipient), in other cases, transmission involves a combination of control points, hand and food contact surfaces, cleaning cloths and other cleaning utensils. Transmission via the hands in itself also depends on the extent to which these surfaces become contaminated with pathogens during normal daily activities, i.e., the risk of hand-to-mouth transfer will be increased if extensive transfer from raw food to food preparation surfaces also occurs. Other control points include clothing and household linens, together with other surfaces which come into contact with the body such as baths and hand basins.

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**Figure 3** – Ranking of sites and surfaces based on risk of transmission of infections
Although Figure 3 gives a useful “rule of thumb” ranking, it is not a constant. Risks can increase substantially where a family member is infected. Risks are also increased in situations where there are family members living at home who have reduced immunity to infection.

Whereas Figure 3 is constructed mainly in relation to westernized home where there is adequate access to clean water and a means of safe faeces disposal, it must be recognised that the priorities of home hygiene practices vary substantively between developing and developed countries. In developing countries the home is the vital interface between personal and domestic hygiene and environmental/community hygiene. Given that the level of environmental and community hygiene particularly in respect of safe water and sanitation are often extremely poor, particularly in low income communities, Figure 4 gives a more realistic basis for prioritising hygiene interventions in the homes of developing countries, where safe disposal of faeces, adequate and safe water, and hand washing are regarded as the basic “pillars” for building effective hygiene practice.

![Figure 4](image)

**Figure 4 – Ranking of sites and surfaces based on risk of transmission of infections**

For example:

- For rural and urban unserved communities, the priority is to educate and empower people on how to achieve safe disposal of faeces, ensure a sufficient supply of clean water for drinking and how to develop a culture in which handwashing at critical times is an accepted norm.
- For other communities, the extent to which the community needs to take responsibility for activities in stage 1 and 2 will vary according to prevailing conditions i.e. the availability of water, sanitation, municipal waste collection and wastewater drainage.
- For urban middle class served communities, although basic amenities of sanitation, water and refuse collection may be available, promotion of handwashing at critical times and safe refuse disposal are still a major priority. If municipal water quality is poor, promoting “water at point of use”, hygiene must also be included as a priority. For these communities it should be possible to build stage 2 and 3 interventions into hygiene promotion programmes.

This approach is described in more detail in the IFH home hygiene training resource for developing country situations. The IFH Home Hygiene guidelines contain the results of a review by Feacham in which he rates the importance of different interventions in relation to different types of infections e.g. diarrhoea, helminth, skin, eye etc.
SECTION 3. ASSESSMENT OF THE CAUSAL LINK BETWEEN HYGIENE PRACTICE AND INFECTIOUS DISEASE TRANSMISSION

In this section the data from microbiological, observational and intervention studies, and studies involving Quantitative Microbial Risk Assessment (QMRA), as documented in the Appendices, are integrated and compared in order to draw conclusions about the routes of infection transmission, the strength of the causal link between hygiene and infectious disease, and the relative impact of different hygiene interventions on infectious disease rates in home and everyday life settings.

3.1. SOURCES OF PATHOGENS IN HOME AND EVERYDAY LIFE SETTINGS

Appendices 1-4 show that the main sources of pathogens in home and everyday life settings are people or animals that are infected (or are carriers), and contaminated food and water. Surveillance data suggest that these pathogen sources are constantly present in our homes and elsewhere. An interesting finding of this 2011 review is the extent to which the data (not only microbiological, but also observation study data) implicate domestic animals as a source of GI infections in the home. Case-control studies, as cited in Appendix 5.1, identified pets and domestic animals as significant risk factors for campylobacter infection in 3/5 studies, whilst pets and reptiles were identified as risk factors for *Salmonella* in 6/9 studies. In one of these studies, the authors concluded that environmental sources, infected family members and pets were more significant risk factors for salmonellosis in children than contaminated foods. The data also suggest that dogs and cats can act as a source and/or vector of MRSA in the home. Although the public are traditionally most concerned about the risks associated with the “germs” that can form permanent resident populations in their home environment (e.g. in the toilet or sink waste trap), the data (as reviewed in appendix 3) suggest that these are mostly (although not always) potential or conditional pathogens which represent a risk mainly to those who are immuno-compromised.

3.2. ASSESSING THE CAUSAL LINK BETWEEN HYGIENE AND INFECTIOUS DISEASE USING MICROBIOLOGICAL DATA

Microbiological data from field studies and laboratory models (Appendices 1.1.1, 1.2.1 and 1.3.1.1) show that pathogens are constantly being shed or spread (often in high numbers) from human, animal and food sources in home and everyday life settings, and are transmitted via environmental sites and surfaces such that people become exposed. The IFH targeted approach to hygiene focuses on breaking the chain of infection transmission by intervening at “critical points” in the chain. The key principle of this approach is that, in order to identify critical points, it is necessary to assess not only the likelihood that pathogens may be present, but equally, whether they are likely to be transferred around the environment such that we are exposed to them.

Microbiological data showing shedding of pathogens from an infected person, contaminated food, domestic animals etc., is consistent with data (Appendix 1.1.2, 1.2.1, 1.2.4, 1.3.1.2, 1.3.2, 2 and 4) showing that these agents can be isolated from hands, hand contact surfaces, food contact surfaces and cleaning utensils in the home and elsewhere. The data suggest that the greatest risks occur immediately after contact with, or shedding from an infected source. During the 1980s, infection risks associated with environmental sites and surfaces were largely assessed from audit studies which involved microbiological sampling of sites and surfaces in homes sampled at random. These studies, as reviewed in Appendix 3, showed that, although pathogenic species are present, detection is relatively infrequent in
homes sampled at random, even in studies involving up to 200 or more homes. These data tended to foster a view that infection transmission risks via hands and environmental sites and surfaces in the home are relatively low. Since around 1990, studies now tend to focus on looking at the extent of shedding, persistence and spread of organisms via hands and surfaces from a known infected source such as contaminated food or an infected person. This report contains the significant amount of data, published since the 2002 IFH review (see Appendix 1.1) which confirms that, following handling of contaminated food, or where there is an infected person present, enteric pathogens such as *Salmonella* or *Campylobacter* are frequently isolated from hand and food contact surfaces. Of particular interest is the range of new studies, which support earlier data (Appendix 1.2) showing the extent to which, not only enteric viruses such as norovirus, but also respiratory viruses such as rhinovirus, influenza and parainfluenza viruses, can be found on “critical point” surfaces, in situations where there is known to be, or is likely to be, an infected person. Data in Appendix 1.3 show the extent to which *S. aureus* (including MRSA) can persist and be transferred via hands and environmental surfaces where there is a known infected person. Most surprising perhaps, (in contrast to the audit studies as mentioned above) is the 2010 study of Boone and Gerba\(^\text{22}\) where parainfluenza virus was isolated from 37% of surfaces in office buildings sampled at random. Appendix 1.1.2 also contains 3 examples from studies reported in 2010 and 2011 where norovirus was detected on environmental surfaces in the absence of an identified infected source.\(^\text{23,24,25}\) Another new study\(^\text{26}\) shows that, not only *S. aureus* but also MRSA, can be found on environmental surfaces in homes sampled at random (i.e., not selected on the basis that there was an identified carrier). Although the hands are assumed to be the main vehicle for transmission of infection in the home there is surprisingly little data on the nature and extent of hand contamination, both during normal daily activities or associated with exposure to an infected source, but some studies e.g. studies involving handling of contaminated poultry or contaminated cloths confirm this.

From the data which shows the high levels of pathogens (up to $10^4$-$10^{11}$/g for enteric pathogens, $10^7$/ml for influenza virus) found in very small volumes of faeces, vomit, food particles, skin scales etc., and the amounts of material which are shed or spread, it must be assumed that the numbers of organisms deposited within a relatively small area of these surfaces can be well in excess of $10^9$ to $10^4$ or more cells or particles. Importantly, although there is an amount of data, showing the frequency with which pathogens shed from an infected source can be found on surfaces, there is currently little data on the numbers of cells or particles which can be recovered from these surfaces over extended time periods following contamination. One example is the studies of Cogan *et al.*\(^\text{27,28}\) which showed that, following preparation of *Salmonella* and *Campylobacter*-contaminated chickens as an infection risk in domestic kitchens, these species could be isolated from 17.3% of hands, and hand and food contact surfaces. Although 18.3% of sites recorded *Salmonella* counts of <10, on 22 (18.3%) and 2 (1.7%) of occasions, counts were >10 and >1000, respectively. For *Campylobacter*, 20% of sites recorded counts of >1000. Sampling of surfaces 3 hours later\(^\text{27}\) showed that 7% of surfaces were still contaminated with either *Salmonella* or *Campylobacter*.

Although there is relatively little data available, it would be expected that children’s toys are an important hand (or mouth) contact site for transmission of enteric and respiratory pathogens, particularly as these items frequently come into contact with children’s mouths. The available data are reviewed in Appendix 3. Most studies review data for toys sampled at random rather than in situations where there is a known infected source.

A key factor which determines the risks associated with hands and surfaces is the extent to which infectious agents can survive outside a human or animal host and retain their infectivity. The data (Appendices 1.1.2, 1.2.1, 1.3.1.2, 1.3.2, 2) indicate that the numbers of viable units decline at a more or less rapid rate, depending on the species and other factors...
such as surface type and RH. The data indicate that Gram positive spp. such as *S. aureus*, *C. difficile*, and fungal spp. can survive long periods (several days to months) on hands and non-porous surfaces. Although Gram negative species such as *E. coli* and *P. aeruginosa* are generally more sensitive to drying, survival times of the order of up to 4 or more hours are recorded. In one study, survival of *E. coli* O157 for up to 60 days on stainless steel and 10 days on a chopping board was reported. Reported survival times for viruses on non-porous surfaces vary significantly; some data suggest that both enveloped and non-enveloped viruses can survive for up to 3-4 hours, whilst other investigators suggest survival times of days and weeks, particularly for non-enveloped viruses. Survival times for the enveloped influenza and PIV viruses are relatively less than for non-enveloped rhinovirus and Respiratory syncitial virus (RSV), particularly on hands where parainfluenza virus (PIV) and influenza virus appear to survive relatively short periods (measured in minutes). This may be due to the presence of fatty acids on the skin which exert a virucidal effect via the lipid virus envelope. This may have a significant impact in reducing the transmissibility of the enveloped influenza viruses via hands, relative to the non-enveloped rhinoviruses and RSV.

A further determinant of the infection risk is the extent to which these agents are transmitted around the environment such that we become exposed either by direct hand to mouth or to the nasal mucosa etc., or indirectly by transfer to food which is then consumed. Laboratory models (Appendices 1.3.1.2, 1.3.1.3, 1.2.1, 1.2.2, 1.3.1.2, 1.3.1.3, 2) suggest that transfer rates for enteric pathogens from contaminated surfaces to hands and from contaminated hands to surfaces are of the order of 10-60%, but could be as little as 1% or as high as 100%. The data also show significant transfer from contaminated hands to the mouth or other foods, or to the nasal mucosa.

Taken together, the total data indicate that significant numbers of bacterial, viral and fungal pathogens are constantly circulating in the environment such that we are regularly exposed to potentially infectious doses. The data (Appendices 1.1.3, 1.2.2, 1.3.1.3) show that infectious doses for bacteria such as *Campylobacter* and *E. coli* O157 may be as little as 100-500 cells whilst for some viruses, 1-10 particles may be sufficient. For the most part, the body defences are able to deal with this challenge, but in some cases infection results. This is increasingly important for the increasing numbers of people particularly for those with lowered immunity to infection who are now living in the home and community.

Risk assessment shows that clothing and household linens are also potential vehicles for infection transmission. In view of the large amount of data on this subject it was decided to address this issue in a separate IFH report. The data in this report show that fabrics can become contaminated with bacterial, viral and fungal pathogens. The main contaminants are organisms such as *S. aureus* shed from the skin surface and other pathogens from the body flora such as dermatophytic fungi and enteric pathogens. The data suggest that the greatest risks occur immediately after contact with, or shedding from, an infected (or carrier) source, but pathogens can survive on, and be transferred from, fabrics for significant periods of time. The microbiological data suggests however that risks associated with clothing and linens (particularly when dry) are somewhat less than those associated with the hands, hand and food contact surfaces, and cleaning cloths. This is because survival of pathogens on porous surfaces such as fabrics is significantly less than that on non-porous surfaces, and the transfer rates for bacteria and viruses from fabrics to hands are much lower. Opportunities for infection via clothing etc. are also less frequent; whereas there are constant opportunities for person to person transfer through mutual touching of e.g. door or tap handles, we do not deliberately touch other people’s clothing. Whereas the small area of a door or tap handle means that it is highly likely that people will touch the same area, the large area offered by clothing makes this less likely. Although the data suggest that laundry handling represents a risk, the risk is specific to the person handling the laundry. A separate concern is that, where laundry processes are insufficient to eliminate pathogens, these can be transferred to other
clothing. This is a current concern in relation to the trend towards using low temperature laundry cycles. There is little data on the extent to which microbes can be shed onto environmental surfaces from clothing and household linens, but the IFH report\(^{29}\) contains some data on shedding of \textit{S. aureus} from bed linens during changing of bedding.

The major threat posed by antibiotic resistance means that greater emphasis must now be placed on preventive strategies rather than relying on antibiotic therapy. By preventing spread through better hygiene, we also reduce the reservoir of antibiotic resistant strains circulating in the community. An example of this is the community MRSA strains (CA-MRSA) which are just as likely to affect young active people as the elderly or infirm. The findings of the IFH report\(^{29}\) suggest that transmission via clothing etc. is (alongside transfer via hands and surfaces etc.) a risk factor for spread of \textit{S. aureus} (including MRSA), and that the hygienic effectiveness of laundry processes is important in defining their rate of spread in the community. Over the period since 2002, CA-MRSA strains have become a major problem in the US, but are still relatively uncommon in Europe and elsewhere, and there is still an opportunity to avoid the problem escalating to a similar scale. We need to assess the impact of hygiene, not only on MRSA infections, but also on colonisation rates in households and communities. Data assessing the infection risks associated with \textit{S. aureus} (including MRSA) and the impact of hygiene are reviewed in Appendices 1.3, 2, 5.1.3 and 5.2.3. Risk assessment suggests that contact surfaces of \textit{baths, kitchen and bathroom wash basins, draining boards etc.} also have the potential to act as vehicles for transmission of infection. Data from “audit” studies where homes were sampled at random (Appendix 2, Section 3) (i.e., not selected on the basis that there was an identified carrier) indicate that these wet or damp surfaces are commonly associated with high total counts and the presence of \textit{E. coli} and coliforms (isolation rates were mostly of the order of 10-20%, but up to 60% isolation rates were recorded for coliforms on kitchen sink surfaces) and \textit{S. aureus} (including MRSA) (isolation rates for \textit{S. aureus} ranged from 0.5 to 20%). A number of these studies showed the presence of \textit{Salmonella}, \textit{Listeria} and \textit{P. aeruginosa} on kitchen sink surfaces, whilst \textit{P. aeruginosa} was also isolated from baths and wash basin surfaces and \textit{Listeria} spp from toothbrushes in the bathroom. The data suggest that the stagnant water which builds up in sink waste traps can act as semi-permanent sources or reservoirs of organisms (sometimes as biofilms) such as \textit{E. coli} and \textit{Salmonella} and that these free-living populations can transfer back into the basin due to splashing and aerosols.

This report (Appendix 1.1.2) contains new data assessing the potential risk from splashing and aerosols generated by flushing of \textit{toilets}. Although there is an assumption that infection risks from properly functioning toilets are relatively low, the data suggest that dissemination of pathogens by splashing and aerosol formation during toilet flushing, particularly where someone is vomiting into the toilet, or has fluid diarrhoea e.g., where there is a norovirus outbreak or salmonella infection can cause infection. It must be borne in mind that, in the home, there is also risk of direct contact with toilet surfaces, by small children who see this as just another play area to be explored. An issue which has been receiving recent attention is the potential risks associated with \textit{aerosols generated by shower heads}. Recent data as reviewed in Appendix 1.2.4 report isolation of species such as \textit{Mycobacterium avium} and \textit{Legionella pneumophila} from showerheads in homes and apartments, and in some instances this has been linked to outbreaks of \textit{Legionella}. In general, it is concluded that the risks are low, and that preventive action is only/mainly required in homes where there are people who are immuno-compromised.

Microbiological data indicate that infection transfer risks via \textit{floors, walls and furnishings} are relatively low except under certain specific conditions. The report contains data indicating that dry surfaces such as floors and furnishings play a part in the spread of desiccation-resistant organisms such as \textit{S. aureus} (including MRSA), \textit{C. difficile} and fungal spores. This report contains some of the increasing number of studies showing that environmental
cleaning contributes to reducing hospital infection risks from MRSA and C. difficile, but more data are needed to show the extent to which transmission via floors and furnishings (relative to hand contact surfaces etc.) represent a risk in the home. It is interesting to note that, alongside the observation studies suggesting that domestic animals can be a source of Salmonella infection, microbiological data in Appendix 1.1.2 suggest that Salmonella can survive in house dust on floors and furnishings, and can represent an infection risk. However, data reviewed in Appendix 4 shows that damp surfaces, particularly e.g. tiled bathroom or shower surfaces but also other surfaces can support the growth of fungi/moulds which can be spread by hand, feet or body contact or by airborne dispersal of spores.

3.3 ASSESSING THE LINK BETWEEN HYGIENE AND INFECTIOUS DISEASE USING INTERVENTION STUDIES

Appendix 5.2 of this report reviews the growing amount of intervention study data which provides consistent evidence of a strong causal link between poor hygiene and the spread of infections in home and everyday life settings. The majority of studies, as reviewed in Appendix 5.2.1 address the impact of hand hygiene, either alone or in combination with environmental hygiene. Only a few studies have evaluated the impact of environmental hygiene in isolation, and none compared the impact of environmental hygiene relative to hand hygiene.

For studies where hand hygiene (either handwashing or using an alcohol hand gel) was assessed as the sole intervention, the microbiological data are well supported by data from intervention studies. These data (summarised in Table 4) suggest that the hands are the “sufficient”, or a “component” cause of spread of infection, for up to 59 and 79% of GI illnesses for developed and developing country situations, respectively. This fits with the microbiological and observation data which suggest that, although there is a tendency, in developed country situations, to assume that GI infections are mostly food-borne and result from inadequate cooking and inadequate storage of food, in reality, many or most GI infections (particularly in low income communities in developing countries) result from person-to-person (faecal:oral) spread, involving hand to mouth transfer or transfer from hands to food which is then eaten. For RT infection, the data (summarised in Table 4) suggest that transmission via hands could be a sufficient or component cause of up to 53% of illnesses; whereas there has been a tendency to assume that the impact of hand hygiene on RT infections is lower than for GI infections because spread of RT pathogens is mainly airborne, the microbiological data (both laboratory and field data as reviewed in Appendix 3.2.1) suggest that, for RT infections such as rhinovirus and RSV, the hands are the major route of spread. Only 3 studies are reported in which the impact of hand hygiene on skin and eye infections was studied; studies by Luby et al.30 carried out in Pakistan showed a 25-34% reduction in rates of impetigo in children whilst Nicholson et al.31 in Mumbai demonstrated a 46% reduction in eye infections in children aged approximately 5 years old.

Intervention study data presented in this review (Appendix 5.2.2) indicate that unsafe disposal of faeces and household handling and storage of water can be a sufficient or component cause of GI infection. In the most recent reviews Waddington et al.32 estimated that, water quality interventions and safe excreta disposal interventions on average effect respectively a 42% and 37% relative reduction in child diarrhoea morbidity, whilst Cairncross et al. propose a diarrhoea risk reduction of 17 and 36%, associated respectively, with improved water quality and excreta disposal.33 However they concluded that most of the evidence is of poor quality and more trials are needed.
Intervention studies where hand hygiene was combined with cleaning and/or disinfection of environmental surfaces (Appendix 5.2.3) also consistently indicate a positive impact on disease rates. The report includes 5 studies\textsuperscript{34,35,36,37,38} which demonstrate the positive impact of combined hand and environmental hygiene in reducing GI (including 1 norovirus study), RT and skin infections, together with absenteeism. Only 1 of these studies was carried out in the home. In this 2007 study of 685 households in South Africa, Cole \textit{et al.}\textsuperscript{36} demonstrated that intensive hand and environmental hygiene education alone and in combination with use of hygiene products (soap, surface cleaner/disinfectant, antiseptic) could produce a significant reduction in GI infections (65-78%), RT (20-75%) and skin (26-77%) infections. Some of the most compelling data demonstrating the impact of hygiene on surface to hand to mouth/eye/nose transfer of GI and RT viruses come from the studies carried out during the 1980s that showed that surface hygiene could prevent experimental rhinovirus infections caused by touching contaminated surfaces\textsuperscript{39} and the studies of Ward \textit{et al.}\textsuperscript{(1991)} which showed that, of 13 out of 14 individuals who touched rotavirus-contaminated plates with their fingers and put the fingers to their mouths, about half became infected.\textsuperscript{40}

Only a few studies have been reported on the impact of environmental cleaning and/or disinfection in isolation. Although these studies consistently indicate a positive impact on disease rates, there was no attempt to assess the separate effects of one type of intervention (e.g., touch surfaces, food contact surfaces, laundry etc) relative to another and thereby rank their importance. The most compelling data showing a positive impact of environmental cleaning relate to MRSA,\textsuperscript{41} \textit{C. difficile} and norovirus infections.\textsuperscript{42,43} This is perhaps unsurprising in view of the microbiological data which demonstrate the ability of these species to survive and retain their infectivity on environmental surfaces. Data showing a positive impact on combined RT and GI infection rates also come from a 2008 school intervention study by Bright\textit{et al.}\textsuperscript{(2009)} in Seattle, US.\textsuperscript{23} This study measured the impact of cleaning surfaces daily with disinfectant wipes before arrival of students on GI and RT illness leading to absenteeism. Despite no significant reduction in bacterial counts on surfaces, children in control classrooms were 2.32 times more likely to become ill than children in intervention classrooms. Studies showing how enhanced cleaning/disinfection can reduce transmission of infection in hospitals is reviewed by Otter\textit{et al.} 2011.\textsuperscript{44}

Although these data come from studies in hospitals\textsuperscript{41,43, and public settings,\textsuperscript{23,42} they indicate the potential for transmission in the home where good hygiene practice is not observed. Data specific to the impact of environmental cleaning on the spread of MRSA in homes come from 3 studies\textsuperscript{45,46,47} where MRSA-colonised healthcare workers (HCWs) were treated to produce eradication, but subsequently became re-colonised. In each case, MRSA was isolated from environmental surfaces (pillows, bed linen, brushes, cosmetics, hand contact surfaces and household dust) in their home, and the problem was only terminated after thorough cleaning of the home environment.

\subsection*{3.4 Assessing the link between hygiene and infectious disease from observation studies}

Appendix 5.1 reviews the growing amount of observational data assessing the link between hygiene and infection. Most, but not all of the data is consistent with the data from microbiological and intervention studies.

For RT infections (Appendix 5.1.2), new data on the impact of interventions such as handwashing, wearing face masks etc. comes from case-control studies prompted by the 2003 SARS outbreak. From a 2003 review of 6 studies relating to this outbreak, Jefferson \textit{et al.}\textsuperscript{48} concluded that handwashing was an effective measure in reducing spread. This report
also contains 2 case-control studies (one related to SARS) which also addressed environmental cleaning, both of which recorded hand and environmental cleaning as risk factors.

For skin infections (Appendix 5.1.3), the only case-control study data relates to MRSA. In addition to reviewing US population-based data citing skin-to-skin contact and indirect contact with contaminated objects such as towels as risk factors, Appendix 5.1.3 reviews 10 studies involving the home environment. Five of these studies involved healthcare workers at home for whom the environment was cited as a causative factor in recolonisation following treatment to eradicate MRSA, whilst 7 reported transmission to other family members.

For GI infections, Appendix 5.1.1 reviews 25 outbreak studies where hands, hand and food contact surfaces, clothing and linen, toilets and other surfaces were implicated as a, or the, route of transmission, including outbreaks associated with Salmonella (6 studies), E. coli (2), Campylobacter (2), Listeria (1), Helicobacter pylori (2), norovirus (9), rotavirus (3) and hepatitis A (3). Some of the data from case-control studies however, tend to conflict with these findings, and with the microbiological data. This IFH report reviews a number of relatively large scale case-control studies, and systematic reviews of these studies, which investigated the links between foodborne infection and food handling behaviour (food preparation, temperature control, and opportunities for cross contamination) in domestic kitchens. In their systematic review Stenberg et al. in general found no differences between cases and controls. Contrary to the microbiological and other data, their reanalysis of the UK IID study showed no difference between numbers of cases and controls which reported not using a separate chopping board for raw and cooked foods, not cleaning the chopping board between raw and cooked food, and using the same cloth for wiping all kitchen surfaces. Since there was no possibility to identify and exclude non-foodborne cases from the data, it is perhaps unsurprising that the studies failed to identify food handling activities as significant risk factors for GI infection. These studies show the difficulties of making accurate assessments about hygiene risk factors for GI disease from studies which use pooled data involving a range of different pathogens with different transfer properties and interdependent routes of transfer. Stenberg et al. conclude “It is doubtful that the impact of domestic kitchen hygiene can be resolved based on case-control studies. There is a need for properly conducted intervention studies to really investigate the contribution which particular domestic kitchen hygiene practices may or may not have on the risk of diarrhoeal disease”. These would only have relevance if it is possible to exclude GI infections outcomes which are non-foodborne.

Although the epidemiological data shed little light on the relative risks associated with different environmental "control points", one factor which was identified as significant in several case-control and other studies was the laundering of clothing and household linens. These data are reviewed in a separate 2011 IFH report. Of particular relevance is the 2001 correlational prevalence study of Larson and Duarte which examined the relationship between specific hygiene practices and prevalence of GI, RT and skin infectious disease symptoms in household members in a city population in New York. In general, the study showed no association between a range of hygiene practices (frequency of personal bathing or showering, cleaning of kitchens, bathrooms and toilets, changing of dish-sponges, or use/non-use of antimicrobial cleaning products) and infection risk. However 2 activities, using a communal laundry and not using bleach in communal laundering were found to be predictive of increased risk of infection (although duration of bathroom towel use was not significant). Again the results are unsurprising since, apart from laundry, the “hygiene” practices investigated were mostly non-targeted daily or weekly routine cleaning activities which are unlikely on their own to have a measurable impact on breaking the chain of infection.
SECTION 4. DISCUSSION – REVIEWING THE IFH RISK-BASED APPROACH TO HOME HYGIENE

In this section the data from microbiological, observational and intervention studies is considered in relation to the validity and development of the IFH targeted approach to home hygiene as outlined in Section 2. The “targeted” approach to hygiene in home and everyday life settings was developed by IFH during 1997 to 2000 using the microbiological evidence available at the time. This approach is outlined in Section 2. In general, the totality of data as detailed in this review continues to fit well with the IFH targeted approach.

Overall, the intervention study data, as reviewed in this report, consistently demonstrate the positive impact of hand hygiene, safe collection, storage, handling and point of use treatment of household water, safe disposal of faeces and environmental hygiene (either alone or in combination with hand hygiene) on infectious disease rates, thereby establishing the critical nature of these interventions, or groups of interventions, as “control points” for breaking the chain of infection. As far as environmental hygiene (surface hygiene, laundry hygiene etc.) is concerned however, there has been little or no attempt in any of these studies to separately assess the impact of individual environmental interventions such as surface, cleaning cloth or laundry hygiene on disease rates. This makes it very difficult to assess their relative importance i.e. their relative contribution to reducing infectious disease rates in the home.

To an extent, the lack of intervention study data can be overcome, by using the microbiological data together with observation studies of people’s behaviour in the home (such as the studies of Griffiths et al. as described in section 4.1) to assess the risks associated with different routes of infection transmission (surfaces, cleaning cloths, airborne etc.) relative to those associated with the hands, for which quantitative estimates of the impact of hygiene measures on GI, RT and skin infection diseases rates provide a benchmark. In general, the microbiological data continue to fit well with the ranking hierarchy of risks as shown in Figure 3. The data indicate that, overall, the hands are the single most important transmission route since they come into direct contact with the mouth, nose and conjunctiva of the eyes. Comparison of the microbiological data and observation data for contact surfaces against data for hands indicates that these are also important risk factors or control points. The data suggest that the most important are surfaces which come into contact with our hands and body surfaces, and with food and water. These include hand and food contact surfaces (including children’s toys), cleaning cloths and other cleaning utensils. This conclusion is inferred, not only from the microbiological data which shows that pathogens are readily transferred to these surfaces from contaminated sources during daily life activities, but also the fact that daily life activity and conditions offer constant opportunity for contact with, or onward transmission from, these vehicles. As far as clothing and household linens are concerned, the microbiological data suggest that, although these are important risk factors, the risks are probably somewhat less than those associated with surfaces such as the hands, hand and food contact surfaces, and cleaning cloths. The data in Appendix 1 suggest that surfaces which come into contact with the body such as baths and hand basins can also sometimes act as vehicles of infection, as can surfaces associated with the toilet.

The relative contribution to household illness from transmission of RT and GI infections via aerosol particles, as compared with hand and surface transmission, is not well understood. For colds and flu, based on the available evidence as reviewed in Appendix 1.2 and 5.2.1, opinion as to the importance of the hands and surfaces relative to the airborne route is divided. Some investigators maintain that, for cold viruses such as rhinovirus and RSV, contamination of the hands followed by inoculation of the eyes or nose is of paramount importance whilst others maintain that the evidence favours droplet and droplet nuclei transmission as the most important mode of spread, particularly for influenza virus. Although there is data which shows that wearing of masks can contribute to reducing risk of spread of
RT infections such as SARS and influenza, there is no data on the impact of basic respiratory hygiene (e.g. covering the nose and mouth during coughing and sneezing) on RT infection rates. In section 5.1.1 data supporting aerosol transmission of norovirus is reviewed, but again there is no data to show the importance of this route relative to transmission via hands and surfaces.

As stated in Section 2.2, although this gives us an assessment of the “daily life” risks associated with these various sites and surfaces and the activities associated with them, it is important, in developing hygiene practice codes, to recognise that these risks are not constant, and can increase significantly under certain conditions. For example, although risks from toilets, sinks, floors etc., relate mainly to the relatively low risk of transfer from these sites to hands, hand and food contact surfaces and cloths, this risk can increase substantially where an infected family member has diarrhoea, or where a floor surface is contaminated with vomit or faeces. Similarly, the risks of transmission via clothing and household linens will increase where one family member has a skin or wound infection. Risks are also increased where there are family members living at home who have reduced immunity to infection and may require special care to protect them from infection.

Some quantitative estimation of the health impact (i.e., the infectious disease reduction), and relative impact, of individual hygiene practices, can be achieved using Quantitative Microbial Risk Assessment (QMRA) which, as outlined in Appendix 6, involves using published data on each stage of the transmission cycle to calculate a quantitative estimate of the impact of a specific hygiene intervention on infection rates. Although risk modelling is a promising approach, it has limitations because of the multi-factorial nature of infection transmission and paucity of data to specify model parameters. What QMRA-generated data do illustrate however is how even a relatively small quantifiable increase in the log reduction (e.g., using a process which produces a 3 rather than a 2 log reduction on hands) can translate into a significant decrease in the risk of infection transmission within a national population.

In developing appropriate hygiene practice codes, a particular concern is the fact that the majority of the available microbiological data come from studies in developed countries and from homes with access to “high quality” water and sanitation. Of interest are new studies which are now being carried out in developing countries, as reported in Appendix 3.3, which allow us to begin to assess the risks from environmental contamination in situations where many of the amenities which are standard in westernised homes, are lacking. The recent studies carried out in 8 homes in Cambodia by Sinclair and Gerba are of particular interest. The data suggest that levels of faecal and faecal indicator bacteria were up to 2 logs higher than in equivalent situations (sites and surfaces) in homes in the US and Japan, despite the fact that the Cambodian homes had a pour-flush latrine for disposal of faeces. The extent of the differences in environmental contamination levels suggest that more extensive studies of these environments should be carried out to better inform decisions about hygiene promotion in developing country settings in relation to their access to adequate water, sanitation and other amenities.

4.1 Using data from all sources to assess hygiene risks and develop codes of hygiene practice

This report is unique, because it brings together data from various experimental approaches to provide clearer insights into the causal link between hygiene and infectious disease rates. One of the things which clearly emerges from this exercise is the need to always consider data from microbiological as well as from epidemiological studies in making risks assessment and informing decisions about codes of hygiene practice. In the past, as
discussed in Section 2, there has been a tendency to demand that a specific intervention should only be recommended on the basis of intervention study data which shows a clear health benefit. New thinking on infection prevention is now challenging the assumption that decisions regarding which interventions should be considered as critical control points and which should be excluded, should only be made on the basis of clinical evidence of health benefit. It is now being argued that not only is this not achievable, where routes of transfer are closely inter-dependent, but is also not the most effective or practical approach. This report shows that reliance on intervention study data alone can be misleading and that predictive tools such as models to assess transmission risk must be used in conjunction with interventions studies to structure decision when formulating hygiene codes. Since there is little epidemiological data available on the impact of environmental interventions, IFH has relied almost entirely on microbiological data coupled with known modes of infection transmission to formulate hygiene codes for home and everyday life settings.

This report shows that using pooled data from intervention studies from different communities to estimate disease reductions rates, can also be misleading. Hand hygiene intervention data, as summarised in Table 4, for example, indicate that disease reduction rates can vary significantly e.g., they suggest that the impact on GI diseases in developing country situations may be as little as 26% up to as much as 79%. This could be due to different methodologies and methodological issues, but could just as well be due to real difference in the level of impact within and between study communities. Microbiological data suggest that differences in outcome may relate to differences in the range of pathogens with differing modes of spread prevalent in different study groups, which means that hand hygiene has greater impact in some intervention groups than others. As stated by Eisenberg et al. 2007\textsuperscript{52} “the efficacy of any hygiene intervention strategy depends on the level of pathogen exposure through other pathways. This may explain why some household water quality interventions have shown disease reductions as high as 85% whilst others have shown none”. For practices such as hand hygiene, it may also reflect differing levels of hand hygiene compliance; the quality of the hygiene education, the approach to hygiene promotion, and the enthusiasm with which it was received, may have given some intervention groups a better understanding of what was required, with the result that they were more likely to apply it at critical times or use better hand hygiene technique. As discussed in Appendix 6, QMRA illustrates how, even a relatively modest increase in log reduction on hands within a population, could produce a significant increase in the health impact of a hygiene promotion campaign.

The microbiological data also shows that, although intervention studies assessing the impact of hygiene measures on “pooled” GI or RT infection rates determined on the basis of non-specific symptoms rather than identification of the causative agent may be the most cost effective approach, results must be extrapolated with care. Microbiological data in Section 1.2.1 show, for example, that survival of influenza on hands is less than for rhinovirus and RSV, which means that assessments of the impact of hygiene on RT infections, measured on the basis of respiratory symptoms alone may not reflect the impact on spread of influenza. The review of case-control studies as described in Appendix 5.1.1 suggests that, to get any meaningful assessment of the impact of food hygiene practices in the kitchen, data from food-borne infections must be separated from data on GI infections transmitted via the faecal:oral route.

Viewed from another perspective, this review suggests that the quality of data obtained from intervention and case-control studies could be significantly improved by taking account of microbiological data in designing such studies. Preliminary data on the types of GI pathogens circulating in the study community, for example, could give significant insights into potential sources and routes of spread which could inform better design of the intervention. This is particularly important in meeting the differing hygiene needs of low
income compared with high income communities, and developed compared with developing country situations. Most of the microbiological data in this report come from studies in higher income homes in developed countries. Microbiological data from settings in developing country situations could, at relatively low cost compared with intervention studies, enable us to better understand the similarities and difference between hygiene needs in these situations. It should be noted that, on one hand, the largest amount of data on the efficacy of handwashing comes from studies in developing countries, whilst the majority of microbiological data comes from homes in developed countries. In recent intervention studies of Sandora et al. 2008 and Bright et al. 2009, microbiological sampling during the intervention, enabled the investigators to examine the relationship between diseases rates and isolation of norovirus and influenza virus.

Other valuable sources of information about hygiene, which are sometimes overlooked, are studies which examine the interaction between human behaviour and the behaviour of pathogens. Over the past 20 years Griffiths and co-workers have carried out studies to evaluate consumer behaviour during preparation of food in a domestic kitchen to identify opportunities for cross contamination which can lead to infection. In a study reported in 2004 they used observational data indicating cross contamination behaviours in conjunction with microbial sampling of surfaces and prepared foods in a domestic kitchen to gain a better understanding of microbial risks associated with food-handling malpractices. Thirty participants were asked to prepare a chicken salad meal using chicken pieces, 80% of which were subsequently found to be contaminated with either Campylobacter or Salmonella. Food safety behaviours were observed using CCTV and behavioural malpractices were scored using a risk-based scoring system. The kitchen was sampled immediately after participants had completed individual food preparation sessions. Most samples were taken from pre-determined locations e.g., work surfaces and tap handles. Other sampled locations were variables depending on observed behaviours during individual food preparation sessions, for example, the number and types of chopping boards used or hob controls/door handles touched after handling raw chicken. Observations enabled identification of surfaces and/or materials that may have been directly contaminated from raw chicken/raw chicken packaging or indirectly contaminated by hands that had been in direct contact with raw chicken. Cumulatively, positive Campylobacter isolations were made from 3 end-products, 3 surface wipers (a scourer and 2 dishcloths), a T-towel, a hand towel and a Formica kitchen work surface. Using observational data, suspected routes of cross contamination from positive raw chicken pieces were identified for each of the Campylobacter positive sites. The presence of Campylobacter in 3 end-products was traced back to hygiene errors. During preparation of salads, participants handled ready to eat (RTE) ingredients or the assembled salad with potentially contaminated hands and also used the same, inadequately decontaminated chopping board and/or knife for preparation of raw chicken and then RTE salad ingredients. Fifty-six per cent of Campylobacter positive samples taken after food preparation were dishcloths, T-towels and hand towels. These materials were all placed on, or used to wipe surfaces in the model kitchen. A hand towel and T-towel also became contaminated with Campylobacter after being used to dry inadequately washed and unwashed hands. One dishcloth may also have been contaminated with Campylobacter due to direct contact with a piece of raw chicken.

In a 2012 study Kennedy et al., adopted the concept of the IFH targeted approach in order to carry out a study to identify and prioritise critical points (CPs) in the home kitchen environment during food preparation in order to inform food safety campaigns. The aim of the study was to link observed consumer food safety practices in the home to food safety knowledge, attitudes, perceptions, psychosocial and demographic factors to identify these CPs. The study involved filming participants (n = 60) while they prepared a meal according to a specified recipe (30 beef/salad burgers and 30 chicken salads), microbiological sampling of key potential contamination sites in the participant’s kitchen, sampling the meat
and salad components of the meal for microbiological testing, visual inspection and temperature check of the meat after cooking, and administering a survey of knowledge, attitudes and demographic factors. The study confirmed the critical points (CPs) during domestic food preparation as: CP1: correct cooking practices; CP2: prevention of cross-contamination; and CP3: correct food storage practices. Importantly statistically significant links were found between food safety knowledge and behaviour as well as between food safety attitudes and demographic factors.

**SECTION 5. IMPLICATIONS FOR FURTHER DEVELOPMENT OF TARGETED HYGIENE, AND FOR DEVELOPMENT OF HYGIENE PROMOTION PROGRAMMES BASED ON TARGETED HYGIENE**

In this section the data from microbiological, observational and intervention studies are considered in relation to the future development of the IFH targeted approach to home hygiene and its promotion as a means to reduce the impact of infectious disease.

In Sections 2-4, the IFH targeted approach to home hygiene is outlined and assessed. The microbiological data in Appendices 1-4, however, show significant differences in the nature of the infection risk within and between communities which means that what are considered the “most risky practices” are likely to vary quite considerably from one region or one community to another demanding different codes of hygiene practice according to the types of pathogens prevalent in the community, access to adequate water and sanitation, climatic conditions, social conditions and so on. Translating the concept of a risk management approach into identifying priorities and developing codes of hygiene practice which meet the needs of specific communities and deliver maximum health benefit, requires consideration of a number of factors as outlined in the following section. This relates not only to identifying what are the most risky practices in that community, but equally importantly to how we best get the community to change their behaviour and adopt new practices.

### 5.1 DEVELOPING AND PROMOTING HYGIENE CODES – A SINGLE OR MULTI-BARRIER APPROACH?

The adoption of risk management approaches dates from the mid-1900s when scientists in the food, pharmaceutical and other industries recognised the need for a new approach to controlling microbial contamination in products. They came to recognise that, because pathogens are transmitted through a complex system of interdependent pathways, it was not sufficient to implement processes such as handwashing or manufacturing plant cleaning as single/isolated interventions. What was needed was an integrated system, in which the major transmission routes, and the interactions between them, were identified – and an integrated system of controls put in place to ensure that all major routes for transfer of microbes into their products were controlled. This scientifically-validated system has now become standard practice in a range of manufacturing settings.

More recently the US Institute for Healthcare Improvement (IHI) and other groups have begun to adopt this type of approach by using “care bundles” as the optimum means to reduce Healthcare Associated Infections (HAI).\(^{55,56}\) These are defined by IHI as “bundles of scientifically grounded elements (usually 3-5 practices) essential to improving clinical outcome”. The concept is that several effective practices are used in combination in order to have a greater impact on HAI rates compared to their individual use. Aboelela\(^{65}\) et al. argue that “while the traditional view of causality dictates that a single cause leads to a single effect, because of the multi-factorial nature of interventions to prevent HAI, the definition of a ‘single cause’ should be expanded to include a ‘set of interventions’ ”.
The debate about promoting hand hygiene, not in isolation but as part of a multi-barrier approach in healthcare settings is reflected in a recent paper entitled “Control of Transmission of Infection in Hospitals Requires More than Clean Hands” by Dr Stephanie Dancer. She argues “Unfortunately, people do not always clean their hands when they should, and even if they do, there are other factors that contribute to the acquisition of infection”. She concludes “Hand hygiene needs to be part of an integrated approach to infection control. Given the costs, work required and time taken to increase compliance with hand hygiene, it is arguable that other control interventions are easier to implement and to maintain, and they produce equally good or better results more quickly. Because people will not - or cannot - always clean their hands, let us engage managerial support for space, time, isolation capacity, staffing, and sufficient cleaning of all hand-touch surfaces.”

The same arguments apply to home and everyday life settings, where focusing on single interventions such as hand hygiene, respiratory hygiene, laundry hygiene etc. means that the impact on disease rates depends on the level of compliance. In reality, the risk of transmission via the hands, depends on the extent to which they become contaminated with pathogens during normal daily activities which must increase as the extent of the contamination of hand contact surfaces increases, which in turn depends on other factors. Intuitively, although there is no supporting evidence, it would be expected that combined hand and environmental hygiene will have a greater health impact than hand hygiene alone, since hand hygiene compliance is always likely to be less than 100%. Taking the “care bundles” approach, it could be concluded that the top 5 groups of environmental hand, food and body contact surfaces, clothing etc., and baths, basins etc. identified in Figure 3 should be regarded as a “set of integrated interventions” for the purpose of developing a code of hygiene practice.

As far as food or respiratory or other hygiene practices areas concerned, it is well accepted that this must involve a multi-barrier approach. Good food hygiene needs to be an integrated set of actions related to safe cooking and safe storage of food, combined with prevention of cross contamination either directly or via hands and surfaces, whilst respiratory hygiene requires blocking coughs and sneezes, disposing of tissues/ handkerchiefs safely and washing hands.

In all parts of the world, not only in healthcare but most particularly in public health, hand hygiene is, for the most part, still promoted as a separate issue from other environmental interventions such as food hygiene, surface hygiene, laundry hygiene etc., rather than as an integral part of a multi-barrier approach. In some/many settings, as discussed below, this focus on hand hygiene is justified. Public health planners, particularly in developing countries where resources are limited, have to make difficult choices about which specific hygiene practices to promote and logically, these should reflect the particular practices that are putting health most at risk. This argument does not necessarily extend into other, more prosperous regions of the world. Making choices about hygiene promotion programme development must also take account of issues such as the educational and social status of the community. Although the scientific data suggests that multi-barrier approaches are the optimum way to reduce infectious disease, experience in the developing world, as outlined below, suggests that behaviour change interventions work best when they focus on a single or small number of hygiene behaviours.

5.2 Bringing about behaviour change
As stated above, the health impact from increased investment in hygiene promotion not only requires the development of effective codes of hygiene practice based on sound scientific
principles, it is equally and critically dependent on persuading people to change their behaviour and to sustain that behaviour change.

In comparison with trained industrial or healthcare personnel, where sanctions can be applied for non-compliance, getting the general public to change their hygiene behaviour is extremely difficult. In recent years, a significant amount of research has been done to identify effective strategies for changing hygiene behaviour. The standard approach to hygiene promotion in developing countries, whether through schools, clinics, or health outreach programmes, has, until recently, been educational. Whereas those who manage hygiene improvements still often choose to promote hygiene by educating people on the links between hygiene and better health, one of the lessons that has been learnt, is that traditional (cognitive) approaches can raise awareness, but do not necessarily achieve the desired effects. This applies to both developed and developing countries.

A considerable amount of work is being carried out to evaluate the impact of different approaches to achieving and sustaining behaviour change and is reviewed elsewhere. 58,59,60,61,62,63,64,65 The various approaches that have been developed and are being tested in developing countries are reviewed by Curtis et al. 66 These workers conclude that “Though changing behaviour is difficult, we know a lot more about hygiene behaviour than we did 10 years ago and promising approaches to changing hygiene on a large scale are emerging.”

In developing countries, approaches which are being tested in low income communities range from the use of social marketing techniques to promote “single” rule-based hygiene messages on practices such as hand hygiene or respiratory hygiene, to community mobilisation approaches based on engaging community participation and developing an understanding of the need for and the principles of hygiene.

Community mobilisation, demand led, approaches:
In the past 2 decades an approach known as PHAST (participatory hygiene and sanitation transformation) or the CHC (community health club) approach has become a predominant model among non-government organisations.67,68 The aim is to involve communities in solving their own hygiene problems. This is mostly an educational approach and is heavily reliant on the skills of trained facilitators, making it more difficult and costly to implement on a large scale. Community mobilisation i.e., training community members in the technology and reasons for use of HHWTSS methods, means involving the community so that they develop a sense of commitment to, and ownership of, the project.

CLTS (Community led Total Sanitation) is another demand led approach, but is concerned solely with the achievement of open defecation-free (ODF) communities and the practice of handwashing with soap.69 CLTS is essentially a “vertical” approach whereas the CHC approach is “horizontal”, seeing the problem as a social issue. Unlike CLTS, the CHC approach addresses a raft of health issues, from HIV/AIDS and malaria to pit latrines, handwashing and refuse pits. The other difference is that, for CLTS, behaviour change is brought about by using tried and tested techniques to elicit emotions such as shame, embarrassment and disgust from villagers as they realise that by practising OD they are in essence eating each other’s faeces. This realisation is designed to bring about a transformation in the community who vow to come up with a plan to stop OD, usually involving the construction of toilets from locally available resources.

In 2011, Whalley and Webster reported a study of the effectiveness and sustainability of the two approaches in Zimbabwe.70 Results showed that, despite little resistance to the idea, a household’s ability to own a latrine depends heavily on affordability. Whilst both approaches effectively encouraged measures that combat open defecation, only CHC’s witnessed a
significant increase in handwashing. However, CLTS proved more effective in promoting latrine construction, suggesting that the emphasis the CHCs place on hygiene practices such as handwashing needs to be coupled with the greater focus on the issue of sanitation brought by CLTS.

Social marketing approaches
Research in low income communities by Curtis and co-workers\(^{53,66,71}\) has demonstrated the effectiveness of hygiene interventions which focus on as few interventions as possible, with simple rule-based messages. Key to this approach is communicating with the target audience in a way that will motivate behaviour change. This involves techniques such as social marketing – the use of marketing techniques to promote altered behaviours through generation of demand. A review of 11 studies in Africa, Asia, and Latin America\(^{69}\) concluded that, although there are local differences, common patterns exist. Three kinds of hygiene behaviour were identified: habitual, motivated, and planned. Hygiene habits were learnt at an early age, but soap use was rarely taught by parents or schools. Key motivations for handwashing were disgust of contamination on hands and to do what everyone else was perceived to be doing (social norms). Other motivations included comfort and nurturance (the desire to care for one’s children). Planned handwashing, with the aim of preventing disease, took place rarely. Mothers did not find the threat of diarrhoeal disease particularly relevant and found the connection between handwashing and diarrhoea in children tenuous.

In 2010, a study was carried out by Sulabh International Academy of Environmental Sanitation in collaboration with IFH South East Asia Office in order to better understand the impact of perceptions and practices of hygiene in the home on reduction of disease burden in respect of cholera, typhoid/enteric fever, diarrhea, hepatitis, worm infection, malaria/dengue\(^{72}\). The study was carried out in 5 Indian states namely Assam, Bihar and Jharkhand & Orissa & West Bengal. The study showed that the level of awareness and perception of public health and hygiene issues is a determining factor for hygiene behaviour and practice in the community and that perception and practice of hygiene plays a role in reducing the burden of communicable diseases. In addition it was shown that, when executed with an awareness campaign on public health and, hygiene, provision of household toilets for safe and sanitary disposal of human excreta, had a strong negative correlation with the burden of communicable disease.

In developed countries, the factors which drive the development of hygiene promotion programmes are very different from those in low income communities in developing countries. One of the key factors in developing countries is the very high levels of endemic diarrhoeal and helminth infection due to inadequate water, sanitation and environmental conditions as well as hygiene. Clearly there is no clear demarcation between “developed” and “developing” country conditions. The infection risks and hygiene needs for middle and upper socio-economic groups in developing countries who have access to adequate water and sanitation can be quite similar to those in developed countries, although the fact that these communities can still have a higher level of endemic diarrhoeal disease needs to be taken into account. This can result from exposure to faecal contamination of public water supply systems, the overall soil and water pollution, and extremely low level of environmental hygiene in the community. This means that hygiene promotion programmes must be tailored to individual circumstances and factors such as access to clean water and sanitation, and should be based on assessment of the local situation in relation to the type of disease being targeted (diarrhoeal, respiratory, eye, skin etc.), the types of pathogens prevalent in the community, climatic conditions, social conditions and so on.

However, some generalisations can be made as discussed in the following 2 sections.
5.3 DEVELOPED COUNTRIES – PROMOTING MULTI-BARRIER APPROACHES AND ACHIEVING BEHAVIOUR CHANGE

The multi-barrier risk-based approach as outlined and assessed in Sections 2-4 has been developed mainly on the basis of microbiological data generated in developed countries in Europe and the US. As discussed in Section 4, the data indicate that, overall, the hands are the single most important transmission route. A comparison of the microbiological data for contact surfaces against the data for hands indicates that surfaces which come into contact with our hands and body surfaces, and with food and water are also important risk factors or control points. Clothing and household linens are also important risk factors, although the risks are probably somewhat less than those associated with other contact surfaces. Surfaces which come into contact with the body such as baths and hand basins can also sometimes act as vehicles of infection, as can surfaces associated with the toilet.

In developing hygiene promotion programmes, the key question is – how big is the risk for each of these “control points”? Or put another way, what is the health benefit from promotion of any given hygiene practice. As discussed in Section 4, although we can make some assessment using microbiological data to compare risks relative to hand hygiene as a benchmark, there is no quantitative intervention data to allow us to determine which risks are significant and should be included and which are insignificant and should be excluded.

Hygiene codes of practice must also, as discussed in Section 4, take account of the fact that, although the microbiological data give us an assessment of the “daily life” risks associated with these various sites and surfaces and the activities associated with them, they also show that the risks are not constant, and can increase significantly under certain conditions. For example, although risks from toilets, sinks, floors etc, relate mainly to the relatively low risk of transfer from these sites to hands, hand and food contact surfaces and cloths, this risk can increase substantially where an infected family member has fluid diarrhoea, or where a floor surface is contaminated with vomit or faeces. Similarly, the risks of transmission via clothing and household linens will increase where one family member has a skin or wound infection. Risks are also increased in situations where there are family members living at home who have reduced immunity to infection and may require special care to protect them from infection.

Governments, under pressure to fund the level of healthcare that people expect, are looking at disease prevention strategies as a means to reduce health spending. Increased homecare is one approach to reducing health spending, but gains are likely to be undermined by inadequate infection control at home. Healthcare workers are now increasingly looking for support in developing and promoting codes of hygiene for the care of infected and vulnerable groups in the home. Much of the care of risk groups in the home is done by family members who thus require a good understanding of hygiene. The principles of hygiene for protection of vulnerable groups or to prevent spread of infection from an index infected person in the home, are no different from those of everyday hygiene. The major difference is that if good hygiene practices are not followed the risk of infection is higher. One of the reasons for this is that the infectious dose i.e., the number of bacterial or viral particles needed to cause infection may be lower for those with reduced immunity to infection.

In developed countries, which enjoy access to adequate safe water and an effective means of faeces disposal, infectious disease prevention priorities are very different from those in low income communities where the overwhelming need is to focus on preventing diarrhoeal, respiratory and trachoma infections. In recent years, developed countries have faced a diverse range of issues which range from reducing the burden of foodborne infection through control from “farm to fork”, to promoting respiratory hygiene as the means to reduce the spread of pandemic respiratory viruses, to preventing cross infection from MRSA or C
difficile, to caring for vulnerable/at-risk groups in the home and community from infection. All of these issues place a significant additional burden on the already overstretched health budgets of developed nations, which could be reduced through adoption of better hygiene in home and everyday life settings.

In the last 20 years we have seen significant investment across Europe in reducing the burden of infectious diseases, not only with the establishment of ECDC, but also through national hygiene promotion programmes. In the UK, for example, there has been extensive investment in programmes to promote food hygiene at home. In 2009 we saw investment in promotion of hand hygiene as a means to mitigate the spread of the pandemic H1N1 influenza strain. Although current thinking might suggest that the most effective way to change hygiene behaviour is through single rule-based messages, the data in this review suggest that, in developed countries, the complexity and shifting nature of the infectious disease threat is such that a rule-based approach to hygiene is inadequate to meet current public health needs. IFH also believes that the impact of hygiene promotion programmes on the public is being weakened by the fact that the different aspects of hygiene are dealt with by separate agencies which means that the information that the family receives is also fragmented. If things are to improve we need a family centred (rather than an agency oriented) i.e. an approach which looks at hygiene from the point of view of the family and the range of problems they face in order to reduce infection risks, and provides them with an integrated approach to home hygiene. This includes risks related to poor food and water hygiene, poor personal hygiene (particularly hand hygiene), respiratory hygiene, hygiene related to clothing and household linens, and hygiene related to the general environment (toilets, baths, hand basins, surfaces etc.). It also includes hygiene related to care of domestic animals, and to family members at increased risk of infection. It also includes risks associated with unsafe disposal of faeces and refuse.

The need is for an approach founded on awareness of the chain of infection transmission and how it differs for different groups of infections. Hygiene education needs to be consistently incorporated as part of hand hygiene promotion programmes, if people are to properly understand the risks, and adapt their behaviour accordingly. At the very least we must ensure that the principles of infectious disease transmission and hygiene are part of the school curriculum. In line with this, the EU-funded e-Bug project (http://www.e-bug.eu/) is working to roll out education on antibiotic resistance and hygiene at primary and secondary school level across Europe.

5.4 DEVELOPING COUNTRIES – PROMOTING SINGLE AND MULTI-BARRIER APPROACHES AND ACHIEVING BEHAVIOUR CHANGE

In developing countries, the issue of single versus multi-barrier approaches to infectious disease prevention is a matter for considerable debate – at 2 levels

Firstly in relation to whether, and to what extent, programmes to improve water in the absence of programmes to improve sanitation are effective in reducing diarrhoeal disease. On one hand, using modelling approaches, Eisenberg and co-workers 2007 argue that, when sanitation conditions are poor, water quality improvements are likely to have minimal impact regardless of amount of water contamination. They conclude that, if each transmission pathway alone is sufficient to maintain diarrhoeal disease, single-pathway interventions will have minimal benefit, and ultimately an intervention will be successful only if all sufficient pathways are eliminated. On the basis of a Cochrane review of 38 trials of water quality interventions for preventing diarrhoea involving more than 53,000 persons from 19 countries over 20 years, Clasen, Cairncross and co-workers however concluded that
“pooled estimates of effect showed that water quality interventions were effective in settings without “improved” sanitation.\textsuperscript{74}

Secondly, in the past 10 years or so, significant investment has been made to integrate “hygiene promotion” into programmes aimed at providing improved water and a means of safe faeces disposal to low income communities in developing countries. In these situations, the focus of hygiene promotion has been on the promotion of hand hygiene on the basis that this is the single most important intervention which, based on intervention study data, can produce up to 50\% or more decrease in diarrhoeal disease rates and up to 23\% reduction in respiratory infections. The extent of the emphasis on hand hygiene means that in some circles, hygiene is considered as synonymous with handwashing.

In developing countries, where investment in hygiene promotion is now recognised as a vital component, alongside provision of adequate water and sanitation, hand hygiene is being promoted as a single issue, rather than as an integral part of a multi-barrier approach to infection prevention i.e. an approach which also involves food hygiene, respiratory hygiene etc. To an extent, as discussed above, this focus on hand hygiene is justified; public health planners, particularly in developing countries where resources are limited, have to make hard choices about which specific hygiene practices to promote and logically, these should reflect the particular practices that are putting health most at risk.

Until recently there has been little or no data to suggest whether the risks associated with other interventions such as surface hygiene, laundry hygiene and so on, relative to those associated with the hands are the same or different from those in developed countries. Until recently the microbiological data has come almost exclusively from developed countries, most particularly the US and Europe. New data is now emerging which suggests that this may not be the case. Thus, for example, recent data such as that produced by Sinclair and Gerba\textsuperscript{51} suggest that surfaces may be more important than in developed countries even in homes where there is access to improved water and sanitation. In their 2010 study of environmental contamination in homes in Cambodia, Sinclair and Gerba showed that levels of faecal and faecal indicator bacteria were up to 2 logs higher than in equivalent situations (sites and surfaces) in homes in the US and Japan, despite the fact that the Cambodian homes had a pour-flush latrine for disposal of faeces. From this, they concluded that “these results indicate that a latrine barrier alone is only partially effective for household sanitation. For complete sanitation, multiple environmental barriers may be necessary”. When compared to homes in Cambodia, homes in industrialised countries have a range of additional environmental barriers that may control surface contamination including chlorinated water distribution systems, solid waste disposal systems, more elaborate home construction with easily washable surfaces, and cleaning product availability. Homes in these countries also have indoor climate control systems and lower relative humidity than tropical Cambodia. Sinclair and Gerba propose that efforts should be made to include as many pathogen control points as possible in hygiene and sanitation improvement programmes.

At the very least, these data indicate that more studies should be carried out to better understand the role of the environment most particularly in situations where faecal contamination of the environment is likely to be higher due to higher incidence of diarrhoeal disease and lower standards of sanitation, and how this may contribute to transmission via the faecal:oral route or via food.

To explore these issues further, Eisenberg and co-workers\textsuperscript{75} have developed a model which uses microbiological data to evaluate the health impact of not only single but also multiple environmental hygiene interventions to prevent person-to-person transmission. The model describes the dynamics of human interaction with pathogens in the environment in relation to
factors such as physical proximity, microbe pick-up rate, pathogen elimination rate, deposition rate and social encounters. These insights provide theoretical contexts which could be used to examine the role of the environment in pathogen transmission and a framework to interpret environmental data in order to inform hygiene interventions.

5.5 IFH – Developing codes of hygiene practice for developed and developing country situations

Over the past 10 years, IFH has used the targeted approach to produce a code of hygiene practice for the home, and to produce a series of guidelines and training resources for use by community healthcare workers in both developed and developing countries (see Table 1).

The IFH “Guidelines for Home Hygiene” are based on a multi-barrier approach and give detailed guidance on all aspects of home hygiene including food hygiene, general hygiene, personal hygiene, care of pets, care of vulnerable groups and those who pose an infection risk to others. In turn, using the guidelines and recommendations as the basis, IFH (in collaboration with the UK Infection Prevention Society and the Water Supply and Sanitation Collaborative Council) has also produced teaching resources on home hygiene (2 editions are available one of which focuses on the developed world, the other on issues in developing countries) which present home hygiene theory and practice in simple practical language which can be understood by community workers with relatively little infection control background. All of these materials are downloadable from the IFH website.

The primary aim of these materials is to give healthcare workers a basic understanding of how infections are transmitted in the home, and the principles of a multi-barrier approach to breaking the chain of infection transmission through good hygiene practice. The training resource for use in developing country situations also addresses the problem of adapting hygiene promotion programmes in order to meet local needs and constraints.

Table 1 – IFH guidelines, recommendations and training resources on home hygiene

<table>
<thead>
<tr>
<th>Guidelines on home hygiene</th>
<th>Guidelines for prevention of infection and cross infection in the domestic environment. 76</th>
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<td>Recommendations for selection of hygiene procedures</td>
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<td>Home Hygiene – prevention of infection at home: a training resource for carers and their trainers. 78</td>
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<td>Home Hygiene in Developing Countries: prevention of infection in the home and peridomestic setting. A training resource for teachers and community health professionals in developing countries. 20</td>
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Section 6. Conclusions and Recommendations

Microbiological and other data reviewed in this report show that pathogens are constantly being shed or spread from human, animal, food and water sources in home and everyday life settings, and are transmitted via the hands and via environmental sites and surfaces etc. such that people become exposed and infected. It is now well accepted that reducing the infection risk is not achieved by trying to eliminate infectious agents from our environment.
Not only is this unachievable, it is also undesirable. The optimum approach is to focus on breaking the chain of infection transmission by intervening at “critical points” in the chain. This maximises protection against infection exposure whilst disturbing our human and natural environment to the least extent. This is the basis of the “targeted” approach to home hygiene developed by IFH during 1997 to 2000 using the microbiological evidence available at the time.

**IFH – Advocating increased investment in hygiene promotion**

Governments worldwide are under considerable pressure to fund the level of healthcare that people expect, and are more and more looking to disease prevention strategies, including the promotion of hygiene, as a means to reduce health spending. This is particularly so in developing countries, where there is growing awareness of the need for more investment in hygiene promotion alongside programmes to provide improved water and sanitation in order to reduce the unacceptable burden of diarrhoeal disease. Hygiene is now recognised as a means to reduce the spread of respiratory diseases, and is an component part of pandemic influenza preparedness plans. It is also recognised as a key strategy for reducing the impact of antibiotic resistance. Healthcare workers now accept that reducing the burden of infection in healthcare settings cannot be achieved without also reducing the circulation of pathogens such as norovirus and MRSA in the community. For the Transatlantic Task Force on Antimicrobial resistance (TATFAR) one of the 3 component strategies for tackling antibiotic resistance is “Prevention of both healthcare- and community-associated drug-resistant infections”.\(^7\) Hygiene provides a means to reduce the “silent epidemic”, which is the spread of MRSA, and ESBL and NDM-1-producing gram negative strains in the community. As persistent nasal or bowel carriage of these strains in the healthy population increases, this increases the risk of infection with these strains in both hospitals and the community.\(^8\),\(^80\),\(^81\) Milstone et al. 2012,\(^82\) for example, have shown that MRSA colonization is a risk factor for subsequent MRSA infection. Admission prevalence of MRSA colonization among 3140 children admitted to a paediatric care unit was 4.9%. Nearly 10% of children with MRSA colonization or infection on admission to the intensive care unit developed a later MRSA infection, most often after hospital discharge. Cotter et al. 2012\(^83\) demonstrated the potential for acquisition of antibiotic resistant strains in healthcare workers and ongoing possibility of cross-transmission to household contacts. The report describes a case of ESBL-producing *E. coli* bloodstream infection in a healthcare worker associated with subsequent isolation of an indistinguishable strain from one causing a urinary tract infection in his spouse.

What is needed, however, is translation of awareness into action. To achieve this, a number of issues need to be addressed:

- If we are to sustain high level protection against infectious disease, in the face of changing demographics and microbial evolution, we must recognise that the responsibility for hygiene must be shared by the public. To achieve this, we need an integrated family-centred approach to hygiene promotion, co-ordinated by a single agency. In most countries worldwide, public health is currently structured such that the separate aspects of home and everyday life hygiene – food hygiene, personal hygiene, handwashing, safe water, pandemic flu preparedness, patient empowerment etc. – are dealt with by separate agencies. There is a need for the various agencies to work in partnership in order to promote an approach to hygiene which is family-centred rather than issue-oriented.

- If things are to change we must recognise that fragmented, rule-based knowledge is not enough to meet the challenges we face. Hand hygiene, for example is a central component of all hygiene issues and it is only by adopting a holistic, integrated approach that the causal link between e.g. hands and infection transmission in the home can be properly addressed. Where resources and socio-economic conditions allow, at the very least we need to ensure that the principles of infectious disease
transmission and the role of hygiene are part of the school curriculum. What works best is likely to depend on a whole range of factors including socio-economic and educational status, and the resources available. This is particularly so in developing countries.

- If hygiene promotion is to attract public and private investment, there is a need for more data to enable health agencies to assess the health gains from investment in hygiene promotion relative to other preventive measures (e.g., immunisation programmes). A key driver to the successful establishment of the Global Public Private Partnership on Handwashing was the quantitative data showing the health gains from promotion of handwashing with soap in low income communities. In order to argue the case for an integrated approach to hygiene promotion, there is a particular need for intervention study data assessing the health impact (and health cost savings) of an integrated set of interventions based on targeted hygiene over and above that achieved by handwashing alone. Although it is probably not possible to measure the impact of handwashing and environmental hygiene separately (i.e., an intervention promoting environmental cleaning without hand hygiene would not be feasible or ethical), the 2002 US home study (238 households, 48 weeks) by Larson et al.50 and the 2007 household study in South Africa by Cole et al.36 (685 households, 6 months) demonstrate the feasibility (i.e., sufficient statistical power to yield meaningful results) of doing a comparative intervention study measuring the impact of hand hygiene, and the incremental effect of targeted environmental hygiene over that achieved by handwashing alone.

- If the health benefits from hygiene promotion are to be realised, one of the key aspects is persuading people to change their behaviour.

In developing and promoting hygiene practice, the issue of sustainability must also be addressed. A 2010 IFH report84 shows that the IFH targeted hygiene approach provides a framework for building sustainability into hygiene because it minimises the life-cycle impacts of hygiene processes, maximises safety margins against any hazards of their use, and minimises any risks of the development antibiotic resistance from exposure to biocides. It also looks to sustain “normal” interaction with the microbial flora of our environment.
APPENDICES

1. MICROBIOLOGICAL ASSESSMENT OF THE SOURCES, DISPERSAL, PERSISTENCE AND SPREAD OF MICROBES IN THE DOMESTIC ENVIRONMENT

1.1 CHAIN OF TRANSMISSION OF INFECTIOUS GASTROINTESTINAL DISEASE

Within the home, the primary sources by which enteric pathogens are introduced into this setting are people, food and water, pets and to a certain extent (particularly in tropical countries) insects. Additionally, sites where stagnant water accumulates, such as sinks, U-bends, toilets and cleaning cloths, can support microbial growth and become a primary reservoir of infectious agents. GI infections can occur by eating contaminated food that has not been properly cooked, or has been incorrectly stored, or by drinking contaminated water. Food and water can be contaminated at source outside the home, but can also become contaminated in the home, either by contact (handling) with contaminated hands or by contact with contaminated surfaces.

Alternatively, GI infections can occur by direct hand to mouth transfer of infectious agents that are transmitted via hands or environmental surfaces. For some infections e.g. norovirus infection can occur by inhalation of particles of infected vomit.

Infectious agents spread via these routes include bacterial strains such as Salmonella, Shigella, Campylobacter, E. coli (including E. coli O157 and E. coli O104) and Helicobacter pylori, viral strains such as norovirus, rotavirus, adenovirus and astrovirus, and Cryptosporidium. Although Cryptosporidium infections are generally assumed to be waterborne, there is evidence of person-to-person transmission in household settings. The risk of exposure to enteric pathogens in home and everyday life settings, as illustrated in Figure 1, depends on the extent to which these pathogens are brought into the home and the extent to which they are spread via hands and other sites and surfaces, and by airborne transmission.

Data showing the extent to which enteric pathogens are introduced into the home, remain viable and infective, and circulate around the home comes from various sources and is summarised below. Taken together, it suggests that exposure to enteric pathogens via the hands, surfaces and food is a frequent occurrence during normal daily activities, and that the numbers of organisms transferred by hand-to-mouth contact (or into ready-to eat foods or water) can be well within the numbers required to cause infection.

1.1.1. Sources of enteric pathogens in the home

Food as a source of enteric pathogen in the home

Pathogenic micro-organisms are ubiquitous throughout nature and are frequently found on or in raw foods. Pathogens brought into the home on raw or processed food include Salmonella, Campylobacter, Listeria and E. coli O157. A variety of foods can act as a source of these organisms including meat, fish and poultry products, dairy products, fruits and vegetables. Using data from 18 OECD countries, a 2003 World Health Organization (WHO) report concluded that about 31% of reported food-borne outbreaks occur in private homes. The potential for food poisoning at home is indicated by the prevalence of food-related pathogens in products purchased from retail premises:
• The 2010 EFSA report based on data reported back from EU countries in 2008\textsuperscript{87} indicates that \textit{Campylobacter} is mostly found in raw poultry meat with a reported average of 30.1\% of samples showing contamination. The highest proportion of \textit{Salmonella}-positive units was reported for fresh broiler meat, turkey meat and pig meat, on average at levels of 5.1\%, 5.6\% and 0.7\%, respectively. A prevalence study conducted among broilers in Malaysia indicated that 35.5\% of broiler carcasses obtained from wet-markets and 50.0\% from processing plants were contaminated with \textit{Salmonella}.	extsuperscript{88} High rates of \textit{Salmonella} spp. contamination were detected in fresh samples of chicken carcasses from butcheries, while increased \textit{Campylobacter} spp. levels were detected in fresh supermarket samples in another study by Van Nierop \textit{et al.} in South Africa.\textsuperscript{89} A 2000-2005 United States (US) survey on \textit{Salmonella enterica serotype Enteritidis} in broiler chicken carcasses showed that the annual number of isolates have increased by more than 4-fold and the proportion of establishments with \textit{Salmonella enteritidis}-positive samples has increased by nearly 3-fold. Case control studies from the US and England identify consumption of chicken as a risk factor for sporadic human \textit{Salmonella enteritidis} infection.\textsuperscript{90}

• Luber \textit{et al.}(2007) analysed 100 retail chicken breast fillets for surface contamination and 55 fillets for internal contamination. Prevalence was 87\% on the surface and 20\% in the deep tissue. The mean number of \textit{Campylobacter} on the surface was 1903 colony forming units (CFU) (median 537cfu, maximum 38,905cfu). Internal counts were <1 cfu/gram meat. Given the high numbers of the pathogen on the chicken surface, they concluded that cross-contamination during preparation of contaminated chicken is a more important pathway for exposure to \textit{Campylobacter} than eating undercooked meat.\textsuperscript{91}

• A 2005 UK study of 3,662 prepackaged raw meat samples from retail premises showed that the external packaging of raw meats is also a vehicle for potential cross-contamination by \textit{Campylobacter}, \textit{Salmonella} and \textit{E. coli}. These could potentially cross contaminate ready-to-eat foods during and after purchase in consumers' homes.\textsuperscript{92}

• Chapman \textit{et al.} showed that 0.4-0.8\% of meat products purchased from butchers in the United Kingdom (UK) were positive for \textit{Escherichia coli} O157.\textsuperscript{93}

• \textit{E. coli} O157:H7 was recovered from 2.8\% samples of minced beef and beef burgers from butcher shops and supermarkets in the Republic of Ireland. Fresh packaged burgers from supermarkets had the highest prevalence of 4.5\%, while fresh unpackaged mince had the lowest prevalence of 2\%.\textsuperscript{94}

• In a 2007 study in Canada, \textit{C. difficile} was isolated from 20\% of 60 samples of retail ground meat purchased over a 10-month period, and 11 of the isolates were toxigenic.\textsuperscript{95}

• A 2010 study by Weese \textit{et al.} conducted across Ontario, Canada, was the first to report \textit{C. difficile} contamination in retail chicken meat. All isolates of \textit{C. difficile} (26 of 203 chicken samples) were ribotype 078, a strain that has been associated with food, animals and potentially community-associated disease in humans.\textsuperscript{96}

• The food chain can also be a route for transmission of noroviruses. GIII (bovine), GII.18 (swine), and GII.4 (human) norovirus sequences have been isolated from animal faecal samples demonstrating that GII.4 –like strains can be present in livestock.\textsuperscript{97}

• Van loo \textit{et al.}\textsuperscript{98} identified 36 \textit{S. aureus} strains in 79 meat samples. Two meat samples (2.5\%) contained MRSA. \textit{S. aureus} is found regularly in low amounts in meat sold to the consumers. This study demonstrates that MRSA has entered the food chain. Persoons \textit{et al.} in a 2009 study also confirmed the presence of MRSA in broiler chickens in Belgium. The number of positive samples varied between 20\% and 100\%. Interestingly, from the 1 MRSA-positive farms that was sampled twice, MRSA was isolated on both occasions. This indicates that MRSA may persist on a farm and colonize future flocks.\textsuperscript{99} Van Loo \textit{et al.} concluded that, as the amounts of MRSA isolated were low, it is not likely to cause disease, but contamination of food products
may be a potential threat for the acquisition of MRSA by those who handle the food. Despite this, an outbreak of community-acquired foodborne illness caused by MRSA has been reported. This report by Jones et al. showed that a food handler in a delicatessen, an asymptomatic carrier of the same strain of MRSA, probably contaminated the food. The person may have acquired the MRSA strain during visits to a nursing home prior to the outbreak, demonstrating the spread of MRSA into the community.100

Water as a source of bacterial infections in the home
In developing countries, lack of access to clean water is still a significant problem. In 2008, WHO/UNICEF101,102 reported that, in the last few years, the situation has significantly improved and that for the first time since data were first compiled in 1990, the number of people globally who lack access to an improved drinking water source has fallen below 1 billion. The WHO/UNICEF joint monitoring group101,102 assess that the percentage of people served with an “improved water supply” worldwide has now reached 87%. Overall, 54% of the world’s population now has piped water on the premises (piped household connection located inside the users dwelling, plot or yard). The WHO/UNICEF report, however, highlights large disparities within national borders, particularly between rural and urban dwellers. Water supply quality depends on factors such as the quality of the raw water source, the extent and type of treatment used, the integrity of the distribution system and the maintenance of positive pressure within the network.

In general, it is assumed that community water supplies in developed countries are safe. This is not necessarily the case,103 particularly in regions of Europe where political and economic upheaval have led to infrastructure deterioration. Additionally, whereas towns and cities of Europe are generally well supplied, many rural populations still rely on small private supplies, where contamination risks are higher. In situations where water quality is consistently poor, or in emergency situations (e.g., where outbreaks of Cryptosporidium occur as a result of breakdowns in the water treatment or distribution system), point-of-use water treatment within the home is necessary if GI infections are to be prevented. Contamination of domestic water supplies and the burden of waterborne disease is reviewed in more detail in a 2005 IFH report.5

In addition to risks from consumption of contaminated water, waterborne pathogens can be transmitted in the home. Water can easily become contaminated by unsafe consumer storage and handling practices at home. This can happen when water has to be collected from a communal source. This water is stored in containers of various designs and often, is not protected from subsequent contamination during use, and/or water storage containers are not cleaned before refilling.104,105,106 The extent and causes of contamination of household drinking water are reviewed by Sobsey107 and Wright et al.108

Humans as a source of pathogens in the home
Household members who are, or have been recently infected, or who are persistent carriers, are a primary source of GI infection in the home. Enteric pathogens which can be carried persistently by otherwise healthy people include Salmonella and C. difficile. Other enteric pathogens which are spread in the home from infected people include E. coli O157 and O104, Campylobacter, norovirus, rotavirus etc. Studies carried out in Germany and France in 2011 report on secondary transmission of E. coli O104 within the family.109,110 People that carry enteric pathogens shed large numbers of organisms in their faeces, or when they vomit:
- A single vomiting incident following norovirus infection may produce 30 million viral particles,111 whilst, at the peak of a rotavirus infection >10¹¹ virions may be excreted per gram faeces.112 Atmar et al. evaluated the magnitude and duration of shedding in
faeces of persons experimentally infected with norovirus. Shedding was detected 18 hours after infection and lasted a median of 28 days. The median peak shedding was $95 \times 10^9$ (range $0.5-1,640 \times 10^9$) genomic copies/gram faeces.\textsuperscript{113} Aoki et al. in a 2010 study suggested that precautions should be taken for at least 14 days after onset of symptoms.\textsuperscript{114}

- Gibson et al.\textsuperscript{115} review data which suggests that the number of particles of adenovirus, rotavirus and hepatitis A virus shed per gram of faeces is approx. $10^{10}-10^{11}$ cfu/g, whilst for Shigella, the number of organisms shed reportedly ranges from $10^5-10^9$ cfu/g of faeces. If infection is asymptomatic, the average number is typically between $10^2$ and $10^6$ cfu/g. Although the average duration of Shigella infection is a week, one study suggests that 7% of infected persons may shed the organism for more than 1 year.\textsuperscript{116}

As discussed below, surfaces in the home may become contaminated by enteric organisms such as norovirus that are aerosolized during vomiting or by transfer of vomitus and fecal matter from hands to surfaces. Viruses aerosolized from flushing the toilet can remain airborne long enough to contaminate bathroom surfaces.\textsuperscript{117}

Although there is a tendency to assume that GI infections are the result of eating contaminated food or drinking contaminated water, it is increasingly recognised that a substantial proportion of the total GI infection burden in the community is due to person-to-person spread within households, particularly for viral infections such as norovirus. Person-to-person transmission in the home can occur by direct hand-to-mouth transfer, via food prepared by an infected person, or by transmission due to aerosolised particles resulting from vomiting or fluid diarrhoea. Evans et al.(1998)\textsuperscript{118} reported that, whereas 174 out of 233 outbreaks of infection in the UK attributed to Salmonella were “mainly foodborne” and 15 regarded as “mainly person-to-person”, for 680 reported outbreaks of norovirus infection, 607 were attributed to person-to-person transfer and only 21 were reported as foodborne. In a more recent study of data from 4083 outbreaks, Le Baigue et al.(2000)\textsuperscript{119} suggested that 19% of Salmonella outbreaks were transmitted by other means and fewer than half of E. coli O157 outbreaks were foodborne. Friedich (2011) reviews data which shows the potential for transmission of Enterohaemorrhagic Escherichia coli (both O104 and O157) arising from household transmission.\textsuperscript{120}

The risk of exposure to GI pathogens from a human source depends on the extent to which they are circulating in the community. Surveillance data gives some indication of incidence and prevalence, but it is well accepted that GI diseases are under-reported. National surveillance systems mostly focus on foodborne disease which means that non-foodborne infections circulating in the community are under-reported. The prevalence of GI infections circulating in the community is illustrated by two large community studies in the UK\textsuperscript{121} and The Netherlands.\textsuperscript{122} The UK study, carried out between 1993 and 1996, estimated that only 1 in 136 cases of GI illness is detected by surveillance and that, for every one reported case of Campylobacter, Salmonella, rotavirus and norovirus, another 7.6, 3.2, 35 and 1,562 cases, respectively, occur in the community. The UK study indicated that up to 1 in 5 people in the UK population develop IID each year (an estimated 9.4 million cases) of which about 50% is non-foodborne.\textsuperscript{121,123} Although it is not possible to obtain proof since the sources of these cases was not investigated, the most obvious conclusions are that a significant proportion relate to community settings including the home. The Netherlands\textsuperscript{122} study estimated that about 1 in 3.5 people experience a bout of GI infection each year. A 2007 report of food and non-foodborne outbreaks in Germany\textsuperscript{124} suggested that the most common settings for outbreaks are households (53%); of 14,566 outbreaks, 5,400 were attributed to person-to person spread, 1637 to food, and 85 to water.
Indications are that norovirus is now the most significant cause of GI infection in the developed world.\textsuperscript{125} Rotavirus is the leading cause of gastroenteritis in children under 5 years of age.\textsuperscript{126} Parashar \textit{et al.}\textsuperscript{127} estimate that, globally, each year, rotavirus causes approx. 111 million episodes of gastroenteritis in children less than 5 years of age. Hepatitis A virus is common worldwide,\textsuperscript{128} whilst adenovirus is also a frequent cause of gastroenteritis. \textit{C. difficile}-associated intestinal disease occurs with increasing frequency in the community, where it mostly affects home-based patients, but occasionally affects healthy individuals.\textsuperscript{8} Over 80\% of cases are in the over-65 age group. Carriage rates in healthy people in the community may be around 3 up to 5\%.\textsuperscript{128,130,131} Although there are no data to indicate what proportion are carriers of toxin-producing strains, indications are that the numbers which are toxin producers has increased.\textsuperscript{132,133} Release of spores is easily accomplished as \textit{C. difficile} causes explosive diarrhoea; it is estimated that infected patients excrete over 100 \textit{C. difficile} per gram of faeces.\textsuperscript{134}

**Pets, domestic animals etc as a source of GI pathogens in the home**

More than 50\% of homes in the English-speaking world have cats and dogs. Chomel \textit{et al.} \textsuperscript{2011} review data which shows that in the US, >60\% of households have pets; pet ownership increased from 56\% in 1988 to 62\% in 2008. In the UK, an estimated 6.5 million dogs live in \textapprox25\% of households. In the Netherlands, the pet population is \textapprox2 million dogs and 3 million cats, the percentage of households with pets increased from 50\% in 1999 to 55\% in 2005. In France, the estimated pet population is \textapprox8.1 million dogs in 25\% of households and \textapprox9 million cats in 26\% of households, with the number of dogs increased from \textapprox4 million in the late 1950s to its current 8.1 million.

In the US, up to 39\% of dogs may carry \textit{Campylobacter}, and 10-27\% may carry \textit{Salmonella};\textsuperscript{135} cats are also carriers of these organisms. Carriage of \textit{C. difficile} in household pets is common;\textsuperscript{136} up to 23\% of household pets are affected, although carriage appears to be transient and not associated with IID. The extent of the problem is shown by a number of recent studies:

- Fredriksson-Ahomaa \textit{et al.}(2001) demonstrated that raw pork can be a source of \textit{Yersinia enterocolitica}: 3 infections in dogs and cats. Pathogenic isolates can cause enteritis in dogs and cats, but pets can also shed this organism in the faeces for several weeks after infection. Carrier animals may be a source of infection, especially for young children, due to their close contact with humans.\textsuperscript{137}
- Transmission of cryptosporidium from pets has been recorded.\textsuperscript{138} A study in Indonesia showed that 13 (2.4\%) of 532 cats passed \textit{C. parvum} oocysts.\textsuperscript{139}
- Lefebvrea \textit{et al.}(2006)\textsuperscript{140} evaluated the prevalence of zoonotic agents in a group of 102 dogs from a variety of sources across Ontario, Canada, and zoonotic agents were isolated from 80 of 102 (80\%) animals. The primary pathogen was \textit{C. difficile}, which was isolated from 58 (58\%) faecal specimens; 71\% (41/58) of these isolates were toxigenic. The authors also reviewed reports from the US and Australia indicating asymptomatic carriage in the canine population between 0-37\%.
- People in close contact with farm animals are at risk of animal-to-human transmission of \textit{Salmonella Typhimurium} DT104A variant. \textit{Salmonella enterica serovar Typhimurium} was isolated from a pig, a calf, and a child on a farm in The Netherlands. The isolates were indistinguishable by phenotyping and genotyping methods, which suggested non-foodborne animal-to-animal and animal-to-human transmission.\textsuperscript{141}
- Feeding raw meat to dogs may have an impact on the faecal prevalence of several enteric bacterial zoonotic pathogens. Lenz \textit{et al.} isolated \textit{Campylobacter jejuni} from 2.6\% of raw meat-fed dogs and \textit{Salmonella enterica} from 14\% of raw meat-fed dog faeces. \textit{Salmonella enterica} was recovered more frequently in the vacuum cleaner waste samples from households with raw meat fed dogs than from those where raw meat was not fed to dogs (10.5\% versus 4.5\%).\textsuperscript{142}
• Jhung et al. 2008 observed that there has been a rise in toxinotype V strains of C. difficile from <0.02% before 2001 to 1.3% in 2006. Community-associated CDAD was identified in 46.2% case-patients. Molecular characterization showed a high degree of similarity between human and animal toxinotype V isolates.143

• A review by Tsiodrasa et al. shows that human pathogens can be associated with wild and migratory birds. Indirect transmission to humans has been reported for some of these such as E. coli and Salmonella spp. The authors conclude however that the available evidence suggests wild birds play a limited role in human infectious diseases. Direct transmission of an infectious agent from wild birds to humans is rarely identified.144

• Fielder (2010) reviews the infection risks related to touching animals during visits to open farms zoos etc.145

• Behravesh et al. 2010146 investigated an outbreak of Salmonella Schwarzengrund, primarily affecting young children, in which 79 case-patients in 21 US states were identified; 48% were children aged 2 years or younger. Case-households were significantly more likely than control households to report dog contact and to have recently purchased manufacturer X brands of dry pet food. Illness among infant case-patients was significantly associated with feeding pets in the kitchen. The outbreak strain was isolated from opened bags of dry dog food produced at plant X, fecal specimens from dogs that ate manufacturer X dry dog food, and an environmental sample and unopened bags of dog and cat foods from plant X.

The increasing popularity of exotic pets also increases the risk of humans acquiring zoonotic infections.147 Human salmonellosis associate with exposure to exotic pets is reviewed by Woodward et al. 1997.148 From a review of the period from 1993 to 1995, they estimated that 3-5% of 20,000 laboratory-confirmed human cases of salmonellosis in Canada were associated with exposure to exotic pets. Case:control studies assessing the Salmonella infection risks associated with turtles, reptiles, ducklings etc. are reviewed in section 5.1.1.

Although there is significant evidence that domestic pets have the potential to act as a source of infection in the home, there is little data indicating the extent to which this may or may not occur.149,149 In their 2011 review Chomel et al. 201116 report that in the US, 56% of dog owners sleep with their dog next to them. They also review a study in the Netherlands showing that among 159 households with pets, 50% of pet owners interviewed allowed the pet to lick their face; 60% of pets visited the bedroom; 45% of dogs and 62% of cats were allowed on the bed; and 18% and 30% of the dogs and cats, respectively, were allowed to sleep with the owner in bed. A study in France reported that ≈45% of cat owners and ≈30% of dog owners slept with their pet.

In a 2008 UK study, Westgarth et al. investigated the dog-human and dog-dog interactions among 260 dog-owning households. It was found that contacts were highly variable and were affected by the size, sex and age of the dog, individual dog behaviours, human behaviours and human preferences in the management of the dog. The authors identified a number of situations that may be important in relation to zoonoses such as sleeping areas, playing and greeting behaviours, food sources, walking, disposal of faeces, veterinary preventive treatment and general hygiene.150

Insects as a source of pathogen in the home
Domestic flies are accepted vectors of diarrhoea-causing pathogens. Several studies have examined the impact of fly control on the incidence of diarrhoea. Cohen et al.(1991)151, in a study carried out at a military base in Israel, demonstrated that houseflies can transmit Shigella diarrhoeal infections by acting as a mechanical vector. Shigella was isolated from a proportion of flies. After implementation of fly control measures, the prevalence of houseflies
was greatly reduced. Soldiers at bases where fly control measures were implemented had significantly less diarrhoeal disease and shigellosis.

In Gambian villages, the control of muscid flies resulted in 75% fewer new cases of trachoma in intervention villages than in control villages. In the villages with fly control, there was also 22% less childhood diarrhoea in the wet season and 26% less in the dry season than in the control villages. In a study in Pakistan, the incidence of diarrhoea was lower (23% reduction) in villages sprayed with insecticide than in unsprayed villages.

1.1.2 Survival and spread of gastrointestinal pathogens in the home

The potential for exposure to GI pathogen shed or spread into the home or other environments from a human, animal, food or other source is shown by a whole range of laboratory and field studies which demonstrate the extent to which environmental persistence and spread of enteric bacteria and viruses can occur during preparation of food in the domestic kitchen and during other normal daily activities.

Although drying of inanimate surfaces has a microbicidal effect, there is a significant amount of data from laboratory studies, as reviewed by Kramer et al., and Rzezutka and Cook (see in Table 1) showing that enteric pathogens can survive in significant numbers for several hours, and in some cases, days and weeks, particularly on moist, but also on dry surfaces. In a separate study, Cryptosporidium oocysts have been shown to survive on soiled environmental surfaces for at least 2 days.

### Table 1 – Persistence of gastrointestinal pathogens on dry inanimate surfaces

<table>
<thead>
<tr>
<th>Type of bacteria</th>
<th>Duration of persistence (range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campylobacter jejuni</td>
<td>Up to 6 days</td>
</tr>
<tr>
<td>C. difficile (spores)</td>
<td>5 months</td>
</tr>
<tr>
<td>Escherichia coli</td>
<td>1.5 h to 16 months</td>
</tr>
<tr>
<td>Klebsiella spp.</td>
<td>&lt;90 mins</td>
</tr>
<tr>
<td>Helicobacter pylori</td>
<td>less than 90 min</td>
</tr>
<tr>
<td>Listeria spp.</td>
<td>1 day to months</td>
</tr>
<tr>
<td>Salmonella spp.</td>
<td>1 day</td>
</tr>
<tr>
<td>Shigella spp.</td>
<td>2 days to 5 months</td>
</tr>
<tr>
<td>Adenovirus</td>
<td>7 day – 3 months</td>
</tr>
<tr>
<td>Norovirus and feline calicivirus</td>
<td>8 h to 7 days</td>
</tr>
<tr>
<td>Rotavirus</td>
<td>6-60 days</td>
</tr>
<tr>
<td>Hepatitis A</td>
<td>2h - 60 days</td>
</tr>
</tbody>
</table>

A number of lab-based studies are reported on the survival of enteric pathogens on hands and surfaces:

- Hutchinson (1956) reported that *Shigella sonnei* can remain viable on hands for more than 3 hours.
- Pether and Gilbert (1971) reported survival of *E. coli* and *Salmonella* spp. at 1 hour after inoculation onto the hands (inoculum size $10^3$-$10^6$ per fingertip) although the extent of survival varied significantly between replicate tests.
- Scott and Bloomfield (1990) studied the survival of small numbers (100-500 cells) of environmental isolates and laboratory strains of *E. coli*, *Klebsiella* and *Salmonella* inoculated onto laminate surfaces. To simulate clean and dirty conditions, cells were suspended in either distilled water of nutrient broth. Under clean conditions, between 1 and 50% of the inoculum could be recovered at 1 hour, but after 4 hours and 24 hours, the numbers recovered were very small (1-10 cfu) or undetectable. Under soiled...
conditions, up to 10% of the inoculum was recovered at 4 hours, but the numbers recovered at 24h were very small (1-10 cfu) or undetectable.

- Maulé evaluated the survival of *E. coli* O157 inoculated in high numbers onto surfaces and held at 18°C. Survival times were up to 60 days on stainless steel and 10 days on a chopping board.
- Ansari *et al.* (1988) report 43% and 7% survival of rotavirus on hands at 1 and 4 h respectively.
- Sattar *et al.* (1988) report that hepatitis A can remain viable on the surfaces of vegetables for several days.
- Abad *et al.* (2001) reported that human astroviruses showed considerable persistence when dried onto porous and nonporous material. On china, it survived for 60 days at 4°C and 7 days at 20°C. On paper at 4°C, astrovirus infectivity was detected after 90 days, and for up to 60 days at 20°C.
- Sattar *et al.* (2002) compared survival of bacterial and also viral pathogens on fingerpads of human volunteers. Survival after 1 hour ranged from 4% for *E. coli* to up to 25% for adenovirus, 45% for rotavirus and 63% for hepatitis A virus. They also reported that adenovirus can persist on hands for many hours.

Studies of the survival of bacteria and viruses on fabrics are reviewed separately in the 2010 report on the infection potential associated with clothing and household linens. Comparative studies suggest that survival on porous surfaces is relatively less than that on non-porous surfaces, but enteric bacteria and viruses can survive for several hours to up to days and weeks on fabrics. For contaminated kitchen cleaning cloths, not only survival, but also re-growth of Gram-negative species readily occurs at ambient temperatures, particularly where cloths remain in a damp condition. Growth of bacteria in samples of toilet water has also been demonstrated.

These laboratory studies are supported by an ever increasing range of field studies, as summarised below, showing not only survival but also spread of enteric pathogens via the hands and other surfaces during food preparation and other normal daily activities. These and other studies are also reviewed elsewhere.

**Salmonella, Campylobacter and E. coli**

The spread of bacterial enteric pathogens such as *Salmonella* and *Campylobacter* from a contaminated food source to hands and surfaces during handling and preparation for eating is demonstrated by a range of studies:

- De Wit *et al.* (1979) demonstrated cross-contamination of foodborne pathogens via inanimate surfaces in the domestic environment during preparation of raw chickens.
- Dawkins *et al.* (1984) demonstrated that when fresh or frozen chickens contaminated with *Campylobacter* are introduced into a kitchen preparation area, the surrounding work surfaces are very likely to become contaminated.
- Borneff *et al.* (1988) showed that during preparation of a dinner, micro-organisms in contaminated chopped meat were spread over all the utensils and working surfaces used, thus contaminating ready-prepared food.
- Cross-contamination experiments by De Boer and Hahne (1990) showed that *Campylobacter jejuni* and *Salmonella* are easily transferred from raw chicken products to chopping boards, plates and hands.
- Scott and Bloomfield (1993) evaluated the relationship between bacterial contamination of food preparation surfaces and cleaning cloths during morning food preparation activities in a college kitchen. Cloths used became heavily contaminated during food preparation and the post preparation cleaning process. An increase in the contamination of surfaces after cleaning compared with after food preparation was also observed indicating transfer of contamination from cloths to surfaces during the
• Humphrey et al. (1994)\textsuperscript{177} found that, following preparation of egg dishes using eggs artificially contaminated with *Salmonella enteritidis* PT4, the strain was recovered from fingers and utensils, sometimes even after washing. The organisms could be recovered from dry films of either batter or eggs on work surfaces for up to 24 hours.

• McDermid and Lever (1996)\textsuperscript{178} showed that *Salmonella enteritidis* PT4 could remain viable in aerosols for up to 2 hours.

• Using a laboratory model, Zhao et al. (1998)\textsuperscript{179} showed that bacteria can be readily transferred to chopping boards after cutting and handling contaminated raw poultry. They showed that large numbers of bacteria can survive on chopping boards for at least 4 hours and can cross-contaminate fresh vegetables if the boards are not cleaned or disinfected.

• Cogan et al. (1999, 2003) demonstrated that, following preparation of *Salmonella* and *campylobacter*-contaminated chickens in domestic kitchens, these species were isolated from 17.3\% of hands, and hand and food contact surfaces. Isolation rates were highest for hands, chopping boards and cleaning cloths (25, 35 and 60\%, respectively, of surfaces sampled).\textsuperscript{27,180} Results suggested that not only hands but also cloths were responsible for dissemination. After preparation of the chickens, participants were asked to clean up the kitchen using their normal cleaning routine. Sampling of surfaces 3 hours later showed that 7\% of surfaces were still contaminated with either *Salmonella* or *Campylobacter*.

• In a further study (Cogan et al. 2002)\textsuperscript{28}, involving a limited number of sites (hands, cloths, chopping board, utensils, tap handles), the number of bacteria disseminated was evaluated. For *Salmonella*-contaminated surfaces although counts of <10 were recorded on 18.3\% of occasions, on 22 (18.3\%) and 2 (1.7\%) of occasions (a board and a cloth) counts were >10 and >1000, respectively. For *Campylobacter*-contaminated surfaces, high counts were isolated more frequently with 20\% of sites recording counts of >1000. High counts of both species occurred on chopping boards despite the fact that participants were asked to clean the boards between preparing the chicken and the vegetables. In this latter study, 3 cloth samples showed an increase in *Salmonella* count from $10^2$ to $10^3$ during overnight storage, suggesting growth of *Salmonella* in the soiled cloth. For 3 other cloths, a 1-2 log reduction in count occurred during overnight storage.

• Gorman et al. (2002)\textsuperscript{181} investigated cross-contamination in the domestic kitchen during preparation of a roast chicken lunch. The chickens were found to be contaminated with *Salmonella*, *Campylobacter*, *S. aureus* or *E. coli*, which were subsequently found on hand and food contact surfaces after food preparation.

• Hilton and Austin\textsuperscript{182} evaluated transfer of contamination from un-rinsed and rinsed cloths and sponges taken from domestic homes and inoculated with $10^8$ *E. coli*. Rinsing of clothes and sponges produced a significant reduction (1 and 2 logs for cloths and sponges, respectively) in the numbers of organisms transferred to a chopping board surface, but even where rinsed cloths were used, significant numbers of organisms ($10^4$-$10^5$) were still recovered from surfaces after wiping.

• Meredith et al. (2001)\textsuperscript{183} demonstrated that during the preparation of a chicken meal, artificially seeded bioluminescent *E. coli* was widely disseminated throughout the kitchen and equipment used, especially to hand contact surfaces. All but 2/35 hand and food contact surfaces were contaminated.

• Mattick et al. (2003) determined the temperature of washing-up water and bacterial quality of the water, dishcloths, tea towels and other surfaces following meal preparation by people without food safety training in their own kitchen or by trained staff in a commercial kitchen. *Campylobacter* and *Salmonella*, respectively, were found in 96\% and 13\% of the raw chickens used in the meal preparation. In domestic kitchens, 2 of 45 sponges/dishcloths/scourers and 1 of 32 hand/tea-towels were
contaminated with *Campylobacter* after washing-up and cleaning. *Campylobacter* was detected in 1 of 10 washing-up water samples from the commercial kitchen. In another study by Mattick and co-workers, in a typical UK washing-up process simulation, bacterially contaminated soiled dishes were washed in warm water containing detergent and the risk of bacterial transfer to other dishes and sponges, kitchen surfaces or food was assessed. Some dishes remained contaminated with bacteria after washing-up and water hardness did not appear to affect survival. *E. coli* and *Salmonella* survived towel or air-drying on dishes and after towel-drying, the cloth became contaminated on every occasion. Some sterile dishes washed after contaminated dishes also became contaminated. Washing-up sponges frequently became contaminated with bacteria.

- Studies evaluating cross contamination in the kitchen are reported by van Asselt *et al.* (2008) and de Jong *et al.* (2008). Van Asselt *et al.* estimated transfer rates for *Campylobacter jejuni* and *Lactobacillus casei* as a tracer organism. Transfer for both micro-organisms were comparable when washing regimes and transfer via items (cutting board, hands and knives) were compared. They concluded however that the use of separate rates for transfer from chicken to items and from items to salad may lead to an overestimation of campylobacteriosis risk and that applying good hygiene practices resulted in residual levels of bacteria in the salad below the detection limit. The study of de Jong *et al.* re-enforced the fact that cross-contamination plays an important role in the transmission of food-borne illness, especially for *C. Jejuni*. This study demonstrated that dish-washing does not sufficiently prevent cross-contamination.

- In a study by Bergen *et al.* (2009), surface were contaminated with bacteria (4 cfu/bacteria/cm²), and cleaned with premoistened microfiber clothes. After cleaning, surface imprints of cloths showed a median of 45.5 cfu/plate for *E. faecalis* and 2.5 cfu/plate for *B. cereus*. From cloth sides 2-16, the median values from imprints were 1 and 12 cfu/plate for *E. faecalis* and 0 cfu/plate for *B. cereus*. Samples of contaminated surfaces gave a median of 45.5 cfu/plate for *E. faecalis*, giving a reduction of 5.6-fold. Surface numbers 2-16 had median values between 0.5 and 7.5 for *E. faecalis*, which was spread to 11-15 of the 15 sterile surfaces. *B. cereus* was found in 6 out of 180 imprints on surfaces 2-16, all with 1 cfu/plate.

- Jimenez *et al.* (2009) investigated the effect of refrigeration time and temperature on *Salmonella* on inoculated chicken carcasses and their transfer to a plastic cutting board. It was found that all of the carcasses remained contaminated even after 9 days of refrigeration. On carcasses untreated with a decontaminating acetic acid solution, *Salmonella* numbers increased almost 1.5 log at 8°C, while numbers decreased about 1 log at 2 and 6°C. On acid-treated samples, cell numbers slightly decreased at all of the temperatures studied. Temperature did not affect salmonellae transfer to the cutting board, but time did. Acid decontamination increased cell numbers transferred to the cutting board compared with untreated samples.

- Tang *et al.* (2011) found that the mean transfer of *Campylobacter jejuni* from scored rubberwood (RW) and polyethylene cutting boards contaminated by contact with naturally contaminated chickens to cooked chicken was 44.9 and 40.3%, respectively. Whilst unscored PE and RW boards were not significantly different in regards to the mean transfer, transfer of *C. jejuni* from scored RW was significantly higher than from scored PE.

- Soares (2012) evaluated transfer of *S. Enteritidis* from contaminated poultry skin (5 log cfu/g) to different cutting boards (wood, triclosan-treated, plastic glass and stainless steel) and then to tomatoes. The pathogen was recovered from all surfaces with counts ranging from 1.90-2.80 log as well as from the tomatoes handled on it.

- A 2011 study by Kennedy *et al.* involved filming 60 participants while they prepared a meal according to a specified recipe (30 beef/salad burgers and 30 chicken salads)
and swabbing key potential contamination sites in the participant’s kitchen. Sites sampled included the sink drainer, taps, work top, refrigerator handle, chopping board and knife blade. Results showed that C. jejuni was not detected at all. S. aureus was detected on between 26 and 63% of sites sampled, and more likely to be found and more prevalent than E. coli which was found on between 0 and 10% of sites sampled. S aureus was found on 78% of hands after food preparation and on between 26 and 66 of the items prepared. E. coli was found on 3.3% of hands after food preparation, but was not isolated from any food samples.

- The occurrence and numbers of Salmonella was studied in 60 homes in Culican, Mexico, over a six week period in which half disinfected kitchen cleaning clothes with a sodium hypochlorite based disinfectant (Chaidez et al., unpublished- in press). A total of 360 samples were taken from both home groups (disinfectant using and control groups). Overall, Salmonella was present in 1.11% and 3.89% of the cleaning cloths from test group and control group households, respectively.

The potential for spread of enteric bacterial pathogens such as Salmonella, Campylobacter and also C. difficile, from a human source via the toilet and other environmental surfaces is also demonstrated by a range of studies.

- Gerba et al. (1975)\textsuperscript{117} assessed hazards of household toilets as a source and vector for cross infection in the home. Large numbers of bacteria and viruses were seeded into the household toilet. Detection of these organisms on bathroom surfaces showed that the organisms remain airborne and viable long enough to settle on surfaces.

- Van Schothurst et al. (1978)\textsuperscript{192} demonstrated that, in 73 homes where a case of salmonellosis had occurred, in over half of these homes, the same serotypes were recovered from environmental sites, including worktops, sinks and towels, etc.

- Following the investigation of 9 cases of infant salmonellosis, Haddock (1986) isolated Salmonella from the contents of 4 of 9 vacuum cleaners. Three of the four isolates were of the same serogroup as the infant case.\textsuperscript{193}

- A 1994 study by Haddock et al. carried out on the island of Guam reported isolation of various spp. of Salmonella (S. java, S. houten) from 4/68 (6.9%) soles of shoes taken from a variety of settings.\textsuperscript{194}

- In a study in Mexico City,\textsuperscript{195} where water and soil are thought to be contaminated with human waste, because of inadequate disposal services, dust samples from indoor and outdoor environments, collected using a vacuum cleaner, were found to contain E. coli.

- Barker and Bloomfield (2000)\textsuperscript{196} demonstrated that in 4 out of 6 homes where there was a Salmonella case, the causative species was isolated from faecal soiling under the flushing rim of the toilet and scale material in the toilet bowl, despite the fact that the samples were taken 3 weeks or more following notification of the infection. Toilet-seeding experiments were set up using Salmonella enteritidis PT4 to mimic environmental conditions associated with acute diarrhoea. Flushing the toilet resulted in contamination of the toilet seat and the toilet seat lid. In 1/3 seedings, Salmonella was also isolated from an air sample taken immediately after flushing, indicating that airborne spread of the organism could contaminate surfaces in the bathroom. In seeded toilets, Salmonella was isolated from the biofilm in the toilet bowl below the waterline for up to 50 days after seeding and also on one occasion from the bowl water. Although the risk of exposure to pathogens from the toilet is relatively low under normal conditions, these studies suggest that during diarrhoeal illness, there is considerable risk of spread of Salmonella infection via the environment, including contaminated surfaces in the toilet area.

- Schutze et al. (1999)\textsuperscript{197} studied environmental contamination in 50 homes where children under 4 years were known to be infected with Salmonella spp. In 34% of homes there was also illness in other family members. The authors concluded that environmental sources, infected family members and pets, appeared to be more
significant risk factors for development of salmonellosis in these children than contaminated foods. Cultures were obtained from foods, persons residing in the home, animals/pets/insects, and environmental sources. Isolates with a serotype identical to those in the index patient were found in 16 homes, 3 of which included an isolate of a second serotype. A different serotype was recovered in 3 homes. Serotypes from the subjects and their environment were indistinguishable in all but 2 patients. The identical serotype was found in multiple locations (4), dirt surrounding front doors (4), household members (3), vacuum cleaner (1), animals/pets/insects (1), and a refrigerator shelf (1).

- Barker et al. (2005) evaluated the spread of infection by aerosol contamination of surfaces after flushing a domestic toilet. This study showed that although a single flush reduced the level of micro-organisms in the toilet bowl water, when contaminated at concentrations reflecting pathogen shedding, large numbers of micro-organisms persisted on the toilet bowl surface and in the bowl water which were disseminated into the air by further flushes. 198

- A range of studies are reported showing extensive contamination with C. difficile of hands and environmental surfaces in settings where there is an infected person or a carrier. These are reviewed in more detail in the 2006 IFH report on C. difficile. More recent studies are reviewed by Dubberke et al. 199, Mutters et al. 200, Otter et al. 201, Webber and Rutala. 202 The majority of studies were carried out in hospitals, nursing homes, extended care facilities, and nurseries, but Kim et al. (1981)202 found that 12.2% of environmental surfaces were positive for C. difficile in the home of an infected infant recently discharged from hospital. Surfaces found to be contaminated included floors and furniture. In contrast, in a control home where none of the family members were carriers, none of the 84 environment samples were positive for C. difficile. 202

- Best et al. 2012 performed in-situ testing, using faecal suspensions to measure C. difficile measure aerosolisation and splashing from toilets 203. C. difficile was recoverable from air sampled at heights up to 25 cm above the toilet seat. The highest numbers of C. difficile were recovered from air sampled immediately following flushing, and then declined 8-fold after 60 min and a further 3-fold after 90 min. Surface contamination with C. difficile occurred within 90 min after flushing, demonstrating that relatively large droplets are released which then contaminate the immediate environment. The mean numbers of droplets emitted upon flushing by the lidless toilets in clinical areas were 15-47, depending on design. C. difficile aerosolisation and surrounding environmental contamination occur when a lidless toilet is flushed.

- Gerhards et al. 2012 204 reported studies carried out to simulate the chain of infection from a pathogen source (i.e. stool). Transmission of E. coli, Bacillus atrophaeus spores, Candida albicans and bacteriophage MS2 from hands to surfaces was examined in a transmission model, that is toilet brush and door handle to water tap. Although the load of viable pathogens was significantly reduced during sequential transfer from hands to objects, nevertheless, it was shown that pathogens were successfully transferred to other people in contagious doses by contact with contaminated surfaces.

Norovirus, rotavirus and other viral enteric pathogens
Bellamy et al. (1998) 205 investigated the domestic environment for the presence of viruses and body fluids that may contain viruses. Haemoglobin was found on 2% of surfaces (taps, washbasins, toilet bowls and seats) indicating the presence of blood. Amylase (an indicator of saliva, sweat and urine) was found on 29% of surfaces, which were frequently handled or in contact with urine. These data highlight that surfaces may remain soiled for some time, and that cleaning procedures may not be effective. Enteroviral RNA was detected in 3 out of 448 samples tested (tap handle, telephone handpiece and toilet bowl).
Virus transmission in a childcare centre was studied by using modified cauliflower virus DNA as an environmental marker. The DNA markers were introduced into the environment through treated toy balls. The marker treated objects were removed after one day, but the markers continued circulating in the settings for up to 2 weeks. Hand contact with contaminated surfaces played an important part in the transmission of the markers. After introduction into the child-care centre, the markers were detected in the children’s homes, on toys and environmental surfaces, and from the hands of family members.

In homes where there was an infant recently vaccinated for polio (during which time shedding occurs in faeces), using polio vaccine virus as an indicator of viral contamination from faeces, Curtis et al. (2001) carried out a study of the hygiene practices of mothers with young children in England. A total of 234 surface samples were taken from 10 households and tested for poliovirus. Of these samples, 13% were positive: 15% of bathroom sites were positive, 12% of living room sites and 10% of kitchen sites. Most frequently contaminated were hand contact sites, such as bathroom taps, door handles, toilet flushes, liquid soap dispensers, nappy changing equipment and potties.

Transmission of viruses in a household setting was studied, using bacteriophage X174 as a model virus with resistance properties similar to polio-or paroviruses. Contaminated door handles and skin surfaces were found to be efficient vectors of contamination. At least 14 persons could be contaminated one after another by touching a contaminated door handle. Successive transmission from one person to another could be followed up to the sixth contact person. Transfer from contaminated door handles to other surfaces was also confirmed under everyday life conditions in a flat shared by four students.

The potential for environmental spread of enteric viruses was demonstrated in a 2008 study by Gallimore et al. in 2 UK hospital paediatric wards over a winter season. Environmental swabs were collected weekly from 11 sites in both wards and examined for the presence of norovirus, astrovirus, and rotavirus by reverse transcriptase PCR. Viruses were detected in 17% and 19% of swabs from both wards. Surfaces sampled included tap and door handles, telephones, televisions and light switches.

Norovirus

As mentioned earlier, projectile vomiting associated with norovirus infection represents the major route of cross infection and it is estimated that $3 \times 10^7$ particles may be distributed as an aerosol into the environment during a vomiting attack. The potential for person to person transmission in home and everyday life settings is shown by a whole range of microbiological studies:

- Studies by Cheesbrough et al. showed the extent to which airborne contamination and contamination of environmental sites and surfaces can occur during outbreaks in hospital and hotel settings. The authors found that during and after an outbreak of norovirus-associated gastroenteritis in a hotel, 42% of environmental samples were positive for norovirus nucleic acid. All positive samples were from sites likely to have been directly contaminated (i.e., known recent vomit) e.g. carpets, toilet rims or seats. Positive samples were just as likely to be collected from a high horizontal surface, very unlikely to have been touched, as they were from items to be handled such as telephones and door knobs. Contact with contaminated fomites appears to have played an important role in maintaining the outbreak over several months. The prolonged nature of the outbreak indicates the ability of the virus to survive and be transferred in an infective form.

- Barker et al. (2004) showed that, where fingers come into contact with norovirus-contaminated faecal material, the virus is consistently transferred via the fingers to
surfaces and from there to hand contact surfaces, such as taps, door handles and telephone receivers. Contaminated fingers sequentially transferred the virus to up to seven clean surfaces.180

- A 2006 study212 with feline calicivirus (FCV) showed survival for up to 3 days on telephone buttons and receivers, for 1 or 2 days on computer mouse, and for 8-12 hours on keyboard keys, and brass disks representing facets and door handles. The time for 90% virus reduction was <4 hours on computer keys, mouse and brass disks; 4-8 hours on telephone receivers; and 12-24 hours on telephone buttons.

- During a 2005 outbreak in a long-term care facility, norovirus RNA was identified on 5 of 10 environmental sites collected after disinfection, suggesting widespread persistent contamination. Positive sites included an elevator call button used only by staff. The outbreak resolved following a second, more thorough facility-wide disinfection.213

- Jones et al. (2007)214 reported an outbreak which affected 74% of guests on 3 consecutive houseboat trips. An environmental investigation identified norovirus RNA on 71% of surfaces in bathrooms, kitchens, and door handles.

- Norovirus strains were detected in 2 patients and in environmental swabs from a paediatric immunodeficiency unit in London, UK, during an infection control incident in 2007.215 Detailed genetic analysis demonstrated that the majority of the strains were not related to the patients and that the environmental contamination was most likely due to secondary transfer by the hands of staff or visitors.

- Bright et al. (2009)23 carried out a 6 week intervention study of the impact of hygiene in 6 (3 intervention, 3 control, 148 students) classrooms in a school in Seattle, US. Surfaces were sampled in the afternoon on 4 study days. Norovirus was detected on surfaces in two of three control classrooms sampled. The virus was found on 16.4% (9 of 55) of surfaces tested including student desktops (6 of 27), a paper towel dispenser (1 of 4), a sink faucet handle (1 of 7), and a water fountain toggle (1 of 7) but was not detected on the soap dispenser or the entrance doorknob in any of the classrooms.

- The potential for contamination of environmental surfaces in situations where there is an infected person is demonstrated in a 2011 hospital study24 where norovirus strains were collected over a four-month period from hospitalised patients with symptoms of gastroenteritis. These were characterised in order to estimate how many strains were introduced into the hospital from the community. A total of eight distinct genetic clusters of the GII-4 genotype were identified, with some wards experiencing multiple outbreaks with different GII-4 strains during the season. Norovirus was detected from 31.4% of environmental swabs including surfaces of trolleys, computer keyboards, soap and alcohol dispensers together with surfaces around the bedside environment, and furniture, fixtures and fittings associated with toilets and shower rooms.

- In a 2011 study,25 the prevalence of norovirus in catering companies without recently reported outbreaks of gastroenteritis was investigated and compared to prevalence in catering companies with recently reported outbreaks. Swab samples were collected from surfaces in the kitchens and (staff) bathrooms in 832 randomly chosen companies and analyzed for the presence of norovirus RNA. In total, 1.7% of 2,496 environmental swabs from 35 (4.2%) catering companies tested positive compared with 39.7% of the 370 samples for 44 (61.1%) of the 72 establishments associated with gastroenteritis outbreaks. Sequence analysis showed that environmental strains were interspersed with strains found in outbreaks of illness in humans suggesting that presence of norovirus was associated with presence in the population.

- In a UK hospital, norovirus strains were collected over a four-month period during 2009-2010 from hospitalised patients with symptoms of gastroenteritis.216 These were characterised in order to estimate how many strains were introduced into the hospital from the community. A total of eight distinct genetic clusters of norovirus GII-4 genotype were identified during the four-month period, with some wards experiencing multiple outbreaks with different GII-4 strains during the season. Norovirus was
detected from 31.4% of environmental swabs. Contaminated sites suggested transmission via hand contact, and hot spots were identified as patient monitoring equipment, computers and notes trolleys at the nurses’ stations, soap and alcohol dispensers, hand and grab rails within toilets and the bedside environment.

Rotavirus

- Studies in child day-care centers have shown that rotavirus is widely disseminated when outbreaks occur. In one centre, faecal contamination of hands and the environment was demonstrated during an outbreak of rotavirus diarrhea.\textsuperscript{217} Other studies in day-care centers have shown that 16–30% of surfaces sampled can be contaminated with rotavirus; in particular, hand contact surfaces (e.g. refrigerator handle, toilet handles, telephone receivers, and toys) and moist surfaces, such as sinks, water fountains and water-play tables were contaminated.\textsuperscript{217,218,219}
- Akhter et al.\textsuperscript{(1995)}\textsuperscript{220} and Soule et al.\textsuperscript{(1999)}\textsuperscript{221} found that increases in the number of children suffering from rotavirus gastroenteritis in hospital paediatric units were correlated with an increase in the number of environmental surfaces contaminated with rotavirus. Soule et al.\textsuperscript{(1999)} detected rotavirus in 63% of samples from surfaces in direct contact with children (thermometers, play mats, toys) compared with 36% of surfaces without direct contact with children (telephones, door handles, washbasins). Akhter et al. also showed frequent detection of rotavirus on surfaces such as toilet handles, televisions and toys, i.e., objects handled by humans.
- In a treatment centre in Bangladesh, hand washings from 78% of the attendants of patients with diarrhoea (children under 5 years) were positive for rotavirus antigens.\textsuperscript{222} Rotavirus was also found in hand washings of 19% of attendants of patients with non-rotavirus diarrhoea, indicating that they may have come into contact with other attendants and patients in adjacent beds.
- Sattar et al.\textsuperscript{(1986)}\textsuperscript{223} and Ansari et al.\textsuperscript{(1988)}\textsuperscript{161} demonstrated survival of rotavirus on human hands, and transfer of infectious virus to animate and non-porous inanimate surfaces.
- Ward et al.\textsuperscript{(1991)}\textsuperscript{40} examined the transfer of rotavirus from contaminated surfaces to the mouth and from surfaces to hands to the mouth. All the volunteers who licked rotavirus contaminated plates became infected. Of those individuals who touched the virus-contaminated plates with their fingers and put the fingers to their mouths, about half became infected. Ward et al.\textsuperscript{(1991)} demonstrated that 13 out of 14 adult subjects who consumed rotavirus (10\textsuperscript{5} focus forming units) became infected.
- Rogers et al.\textsuperscript{(2000)} reported an outbreak of rotavirus in a paediatric unit. Rotavirus transmission continued for more than a month even after applying aggressive infection control measures. An examination of the outbreak revealed that communal toys had not been cleaned for several months, in line with the weekly protocol. The authors believe that improperly cleaned toys may have served as fomites in the transmission of rotavirus and contributed to the outbreak.\textsuperscript{224}

Hepatitis A Virus

It is generally agreed that hepatitis A virus (HAV) is most commonly spread via water, food and by person-to-person transmission. However, from an assessment of data showing the occurrence of HAV in secretions, such as saliva, and its ability to survive on dry surfaces, Hadler (1991)\textsuperscript{225} and Cliver (1983)\textsuperscript{226} concluded that fomites are potential risk factors in the spread of the virus, especially in hospital wards, day-care centres or restaurants. A review by Sattar et al.\textsuperscript{2000}\textsuperscript{162} summarises the findings of studies showing how transfer of HAV can occur from contaminated fingers to surfaces and objects during casual contact.
Infection risks associated with spread of Salmonella, Campylobacter, norovirus, rotavirus etc. via hands and surfaces depend on the number of infectious agents transferred via hands and surface etc. by contact between surface, hands, food etc.:

- Scott and Bloomfield (1990) studied the transfer of small numbers (200-600 cells) of environmental and laboratory strains of E. coli and Salmonella from laminate surfaces to fingertips and to a stainless steel bowl surface. To simulate dirty conditions, cells were suspended in nutrient broth for inoculation onto surfaces. Immediately after inoculation and after 1 hour drying, transfer rates of around 10-40% were recorded. At 2 hours, transfer rates were lower, ranging from no detectable transfer of salmonella from laminate surface to bowl, up to 30% transfer of E.coli from laminate surface to fingertips.

- Chen et al. 2001 investigated the transfer of bacteria between hands and other kitchen surfaces during food preparation using Enterobacter aerogenes as a model. Transfer of bacteria was studied when handling a chicken, lettuce and a tap with results showing significant variation but quite a high rate of transfer (as high as 100%) in all of these situations. Chen and co-workers found that transfer rates are highly variable but can range as high as 100% and as low as less than 1%.

- Rusin et al. (2002) determined that transfer from surfaces to hands (using Serratia rubidea, Micrococcus luteus and bacteriophage PRD-1) was highest from non-porous surfaces, such as faucets, with a 48.7% transfer efficiency and much lower from other surfaces such as carrots (<1%) and sponges and dishrags (<1%). Even so, up to 1 million bacteria and viruses were transferred to the hands after wringing out a seeded sponge or dishrag. Rusin et al. sampled volunteer’s hands after touching surfaces contaminated with M. luteus, S. rubidea and phage PRD-1. Activities included wringing out a dishcloth/sponge, turning off a faucet, cutting up a carrot, making hamburger patties, holding a phone receiver, and removing laundry from the washing machine. Transfer efficiencies for the phone receiver and faucet were 38-65% and 27-40%, respectively.

- Paulson showed that when gloved hands were contacted for 5-10 seconds with surfaces such as cutting boards and door knobs contaminated with FCV (log 5.9 particles), the log number of particles recovered from the gloved hands was 4.7-5.4.

- Kusumaningrum et al. (2003) quantified survival of Salmonella enteritidis, S. aureus and Campylobacter jejuni at room temperature on stainless steel surfaces. Transfer from kitchen sponges to surfaces and from surfaces to foods was also investigated. Bacterial levels decreased rapidly, particularly when initial levels were low. S. aureus was recovered from surfaces for at least 96 hours when the inoculum level was high (10^5 cfu/cm²) or moderate (10^3 cfu/cm²). At low levels (10 cfu/cm²), numbers decreased below the detection limit (4 cfu/100cm²) within 2 days. All bacteria were readily transferred from wet sponges to surfaces and then to food (transfer rates between 20-100%).

- By contrast, Montville et al. showed that the effect of inoculum size on transfer rates was highly statistically significant. With higher inoculum sizes, transfer rates were lower, and where inoculum size was less, transfer rates were higher. The negative linear trend has serious implications for research, seeking to determine bacterial cross contamination rates, since transfer efficiencies previously shown to be associated with certain activities may actually be the result of differing inoculum levels.

- Julian et al. 2010 reported a study modelling transfer rates for bacteriophage between fingerpads and surfaces. Aggregating 656 transfer events, they reported that the mean fraction of virus transferred between finger pad and glass was 0.23 +/- 0.22. Transfer rates were significantly affected by virus species and time since last hand washing.
1.1.3 Risks from exposure to gastrointestinal pathogens in the home

As shown in Figure 1, exposure to enteric pathogens can occur either by direct hand-to-mouth contact, or by the consumption of contaminated food or water. The infection risk from oral consumption of GI pathogens depends upon the number of bacterial cells or viral particles which are consumed. For many common GI pathogens, the oral infectious dose is relatively small. Infection risk also depends on the immune status of the recipient and is generally lower for someone with lowered immunity to infection. Table 2 shows examples of infectious doses as estimated for some pathogens, although they should not be regarded as comparative since many are not estimated as ID-50 values. Data on the minimum infectious dose for enteric viruses transmitted through food and the environment is summarized in a 2011 review by Yezli and Otter. ID-50 values for enteric pathogens can also be obtained from the Quantitative Microbial Risk Assessment Wiki site (QMRAwiki) at: http://wiki.camra.msu.edu/index.php?title=Table_of_Recommended_Best-Fit_Parameters

<table>
<thead>
<tr>
<th>Organism</th>
<th>Infectious dose</th>
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<tbody>
<tr>
<td><em>Salmonella</em> spp.</td>
<td>Up to $10^6$, but could be as low as 10-100 cells.</td>
</tr>
<tr>
<td><em>Campylobacter</em> spp.</td>
<td>500 organisms can result in human illness.</td>
</tr>
<tr>
<td><em>E. coli</em> 0157</td>
<td>Oral dose for <em>E. coli</em> 0157 may be as little as 10-100 cells.</td>
</tr>
<tr>
<td>Norovirus</td>
<td>10-100 units or even as little as 1 unit.</td>
</tr>
<tr>
<td>Rotavirus</td>
<td>May be as few as 10 particles.</td>
</tr>
<tr>
<td><em>Hepatitis A</em></td>
<td>According to Yezli et al., recent work suggests that the HID50 of the virus is 18 particles.</td>
</tr>
<tr>
<td><em>C. difficile</em></td>
<td>Consumption of one to two spores may be sufficient to establish colonization and CDAD in clindamycin-treated mice. Less than 1 CFU/cm2 was sufficient to cause <em>C. difficile</em> disease in mice.</td>
</tr>
</tbody>
</table>

*Cryptosporidium parvum* and *C. hominis*, are responsible for most human cases of cryptosporidiosis. Dupont et al. (1995) estimated the median infective dose of *C. parvum* in healthy adults as 132 oocysts. Chappell et al. demonstrated that *C. hominis* is infectious for healthy adults (ID$_{50}$=10 oocysts) and is clinically similar to *C. parvum*-induced illness.

Hand-to-mouth contact is a frequent occurrence, particularly among children; a study of mouthing behaviour in 72 young children showed that children <24 months exhibit the highest frequency, with 81 events/hour; for children >24 months this was reduced, but was still of the order of 42 events/hour.

The potential for transmission of pathogens from hands to ready-to-eat foods, or from hands and surfaces directly to the mouth is supported by a number of studies:

- In a model domestic kitchen, 29% of food preparation sessions using *Campylobacter*-contaminated chicken resulted in positive *Campylobacter* isolations from prepared salads, cleaning materials and food contact surfaces.
Bidawid et al.\textsuperscript{247,248} showed that touching lettuce with fingers contaminated with HAV and feline calicivirus (used as surrogate for norovirus) for 10 seconds resulted in transfer of 9.2 and 18%, respectively, of the virus. Based on the known load in faeces ($10^6$ to $10^9$ viral particles/g), an estimated 1,300 HIV particles were transferred to the lettuce.

Rusin et al. showed that when volunteers’ fingertips were inoculated with a pooled suspension of *Micrococcus luteus* (*M. luteus*), *Serratia rubidea* (*S. rubidea*) and bacteriophage PRD-1 and held to the lip area, transfer rates were 40.99, 33.97 and 33.90\%, respectively.\textsuperscript{228}

Lingaas et al.(2009) indicated low transfer of bacteria during short contact with dry hands of healthcare workers to a recipient wearing sterile gloves. A smaller proportion of *E. coli* was recovered from skin compared with glove surfaces, indicating reduced survival of bacteria in contact with skin.\textsuperscript{249}

### 1.2 Chain of Transmission of Respiratory Tract Infections

Within the home, the primary source by which respiratory pathogens are introduced into this setting is via people who are infected. Infections can spread by transmission of infected particles of mucous generated by coughing and sneezing which remain airborne, or settle on surfaces, including those which are frequently touched (door handles, tap handles etc). Infectious material can also be deposited directly on hands and tissues during sneezing and blowing the nose. Contamination of hands can occur by handshaking or touching contaminated surfaces. Pathogens shed into the environment can survive for significant periods, and are readily spread around the home, to and from the hands, and via surfaces such as handkerchiefs and tissues, tap and door handles, telephones and other hand contact surfaces. Infection occurs by inhaling airborne particles of infected mucous generated by coughing and sneezing. It also occurs by direct transfer of infectious agents from the hands to the eyes, nose or mouth.

Respiratory infectious agents thought to be spread via these routes include rhinovirus, respiratory syncitial virus (RSV), adenovirus, parainfluenza (PIV) and influenza virus. The last 2 years have seen an unprecedented global focus on developing strategies for preventing transmission of influenza. The WHO\textsuperscript{250} has taken the lead on pharmaceutical interventions such as vaccines and antivirals, but has also made recommendations for other interventions\textsuperscript{251} which include highlighting the importance of good respiratory hygiene in minimizing spread in the home and community.

In addition, there is evidence that *Legionella* infection can occur in the home as a result of inhalation of contaminated water sprays or mists which occur in association with showers, spas and hot tubs, whilst *P. aeruginosa* and *Stenotrophomonas maltophilia* represents a risk to patients with increased susceptibility to infection who are cared for at home. To determine the composition of showerhead biofilms and waters, Feazel et al.(2009)\textsuperscript{252} analysed rRNA gene sequences from 45 showerhead sites around the US. They found that microbial assemblages containing sequences representative of non-tuberculous mycobacteria (such as *M. avium* and *M. gordonae*) and other opportunistic human pathogens are enriched to high levels in many showerhead biofilms, >100-fold above background water contents. Other species identified in showerheads included *Pseudomonas* spp. (3.8\% of total clones), *Staphylococcus* spp. (2\%), *Streptococcus* spp. (1\%), *Legionella* spp. (0.1\%) and *Escherichia* spp. (6\%).

The risk of exposure to respiratory pathogens, as illustrated in Figure 1, depends on the extent to which these pathogens are brought into the home and the extent to which they are
spread via hands and other sites and surfaces, and by airborne transmission. Data on the survival and spread of respiratory pathogens in homes and other settings comes from various sources and is summarised below. Taken together, it suggests that exposure to respiratory pathogens by direct inhalation or via the hands and surfaces is a frequent occurrence during normal daily activities, and that the numbers of organisms transferred via the hands to the eyes, nose and mouth can be well within the numbers required to cause infection.

1.2.1 Sources and spread of cold and flu pathogens
The potential for exposure to respiratory pathogens shed or spread from a human, animal, food or other source is shown by a whole range of laboratory and field studies, as summarised below. These studies are also reviewed elsewhere.4,6,22,12,168,253

Rhinovirus
The common cold is reported to be the most frequent, acute infectious illness to humans.254 Estimates suggest that adults suffer 2 to 5 colds per year and infants have about 4 to 8 colds per year.255 People infected with cold viruses shed large quantities of virus-laden mucus. Droplets of nasal secretions generated by coughing, sneezing and talking can travel over a distance >3 m to contaminate surrounding surfaces.251,256,257,258,259

The mean duration of a cold is 7.5 days. Viral shedding may occur 24-48 hours before illness onset, but mostly at lower titers than during the symptomatic phase. Titers generally peak during the first 24-72 hours of illness, and decline within several days, with low or undetectable titres by day five. Children can shed virus for longer periods (up to 3 weeks), whilst immuno-compromised people may continue to shed virus to weeks to months.251

The potential for spread of rhinovirus from infected people during normal daily life activities is demonstrated by a range of studies:

- Hendley et al. (1973)260, Reed (1975)261 and Kramer et al. (2006)254 review data showing that rhinovirus can survive for significant periods (2 hours to 7 days) on dry surfaces, and for at least 2 hours on human skin.
- Hendley et al. (1973)260 found that 2 of 25 persons infected with rhinovirus colds expelled virus in a cough or sneeze and 4 of 10 had virus on their hands. Dried rhinovirus could be picked up by the fingers from skin or environmental surfaces.
- Reed (1975)261 recovered rhinovirus from the fingers of 16 of 38 volunteers, who were swabbed during the acute stages of infection. Very low titres of virus were also recovered from 6 of 40 objects recently handled by infected volunteers, but not from the fingers of 18 non-infected subjects whose flat-mates were shedding virus. When rhinovirus from nasal secretions was dried on skin or other surfaces, approximately 40-99% of infectivity was lost. Virus could be transferred from surface to surface by rubbing, transfer being more efficient if the inoculum was still damp.
- Gwaltney, Moskalski and Hendley (1978)262 showed that hand transfer of rhinovirus from experimentally infected volunteers to susceptible recipients was very efficient. As much as 70% of infectious rhinovirus has been shown to transfer to a recipient's fingers after contact for 10 seconds.
- Gwaltney and Hendley (1982)263 demonstrated that most subjects with experimental colds had rhinovirus on their hands, and that rhinovirus could be recovered from 43% of plastic tiles they touched. For people with natural rhinovirus colds, virus was found on 39% of hands and 6% of objects in their immediate environment.
- Ansari et al. (1991)264 determined the survival of mucin-suspended rhinovirus 14 (RV-14) and the transfer to and from the fingers of adult volunteers. When each finger pad
was contaminated with 10ul of RV-14 (2.1 x 10' to 1.1 x 10 PFU), 37.8% of RV-14 remained viable after 1 h. After 3 hours, nearly 16% of RV-14 could still be detected. Tests on the spread of viruses from contaminated hands or surfaces were conducted 20 min after contamination of the donor surface by pressing together donor and recipient surfaces for 5s. Irrespective of type of donor or recipient surface, 0.7-0.9% of RV-14 was transferred.

- Pancic et al. (1980) estimated recovery rates from 3-1,800 plaque forming units of rhinovirus from fingers of volunteers who handled contaminated door knobs or faucets.265
- In a 2006 study, Winther et al. (2007)266 recruited volunteers with rhinovirus colds to stay overnight in hotel rooms. After checkout, before room cleaning, 10 frequently touched surfaces were sampled for residual rhinovirus. Rhinovirus was found on 35% of objects, including door handles, light switches, pens, faucet and toilet handles, and television remote controls. Some people contaminated none or few sites, most contaminated several, and some contaminated almost all (up to eight) sites. In a second study where the same subjects stayed overnight in a hotel room where hand contact surfaces (light switch phone button and handset) had been contaminated with rhinovirus-contaminated mucus, 60% of subjects became contaminated with rhinovirus.

Based on the available evidence, opinion as to the importance of the hands relative to the airborne route for transmission of rhinovirus colds is divided. Some investigators267, 268, 269 maintain that contamination of the hands followed by inoculation of the eyes or nose is of paramount importance; in fact, Gwaltney and co-workers found that it was exceedingly difficult to transmit virus orally or by kissing, and found little evidence of droplet or droplet nuclei transmission.260,262 Others maintain that the evidence favours droplet and droplet nuclei transmission as the most important mode of spread.270

Respiratory syncytial virus (RSV)
For RSV, there is general agreement that hands are the primary route for spread of infection.253,271,272,273 Infants with RSV excrete prodigious amounts of virus in their nasal secretions for a number of days.274,271 RSV has been shown to survive well on inanimate objects – more than 5 hours on impervious surfaces such as countertops.

- Kramer et al.154 review evidence showing that RSV can survive for significant periods (up to 6 hours) on dry surfaces.

Parainfluenza virus (PIV)
- Brady et al.(1990)275 studied survival of PIV on nonabsorptive (stainless steel, laminated plastic, skin) and absorptive (hospital gown and laboratory coat) surfaces, at room temperature. The inoculum size was approx. 10³ per 2 sq cm. Persistence on stainless steel was greater than on fabrics, but all 3 strains of PIV survived for up to 4 h on fabrics, and up to 10 h on non porous surfaces. PIV virus survived on skin for a minimum of 1 h.
- Ansari et al.(1991)264 determined the survival of mucin-suspended human parainfluenza virus 3 (HPIV-3) and the transfer of the viruses to and from the fingers of adult volunteers. When each finger pad was contaminated with 10ul of HPIV-3 (1.3 x 10⁵ to 5.5 x 10⁵ PFU), <1.0% of HPIV-3 was recovered after 1 h. After 3 hours HPIV-3 became undetectable. Tests on the potential spread of viruses from contaminated hands or surfaces were conducted 20 min after contamination of the donor surface by pressing together donor and recipient surfaces for 5 s. Transfer of HPIV-3 from finger to finger, or finger to a metal disk could not be detected, but 1.5% of infectious HPIV-3 was transferred from disk to finger. The authors concluded that the relatively rapid loss
of HPIV-3 infectivity on hands suggests that their role in the direct spread of parainfluenza viruses is limited.

- Sattar et al. (2002) compared survival of viral pathogens on fingerpads of human volunteers. Survival after 1 hour was only 1% for PIV3 compared with 25% for adenovirus, 45% for rotavirus, 63% for hepatitis A and 35% for rhinovirus.
- Aitken et al. (2001) reported that PIV environmental stability is greatest at 4°C with viral survival decreasing significantly at 37°C and low humidity. Recovery was enhanced by increasing the inoculum size.
- Boone and Gerba (2010) reported a study evaluating the potential role of fomites in human parainfluenza virus 1 transmission in an adult setting (office). A total of 328 surfaces from 12 office buildings in 5 US cities were evaluated including 76 telephone receivers, 62 computer mouse, 51 office and cubical desktops, 26 conference room table tops, 50 chair arms, 42 door knobs or door handles, 21 light switches. HPIV1 was detected on 37% of all office surfaces. It was detected more often on the desktops (47%), the computer mouse (46%), and the phone (45%). Viruses were isolated least often on door handles (26%) and light switch (19%). The quantity of positive surfaces varied within object category from 20% (New York phone) to 66% (Atlanta phone).

Influenza virus

The data suggest that up to $10^7$ infectious influenza particles per ml may be found in nasal secretions. Survival and transfer via hands and environmental surfaces is reported in 2 studies as follows:

- Bean et al. (1982) showed that influenza viruses could survive up to 24-48 hours on non-porous surfaces, and up to 8-12 hours on cloth, paper, and tissues. By contrast, viruses could be recovered from hands for only 5 minutes, and then only if the hands were contaminated with high viral titers. Virus could be transferred from non-porous surfaces to hands for 24 hours and from tissues to hands for 15 minutes. Higher RH shortened virus survival. Virus on nonporous surfaces could be transferred to hands 24 hours after surfaces were contaminated, while tissues could transfer virus to hands for 15 minutes after tissues were contaminated. On hands, virus concentration fell by 100 to 1,000-fold within 5 minutes after transfer.

- In a two and a half year study of US day care centers and domestic homes by Gerba et al., influenza A virus was detected on 23% of day care center surfaces sampled during the fall of 2003 and 53% of surfaces sampled during the spring. Whilst no influenza was detected on home surfaces during the summer, influenza was detected on 59% of surfaces sampled during March in five homes where there was an influenza-infected child. No virus was recovered from three other homes where all household members were healthy. Influenza virus was recovered most frequently from telephone receivers (80%) and least frequently from computer keyboards (40%). Other surfaces found to be contaminated included refrigerators, kitchen faucets, light switches, microwaves, TV remote controls, door knobs, bath and faucet and toilet handles. Virus was recovered from 69% of day care center diaper changing areas indicating presence of virus in infant faeces.

For influenza, although more data is needed, it is increasingly accepted that, not only airborne (both true airborne transmission involving droplet nuclei (<5 µm in diameter), and “droplet transmission” involving droplets >10 µm which deposit onto surfaces quite rapidly), but also surface (including hand) transmission can come into play. The relative contribution of each mode of transmission is unknown, but appears to vary depending on the circumstances, symptoms, respiratory tract loads and the viral strain. Data from animal studies and influenza outbreaks suggest that droplets generated from infected person's cough or sneeze are the predominant mechanism of airborne transmission, although data supporting droplet nuclei spread (especially in unventilated conditions) is also
It is possible however that influenza is less transmissible via hands and surfaces compared with rhinovirus etc., because of its lower ability to survive outside a human or animal host. Data suggest that, to some extent, airborne droplets and droplet nuclei can cause infection as a result of settling on hand contact surfaces. In 2009, Mubareka et al. reported a study using a guinea pig model, demonstrating that transmission of influenza A virus through the air is efficient, compared to spread through environmental surfaces. The data provide new insights into the modes of influenza virus spread and strain-specific differences in the efficiency of transmission. Frequent occurrence of diarrhoea and the detection of viral RNA in faecal samples tested suggest that the H5N1 influenza virus may replicate in the human gut and could be a source of transmission via hands and surfaces. At present, however, it is thought that this is unlikely.

1.2.2 Infection risks from exposure to cold and flu pathogens

As shown in Figure 1, exposure to RT viruses occurs either by inhalation of infected mucous or inoculation of the nasal mucosa or eyes with virus-contaminated hands, which then cause infection via the mucous membranes and upper RT. Rhinovirus and RSV are deposited into the front of the nose or into the eye (where they pass down the lachrymal duct). A feature of rhinovirus is the susceptibility of the nose to the virus. Rubbing the eyes and nose with the fingertips is a common occurrence; Hendley et al. found that one in 2.7 attendees of hospital rounds rubbed their eyes, and 33% picked their nose, within a 1-hour observation period.

A review of the data by Boone and Gerba (2007) (Table 3) suggests that the infectious dose for respiratory viruses is relatively small. Alford et al. suggest that aerosolised doses of as little as one TCID50 of influenza virus could infect volunteers.

<table>
<thead>
<tr>
<th>Virus</th>
<th>Minimal infectious dose associated with intranasal inoculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory syncytial virus</td>
<td>100-640 TCID50</td>
</tr>
<tr>
<td>Rhinovirus</td>
<td>0.032-0.4 TCID50</td>
</tr>
<tr>
<td></td>
<td>also cited as 1-10 TCID50</td>
</tr>
<tr>
<td>Influenza</td>
<td>2-790 TCID50</td>
</tr>
<tr>
<td>Parainfluenza</td>
<td>1.5-80 TCID50</td>
</tr>
</tbody>
</table>

The most recent data on the minimum infective dose for respiratory viruses has been reviewed in a 2011 report by Yezli and Otter. They report an HID50 for influenza A (H2N2) of 0.6-3.0 TCID50 when administered in small particle aerosols to serum antibody-free volunteers. They concluded that the nasal infectious dose of influenza virus A is several orders of magnitude higher than that of airborne infection. They also concluded that Rhinovirus 15 has a greater infectivity in man than in culture, with a HID50 of 0.032 TCID50 and that it is more infectious when given as nasal droplets than as an aerosol spray and has a lower infectious dose in the nose compared to other sites of inoculation such as the mouth. They report that a dose of 30–40 TCID50 of ts-1 mutant RSV vaccine caused infection in an infant. However, because infection studies rely on the use of attenuated vaccine strains, passaged in tissue culture, the MID of wild RSV is probably less. ID-50 values for enteric pathogens can also be obtained from the Quantitative Microbial Risk Assessment Wiki site (QMRAwiki) at: http://wiki.camra.msu.edu/index.php?title=Table_of_Recommended_Best-Fit_Parameters

Evidence for transmission of rhinovirus and RSV infections via contaminated hands to the eye or nose comes from a number of studies. A number of these investigations have
demonstrated that self-inoculation by the rubbing of the nasal mucosa or conjunctivae with rhinovirus-contaminated fingers can lead to infection:

- Hendley et al. (1973)\(^{260}\) found that dried rhinovirus could be picked up by the fingers from skin or environmental surfaces contaminated by shedding from subjects with rhinovirus colds. Four of 11 volunteers became infected after touching their nasal or conjunctival mucosa with fingers previously contaminated by rubbing a dried drop of rhinovirus.
- Reed (1975)\(^{261}\) recovered rhinovirus from the fingers of 16 of 38 volunteers swabbed during the acute stages of infection. Volunteers could infect themselves if a moderately heavy dose (88 TCD50) of virus was inoculated on the finger and then rubbed into the conjunctiva or nostril, especially if the inoculum was still damp. From estimates of virus titres in nasal washings and on fingers, and of amounts transferred by rubbing, it was concluded that spread of colds is unlikely to occur via objects contaminated by the hands of the virus-shedder, but recipients might pick up enough virus by direct hand contact with heavily infected skin or secretions to constitute a risk of self-inoculation via the conjunctiva or nostril.
- Gwaltney, Moskalski and Hendley (1978)\(^{262}\) showed that hand transfer of rhinovirus from experimentally infected volunteers to susceptible recipients was very efficient: 11 of 15 hand-contact exposures initiated infection, compared with one of 12 large-particle (\(P < 0.005\)) and none of 10 small-particle (\(P < 0.005\)) exposures.
- Gwaltney and Hendley (1982)\(^{263}\) examined transfer of experimental rhinovirus infection by an intermediary environmental in healthy young adults by having recipients handle surfaces previously contaminated by infected donors and then touching their nasal and conjunctival mucosa. Five (50%) of 10 recipients developed infection after exposure to virus-contaminated coffee cup handles and 9 (56%) of 16 became infected after exposure to contaminated plastic tiles. Fifty-six per cent (9/16) of recipients exposed to untreated tiles became infected.
- In 1992, Gwaltney and Hayden\(^{269}\) reported that, over a period of 10 years they performed intranasal challenges on 343 healthy young adults who had no antibody to the challenge, and infected 321 (95%).
- Hall et al. (1978)\(^{271}\) found that volunteers touching contaminated objects and, or the fingers, of symptomatic individuals had a higher attack rate of colds if they touched their eyes or nose. In another study they showed that close contact with symptomatic infants infected with RSV, who were producing abundant secretions, or their immediate environment, was necessary for infection.\(^{272}\)

### 1.2.3 Lower respiratory tract infections

Globally, acute lower respiratory infections (ALRIs) such as pneumonia and bronchitis cause up to 4 million deaths annually, mostly of children, the major burden of disease falling in developing countries. There is little data showing whether hygiene plays any significant role in the spread of ALRIs. However, in 2005, Luby et al. reported a study of the impact of handwashing on pneumonia in children under 5, in squatter settlements in Karachi, Pakistan.\(^{289}\) Results indicated a 50% reduction in pneumonia in the intervention compared with the control group. Luby et al. assess that a link between hand washing and the prevention of pneumonia in developing countries is plausible on the basis that, in developing countries, viruses commonly cause pneumonias. It is also known that some viruses that infect the respiratory tract are readily transmitted from person to person via hands. Viruses that cause RT infections can predispose children to bacterial pneumonia.
1.2.4 Other respiratory pathogens

Legionnaires’ disease
Legionnaires’ disease is believed to occur worldwide, but the incidence varies widely. The majority of reported cases are either community-acquired (in public settings), nosocomial (acquired in healthcare settings) or travel-associated, but some cases are thought to be domestically acquired. In Germany, 49% of notified Legionella infections are estimated to be acquired at home. Legionella pneumophila and other Legionella species are found naturally in the environment and thrive in warm water and warm damp places. Investigations have shown that shower heads and hot water taps can produce aerosols containing low numbers of L. pneumophila during routine use. The aerosol particle size generated would be small enough to penetrate the lower human respiratory system. Infection results from inhalation of contaminated water sprays or mists which can occur in the home in association with showers, spas and hot tubs. An infected source can disseminate sprays or droplets of water containing Legionellae. When this occurs, most or all of the water in the droplet evaporates quickly, leaving airborne particulate matter that is small enough to be inhaled. Particles of less than 5 μm in diameter can be deeply inhaled, and enter the respiratory airways to cause legionellosis. Risk factors for community or domestic-acquired legionellosis include: age over 40 years, smoking, immune-suppression, and chronic debilitating illnesses. There is no evidence of person-to-person transmission. Legionella infections have also been reported among previously healthy people, including young people without underlying disease, and those without other known risk factors.

Examples illustrating the potential for infection transmission in the home via domestic shower units, hot tubs etc. is as follows:

- L. pneumophila was isolated from 30% of hot water distribution systems in apartment buildings in Finland, the highest concentration being in the shower water.
- Pedro-Botet et al. evaluated 4 surveys (US, Canada and Germany) where Legionella was isolated from 6-32% of environmental samples taken from homes. They also reviewed 9 anecdotal cases of Legionnaires’ disease linked to homes or apartments colonised by Legionella pneumophila, and 4 prospective studies of community-acquired Legionnaires’ disease linked to homes. Overall they concluded that the risk for individuals residing in homes colonised with Legionella pneumophila appears to be low.
- During August 2006, there was an increase in non-travel related Legionella cases in England and in The Netherlands, possibly associated with fluctuating weather conditions in July. In August and September, 8 cases were reported but no common source could be established. Legionella was isolated from the homes of 2 patients (2 showerheads in one home and a hot tub in the other) but unfortunately clinical isolates were not available for genetic typing. The incident team concluded that multiple sources (both domestic and environmental) may have caused the cluster.
- In Italian houses, Legionella contamination of domestic hot water ranges from 22.6% of 146 samples from a multi-centre investigation around the country to 41.9% of samples obtained from 59 apartments in Bologna.
- Legionella pneumophila is responsible for 6-11% of community-acquired pneumonias. While association with contaminated cold and hot water supplies, condensers, spa pools, thermal springs or respiratory therapy equipment has been documented, garden hoses have not yet been linked to Legionnaires’ disease.
- Wallensten et al.(2010) reported a newly identified risk factor for Legionnaires’ disease. The researchers found that professional drivers are five times more commonly represented among community acquired sporadic cases in England and Wales than expected. An increased risk of Legionnaires’ disease is associated with
driving through industrial areas and driving or being a passenger in a vehicle with windscreen wiper fluid not containing added screen wash.

*Mycobacterium avium*

Two studies suggest that showers may be a source of infection by waterborne *M. avium*:

- Falkinham *et al.* (2008) report that *Mycobacterium avium* was isolated from hot and cold water samples and from sediment (biofilm) collected from the showerhead in the home of a woman with *M. avium* pulmonary disease lacking known *M. avium* risk factors. DNA fingerprinting demonstrated that *M. avium* isolates from the hot and cold water and showerhead sediment demonstrated clonal similarity with the patient's *M. avium* isolate.
- Feazel *et al.* analysed rRNA gene sequences from 45 showerhead sites (including apartment blocks) around the US. They found that complex microbial assemblages occur inside showerheads. They reported that sequences representative of non-tuberculous mycobacteria (NTM) and other opportunistic pathogens are enriched to high levels in showerhead biofilms. *Mycobacterium avium* was found in 20% of showerhead samples and accounted for an average of 32% of the microbes found. The organisms were not however found in the aerosols produced by the shower. The authors concluded that this may be because the mycobacteria are released at the start of the shower and then diluted as the shower progressed.

*Pseudomonas aeruginosa* and *Stenotrophomonas maltophilia*

*P. aeruginosa* and *Stenotrophomonas maltophilia* are opportunist pathogens that are a risk to patients with increased susceptibility to infection including those who are cared for at home. *P. aeruginosa* is widespread in the environment and is isolated from soil, water, plants and some vegetables:

- Studies have shown that wet sites such as sinks, tap water outlets and toilets in hospitals are often colonised with *P. aeruginosa* and may be a source of infection in ICUs.
- An investigation in German hospitals showed a correlation between strains of *P. aeruginosa* isolated from patients with cystic fibrosis (for whom *P. aeruginosa* is a high risk) and from environmental sites, such as sink U-tubes, toilets, cloths and other sites.
- Doring *et al.* (1991) demonstrated transfer of *P. aeruginosa* from contaminated hospital sinks to the hands during hand-washing.
- Studies by Scott and Bloomfield (1985) suggest that in hospitals, where *P. aeruginosa* is prevalent, it can become established as a secondary source/permanent reservoir in toilets, and are spread to surrounding sites in aerosol particles generated by toilet flushing. It was found that, whereas *P. aeruginosa* was isolated from toilet surround surfaces (toilet seat, flush handle, and floor) in 8 out of 144 samples taken from toilets cleaned daily but not disinfected (where sampling of the toilet itself indicated the presence of residual persistent contamination with *P. aeruginosa* in 58 samples), no samples positive for *P. aeruginosa* were obtained from surfaces associated with toilets where a continuous release disinfectant was installed (where only 8 samples from the toilet were positive for *P. aeruginosa*).
- Piper *et al.* (1997) and Ferroni *et al.* (1998) also report hospital infection outbreaks traced to specific reservoirs, such as sinks and also tap water.
- A 2009 review by Kerr *et al.* shows that environmental reservoirs of *P. aeruginosa* are readily identifiable, and reviews outbreaks attributed to environmental sources.
- A study in a UK cystic fibrosis (CF) centre evaluated samples from staff, patients and the environment (drains, bath tubs, showers). *P. aeruginosa* was isolated not only from patients' hands, clothes and bed linen, but was also detected in the majority of air
samples from inside the patients' rooms, the ward corridor and outpatient clinic, suggesting that airborne dissemination plays a role in the spread.

- The *Burkholderia cepacia* complex (Bcc) is a multispecies complex of bacteria that commonly cause respiratory infections in persons with cystic fibrosis (CF). Lucero *et al.* (2011) investigated a cluster of *Burkholderia cepacia* complex colonization in ventilated pediatric patients in hospitals. Isolates from 15 patients, 2 sink drains, and several ventilator components were found to belong to a single *B. cenocepacia* clone. Hospital tap water used during oral and tracheostomy care was identified as the most likely mechanism for transmission.

However, whereas this organism is quite frequently found in hospitals, indications are that, in the absence of a known source, it is not commonly found in the home, although audit studies of the home, as reviewed in section 4 show that the organism is sometimes found. The infection risk for cystic fibrosis patients in the home is illustrated by 2 studies:

- Schelstraete reported a study of 50 newly infected patients attending a cystic fibrosis centre. *P. aeruginosa* could be cultured from 5.9% of the environmental samples (mainly in the bathroom), corresponding to 18 patients. For nine of these, the genotype of the isolate was identical to the patient's isolate.
- Denton, *et al.* (2017) studied homes and hospital environments associated with 41 children with cystic fibrosis, a proportion of whom were colonised with *Stenotrophomonas maltophilia*, an organism which commonly infects such children. They reported widespread contamination with this organism in 36% of homes of colonised children and 42% of homes of non-colonised children, from sites which included dishcloths and sponges, washing up bowls, washing machines and a kitchen work surface.

**Streptococcus pneumoniae**

Kellner *et al.* (2016) describe outbreaks of multidrug resistant *S. pneumoniae* in 3 married couples in Calgary. While *S. pneumoniae* outbreaks have been reported from a variety of community settings, cases within households have rarely been reported. Outbreaks of the disease generally occur in institutions with crowding, poor air quality, or increased host susceptibility, but these factors can also exist within households.

### 1.3 Chain of Transmission of Skin and Wound Infections

Skin and wound infections are common in the home and community. Within the home, the primary source by which skin and wound pathogens are introduced into this setting is via people who are infected – and possibly also via domestic animals. Fungal skin pathogens can enter the home via the airborne route or via dust particles.

Van loo *et al.* (2006) found 36 *S. aureus* strains in 79 meat samples (including 2 samples containing MRSA). Furthermore, low amounts of *S. aureus* are regularly found in meat sold to consumers demonstrating that MRSA has entered the food chain. Persoons *et al.* in 2009 confirmed the presence of MRSA in broiler chickens indicating that MRSA may persist in farm environments. Van Loo *et al.* concluded that the contamination of food products may be a potential threat for the acquisition of MRSA by those who handle the food.

Skin and wound pathogens shed into the environment from human and animal can survive for significant periods, and are readily spread around the home, to and from the hands and via surfaces such as tap and door handles, telephones or other hand contact surfaces. Infections can also be transmitted via clothing and household linens such as towels and bed linen which come into direct contact with the skin. Contamination of the hands can occur by
handshaking or touching contaminated surfaces. Exposure of the skin to these agents may produce colonisation and/or infection which usually occur where there are cuts, abrasions or other conditions that damage the integrity of the skin. Some organisms, such as fungi which cause superficial fungal infections, can invade and infect the intact skin.

Infectious agents which spread via these routes include bacteria such as *S. aureus* and *Streptococcus pyogenes*, and viruses such as herpes simplex virus (cold sore lesions) and varicella-zoster virus (chicken pox and shingles). Typical fungal infections are ringworm (caused by *Tinea capitis*) and athletes foot (caused by *Tinea pedis*).

The risk of exposure to skin and wound pathogens in home and everyday life settings, as illustrated in **Figure 1**, depends on the extent to which these pathogens are brought into the home and the extent to which they are spread via hands and other sites and surfaces, and by airborne transmission. Data on the survival and spread of skin and wound pathogens via hands and surfaces in the home are summarised below (data on survival and spread via clothing and household linens is reviewed in a separate IFH report). Taken together, it suggests that exposure to skin and wound pathogens via the hands, clothing and linens, and environmental surfaces etc is a frequent occurrence during normal daily activities, and that the numbers of organisms transferred can be well within the numbers required to initiate infection in a susceptible recipient.

### 1.3.1 Staphylococcus aureus and methicillin resistant Staphylococcus aureus (MRSA)

*S. aureus* is the most common cause of skin and soft tissue infections, which are mostly self-limiting, but a small proportion of cases, lead to severe invasive bacteremia or pneumonia. A UK study indicates a major increase in pathogenic community-onset staphylococcal disease over the past 15 years. It was found that hospital admission rates for staphylococcal septicemia, pneumonia, impetigo etc increased >5-fold. It was postulated that this trend may be partly due to changes in hygiene behaviour.

MRSA in the home and community was reviewed in the 2006 and 2009 IFH reports which show that MRSA is no means confined to the hospital setting. Infected patients discharged from hospitals may continue to carry MRSA, even after their infection has healed, and pass it on to healthy family members who become colonised, thereby spreading the organism into the community and then back into hospitals. Healthcare workers caring for MRSA-infected hospital patients may also bring MRSA back into the home on their hands or uniforms etc. MRSA has the same potential to infect the elderly and immuno-compromised in a home setting, whilst family members who are MRSA carriers risk self-infection, following hospital admission or outpatient treatments.

A new concern, as also reviewed in the 2006 IFH report on MRSA is the emergence of new “community” strains of MRSA (community-acquired MRSA or CA-MRSA). Whereas healthcare associated (HCA) MRSA strains are mainly a risk to vulnerable people, for CA-MRSA any family member is at risk, although US experience suggests that CA-MRSA strains present a threat mainly to those engaging in activities involving close skin contact and abrasion such as sports clubs and schools. Some *S. aureus* strains circulating in the community (both CA-MRSA and methicillin sensitive *S. aureus* strains (MSSA)) strains have also acquired the ability to produce Panton-Valentine Leukocidin (PVL) toxin. These can cause severe invasive infections such as bacteraemia, or necrotising pneumonia that kills more than 40% of patients.
1.3.1.1 Sources of S. aureus in the home

**Humans as sources of S. aureus in the home**

Household members who are, or have been recently infected, or who are carriers, are the primary source of S. aureus infection in the home. People who carry S. aureus can shed the organism in large numbers most usually associated with skin scales. It is estimated that between 30 and 60% of the general population carry S. aureus as part of their normal body flora. People who carry S. aureus can shed the organism in large numbers into the air and onto clothing in contact with the skin, most usually associated with skin scales. It is estimated that around $10^6$ skin squames containing viable organisms are shed daily from normal skin. Solberg (2000) reported that whereas some people are extensive shedders, others are not. Shedding also varies over time, and may increase when the carrier has a cold or is under antibiotic therapy. Solberg presented the results of 157 patients with persistent MRSA carriage and 18 patients with MRSA lesions in a medical department in Bergen, Sweden. The numbers of organisms recovered from the hands of nasal carriers varied widely, from $10^2$ to $2 \times 10^6$ cfu. They also found correlation between the numbers found on hands and the numbers liberated into air.

Establishing the prevalence of MRSA circulating in the general community is difficult and can vary significantly from one area to another. In the US, although it is concluded that MRSA colonisation rates in the community are still low, it is thought to be increasing. Graham et al. reported an analysis of 2001-2002 data from the National Health and Nutrition Examination Survey (NHANES) documenting colonisation with S. aureus in a non-institutionalized US population. From a total of 9622 participants, it was found that 31.6% were colonised with S. aureus, of which 2.5% were colonised with MRSA. Of persons with MRSA, half were identified as strains containing the SCCmec type IV gene (most usually associated with CA-MRSA), whilst the other half were strains containing the SCCmec type II gene (most usually associated with HCA-MRSA). Other US studies suggest sporadic distribution of CA-MRSA, with carriage rates ranging from 8-20% in Baltimore, Atlanta and Minnesota, and up to 28-35% for an apparently healthy population in New York.

In the UK, indications are that the proportion of the general population carrying antibiotic resistant strains of S. aureus is somewhere between 0.5-1.5%, the majority being carriers of HCA-MRSA who are >65 years of age and/or have had recent association with a healthcare setting. Although cases of CA-MRSA and PVL-producing MRSA have been reported, indications are that the prevalence of MRSA and PVL-producing strains circulating in the community is small. Although CA-MRSA strains are now a major problem in the US, they are still relatively uncommon in Europe, and there is thus still an opportunity to avoid the problem escalating to a similar same scale. CA-MRSA strains are reported not only in UK, France, Switzerland, Germany, Greece, Ireland, Nordic countries, Netherlands and Latvia. The burden of MRSA infections across Europe is reviewed in a 2010 survey by Kock et al. who estimate that the proportion of CA-MRSA with respect to total MRSA ranges between 1% and 2% in Spain and Germany and 29–56% in Denmark and Sweden. Among outpatients with S. aureus infections, MRSA accounted for 6% in the Ligurian region in Italy, 14% in Germany, 18% in France and 30% in Greece.

The potential for spread of MRSA to family members from healthcare workers in the home was shown by Albrich et al.(2008), Ben-David et al.(2008), Zafar et al.(2007) and Aiello et al.(2003). Albrich et al.(2008) evaluated data from 27 mostly high income countries. In 127 investigations, the average MRSA carriage rate among 33,318 screened health-care workers was 4.6%, while 5.1% had clinical infections. Risk factors included chronic skin diseases, poor hygiene practices, and having worked in countries with endemic MRSA. According to Ben-David et al., transmission of MRSA in an ICU was observed despite infection control precautions. Identifying and treating colonised healthcare workers (HCWs)
was followed by a significant reduction in the incidence of MRSA. Unrecognized MRSA-colonised HCWs may be an important source of MRSA in the home.\textsuperscript{337} The report by Zafar \textit{et al.} (2007) suggested that the frequency of CA-MRSA colonisation among household members of patients with CA-MRSA infections is higher than among the general population. Among colonised household members, only half of MRSA strains were related to the patients' infective isolate. Within the same household, multiple strains of CA-MRSA may be present.\textsuperscript{338} Aiello \textit{et al.} in a 2003 study found that the mean total log counts of bacteria were 5.73 and 5.24 for the homemakers and nurse hands, respectively. There were a higher proportion of antibiotic resistant bacteria on the hands of the nurses. This study demonstrates differences in prevalence, bacterial composition and antimicrobial resistance of hand flora of hospital personnel compared with homemakers.\textsuperscript{339}

**Domestic animals as sources of \textit{S. aureus} exposure in the home**

Indications are that \textit{staphylococci} are commonly carried by animals, but tend to be host-adapted varieties. \textit{S. intermedius} is the most common isolate from dogs. Domestic pets can also be a source of \textit{S. aureus}, including MRSA and PVL-producing strains. Although little information is available on the prevalence of MRSA in the domestic animals, isolation from household pets has been documented:

- Cefai \textit{et al.} (1994)\textsuperscript{340} reported persistent carriage of MRSA in a health-care worker where the source or colonisation (or recolonisation) was identified as a domestic dog.
- Manian \textit{et al.} (2003)\textsuperscript{341} described two dog owners suffering from persistent MRSA infection, who suffered from relapses whenever they returned home from the hospital. Further investigation revealed that their dog was carrying the same strain of MRSA.
- van Duijkeren \textit{et al.} (2004)\textsuperscript{342} isolated MRSA from the nose of a healthy dog, the owner of which worked in a Dutch nursing home and was colonised with MRSA. Typing of the staphylococcal chromosome showed that the MRSA strains were identical.
- Rankin \textit{et al.} (2005)\textsuperscript{343} carried out a study to determine the presence of \textit{S. aureus} PVL toxin genes in MRSA strains isolated from companion animals. Eleven MRSA isolates from 23 animals were found to be positive for the PVL toxin genes as well as for methicillin resistance (mecA) genes.
- Enoch \textit{et al.} (2005)\textsuperscript{344} reported a pet therapy dog that acquired MRSA in a UK district general hospital after visiting care-of-the-elderly wards. The dog and owner were asymptomatic and had no observable source of MRSA. Two other pet therapy dogs, screened before visiting the hospital, were found to be MRSA negative. Further investigations suggested that the dog was colonised by contact with a human carrier.
- A colonisation prevalence of study in clinically normal dogs by Vengust \textit{et al.} in 2006 in Ontario, Canada reported that at present Methicillin-resistant \textit{Staphylococcus intermedius} (MRSI) is not considered to be a significant zoonotic concern; however, it may become an important pathogen in dogs. Although Methicillin-resistant coagulase negative \textit{staphylococci} mostly cause disease in compromised human or animal hosts, these bacteria can serve as reservoirs of resistance determinants in the community, which could lead to the emergence of novel MRSA strains.\textsuperscript{345}
- Sing \textit{et al.} (2008) reported transmission of PVL-positive MRSA between a symptomatic woman and both her asymptomatic family and their healthy pet cat. This case illustrates that MRSA transmission also occurs between humans and cats and that pets should be considered as possible household reservoirs of MRSA that can cause infection or reinfection in humans.\textsuperscript{346}

Transmission of \textit{S. aureus} (including MRSA) between humans and cats and dogs is further reviewed by Oehler \textit{et al.} (2009).\textsuperscript{347} Several workers have noted that MRSA in pets is closely linked to MRSA in humans and concluded that that the source of MRSA in pets or other animals may often be colonised or infected humans, although this is by no means proven.\textsuperscript{348}
A one day survey conducted at a veterinary hospital in February 2004 by Loeffler et al. 2005\textsuperscript{349} identified MRSA carriage in 17.9\% of veterinary staff, 9\% of dogs, and 10\% of environmental sites. CA-MRSA has also been identified in livestock animals (particularly pigs), veterinarians, and animal farm workers. Angelo et al.\textsuperscript{(2009)} reported a case of infection in a pig-farm worker in an animal farming area in Italy. The infection was caused by MRSA of swine origin, ST398.\textsuperscript{350} Veterinary staff and owners of MRSA-infected pets are high risk groups for MRSA carriage despite not having direct hospital links. As part of a UK-wide case-control study investigating risk factors for MRSA infection in dogs and cats between 2005 and 2008, 608 veterinary staff and pet owners in contact with 106 MRSA and 91 methicillin-susceptible \textit{S. aureus} (MSSA)-infected pets were screened for \textit{S. aureus} nasal carriage. This study indicated for the first time an occupational risk for MRSA carriage in small animal general practitioners.\textsuperscript{351}

In a 2011 review, Kassem conclude that, besides humans, perhaps the most important community reservoirs of staphylococci are pets and livestock.\textsuperscript{352} He cites evidence showing that MRSA has been isolated from pigs, horses, dogs, cats, cattle, sheep, chinchillas, and parrots. Targeted sampling suggests that up to 8\% of dogs, 12\% of horses, 15\% of lactating cows, 14.3\% of broiler farms, and 68\% of fattening pig farms were potentially positive for MRSA. In many cases, MRSA clones from animals were shared by their owners and/or handlers, suggesting the possibility for MRSA transmission between animals and humans.

### 1.3.1.2 Survival and spread of \textit{S. aureus} in the home
The potential for exposure to \textit{S. aureus} (including MRSA) following shedding from a human, animal, or other source depends on the extent to which dispersal and persistence of \textit{S. aureus} can occur during normal daily activities. Although \textit{S. aureus} cannot multiply outside a human or animal host, it is particularly resistant to dessication and can survive in the environment for significant periods of time. Survival and transfer of \textit{S. aureus} via hands and surfaces is shown by a range of laboratory and field studies as follows. Survival and transfer of \textit{S. aureus} via clothing and household linens is reviewed in a separate IFH report:\textsuperscript{25}

- Kramer \textit{et al.}\textsuperscript{154} review data showing that \textit{S. aureus} (including MRSA) can survive on dry surfaces for periods from 7 days up to 7 months.
- Wagenvoort \textit{et al.} 2000\textsuperscript{353} studied long term survival suspensions of 2 outbreak and 3 sporadic MRSA strains, with and without added hospital dust. A gradual decline was noted for all strains. All survived longer than six months, but the two outbreak strains survived significantly better and for 1–3 months longer. Survival patterns of the MRSA strains with and without added dust were similar.
- Makison \textit{et al.} in a 2006 study measured the effect of different humidities potentially achievable on a hospital ward on survival of MRSA on hard surfaces. Surface type had a greater effect on the rate of reduction of MRSA than humidity.\textsuperscript{354}
- Scott and Bloomfield 1990\textsuperscript{159} showed that when \textit{S. aureus} was inoculated onto clean cloths and surfaces (200-300 cfu/sq cm) and allowed to dry, the organism could be isolated from surfaces for up to four hours, and on soiled surfaces for up to 24 hours. During a 4-hour drying period, up to 50\% of \textit{S. aureus} inoculated onto laminate could be transferred to fingertips by contact. Transfer to fingertips also occurred cloths contaminated with \textit{S. aureus} were used to wipe clean surfaces.
- A study by Desai \textit{et al.} (2009) showed MRSA may persist on contaminated surfaces for >5 weeks. The study also determined that 3 s of skin contact with a MRSA-contaminated surface or object was all that was required to transfer MRSA to the skin under laboratory conditions.\textsuperscript{355}

Studies on the survival and transfer of \textit{S. aureus} in healthcare settings, are reviewed in the 2006 IFH report on MRSA\textsuperscript{8} and elsewhere.\textsuperscript{356,357} The IFH report summarises results of 11
studies which show that, where there is an infected or carrier individual, MRSA can be isolated from hands, environmental surfaces and cleaning utensils, including surfaces frequently touched by hands such as computer keyboards, pens, television sets, etc and also from clothing, mattresses, pillows, beds and chairs, and door handles. Although these investigations were largely carried out in hospitals, they show the potential for contamination of the home environment, where there is a family member carrying and shedding MRSA.

Other studies not included in the 2006 IFH report are as follows:

- Data reporting isolation of MRSA from the hands of patients or caregivers in settings where there is an MRSA carrier are reviewed by Pittet et al. (2006).\(^\text{14}\)
- Colbeck et al.\(^\text{358}\) studied patients suffering from S. aureus infections in a Canadian hospital. S. aureus was isolated on a number of occasions from baths and wash basins.
- Oie et al.\(^\text{359}\) report survival of MRSA on dry mops. Exner et al.\(^\text{360}\) carried out tests in which the first (field 1) of 4 flooring pieces was inoculated with S. aureus. After drying, a mop was wetted with cleaning product, and swept over the contaminated field followed by the other 4 fields and then back to field 1. Under these conditions, water and surfactants did not achieve complete reduction of S. aureus in Field 1 and the contamination was disseminated from Field 1 to other fields.
- Davies et al.\(^\text{361}\) sampled 34 toys from 19 infants in an ICU in an Australian hospital. MRSA was isolated from the toys of 6 infants, and from 1 of those infants.
- Bures et al. 2002 found that computer keyboards were uniformly contaminated by MRSA throughout the ICU regardless of their proximity to patients or geographic location.
- A 2006 study by Hardy et al. showed that MRSA was isolated from the environment at every environmental screening, when both small and large numbers of patients were colonised. Evidence strongly suggested that patients who acquired MRSA while in the intensive care unit acquired MRSA from the environment.
- Wilson et al. in 2007 showed that 34 out of 52 colonised patients had a similar strain found subsequently in their environment. Thus, it was interpreted that although MRSA-colonised patients frequently contaminates their environment, transmission from the environment to the patient was relatively uncommon.
- In a culture survey by Trillis et al. in 2008, it was found that 42% of hospital privacy curtains were contaminated with vancomycin-resistant enterococci (VRE), 22% with MRSA, and 4% with C. difficile. Hand imprint cultures demonstrated that these pathogens were easily acquired on hands.
- Giannini et al. studied contamination of toilet seats in a children's cancer hospital to validate a policy requesting that immune-compromised children should use alcohol wipes on the seats prior to use of the toilets. MRSA was recovered from 3.3% of hospital toilets when wipes were not in use. Use of wipes resulted in a 50-fold reduction in mean daily bacterial counts and eliminated MRSA.
- A 2006 study in an Indian hospital indicated that soap may act as a vector for spread of S. aureus.
- A 2011 study of 40 MRSA carriers showed that hand contamination was equally likely after contact with commonly examined skin sites and commonly touched environmental surfaces in patient rooms (40% vs 45%). These findings suggest that contaminated surfaces may be an important source of MRSA transmission.

There is evidence suggesting that airborne transmission may also be important for transmission of S. aureus.\(^\text{369}\) For example, an MRSA outbreak originating from the exhaust ducting of an adjacent isolation room ventilation system was terminated once the ventilation system was repaired and an opening in a window sealed. In a 2011 study evaluating the potential for aerosol dispersal, Thompson et al.\(^\text{370}\) evaluated survival of *Staphylococcus*
epidermidis, as surrogate for S. aureus, in aerosols at RH of <20%, 40-60%, 70-80% and >90%. At all relative humidities, 13% of the initial aerosol was recovered after 5 h. RH did not have a significant effect on the survival in aerosol form. Additional experiments indicated that S. epidermidis was recoverable after five days at 76% humidity.

In recent years, a wide range of laboratory and field studies have been carried out that focussed specifically on the spread of pathogens in a domestic setting. These studies show that, in situations where good hygiene practice is not observed, S. aureus are readily transferred in the home during normal daily activities via hands, cleaning cloths, hand contact surfaces, clothing, linens and sometimes also via the airborne route such that family members are regularly exposed:

- In studies of HCWs colonised with MRSA, the HCW was treated to eradicate the organism, but subsequently became recolonised. In each case, MRSA was isolated from environmental surfaces in the home of the HCW, including door handles, a computer desk shelf and computer joystick, linens, furniture, and in some cases also from other family members and family pets. Also, HCWs may become a source of MRSA infection for their own families as well as for patients.

- A number of cases are reported where family members in the home of an infected person have become colonized. Hollis et al. found that transmission of the MRSA strain from an index case to two siblings and the mother occurred at least three times, and one family member was colonised for up to 7 months or more.

- Lis et al. evaluated the airborne Staphylococcus genus features in homes in which inhabitants had contact with the hospital environment and found a higher prevalence of methicillin-resistant (MR) strains among the species isolated (40% of S. epidermidis, 40% of S. hominis, and 60% of S. cohnii spp cohnii) was found in homes of persons who had contact with a hospital environment compared with the reference homes (only 12% of S. hominis).

- A sample of 35 homes of healthcare and non–healthcare workers, each with a child in diapers and a cat or dog, was recruited from the Boston area between January and April 2006. In each home, 32 surfaces were sampled in kitchens, bathrooms, and living areas. S. aureus was found in 34 of the 35 homes (97%) and was isolated from all surfaces in 1 or more homes, with the exception of the kitchen chopping board and the child training potty. MRSA was isolated from 9 of 35 homes (26%) and was found on kitchen and bathroom sinks, countertops, kitchen faucet handle, kitchen drain, dish sponge/cloth, dish towel, tub, infant high chair tray, and pet food dish. A positive correlation was indicated for the presence of a cat and the isolation of MRSA from surfaces.

- Roberts et al. (2011) studied the presence of MRSA on 509 frequently touched non-hospital environmental surfaces at university, student homes and local community sites. Twenty-four isolates from 21 (4.1%, n = 509) surfaces were MRSA positive and included ten (11.8%, n = 85) student house samples, eight (2.7%, n = 294) university samples and three (2.3%, n = 130) community samples. MRSA-positive university samples were isolated from the bathroom, floors, ATM keypads, elevator buttons, locker handles, but not computer keyboards. Two university ATM keypads were sampled nine times over a 6-month time period. During that time, one keypad was positive 3 (33%, n = 9) times for S. aureus including twice for MRSA and MSSA, while the other was positive 4 (44%, n = 9) for S. aureus including once with MRSA and three times with MSSA.

- Uhlemman et al. carried out a community-based, study of 95 case and 95 control patients. Case patients presented with CA-MRSA infections to a New York hospital. During a home visit, nasal swabs were collected from index respondents and household members and environmental surfaces were swabbed. Among case households, 53 (56%) were environmentally contaminated with S. aureus, compared
to 36 (38%) control households (p = .02), MRSA was detected on fomites in 30 (32%) case households and 5 (5%; p = .001) control households. More case patients, 20 (21%) were nasally colonized with MRSA. In a subgroup analysis, the clinical isolate (predominantly USA300), was more commonly detected on environmental surfaces in case households with recurrent MRSA infections (16/36, 44%) than those without (14/58, 24%, p = .04).

**S. aureus in public places**

Boost *et al.* (2008) examined levels of contamination of common-access environmental surfaces over a 5-week period. 100 samples were collected from a range of publicly accessed surfaces in a densely populated area of Hong Kong, with each of the 25 sites being sampled 4 times daily. Of 500 samples, 11.2% yielded *S. aureus*. Frequently contaminated sites were ATM machines (11.9%), drink vending machines (15%), ticket vending machines (15%), escalator belts (10%), game center consoles (10%), public toilet door plates (11.7%), elevator buttons (8.3%), travel card add-value machines (10%) and door access keypads (13.3%).

**1.3.1.3 Risks from exposure to *S. aureus***

Exposure to *S. aureus* can produce colonisation and/or infection which usually occur where there are cuts, abrasions or other conditions that damage the integrity of the skin. Where there are pre-disposing factors, the numbers of organisms required to produce infection may be relatively small. Foster *et al.* estimated that less than 15 *S. aureus* cells were sufficient to cause infection in experimental lesions. Marples showed that up to 10⁶ cells may be required to produce pus in healthy skin, but as little as 10² may be sufficient where the skin is occluded or traumatised. Shinefield *et al.* (1963) showed that it was possible to establish a *S. aureus* carriage rate in the nose of 50% of newborn infants by the inoculation of between 200 and 400 cocci. In experimental colonisation of burns on rabbits, an inoculum of 10⁴ to 10⁵ cfu. *S. aureus* was necessary for 100% colonisation. Foster and Hutt (1960) reported that less than 15 *S. aureus* cells were sufficient to cause infection in experimental lesions. Experimental models of staphylococcal disease, however, may bear little resemblance to the natural disease in man. The risks associated with exposure to HCA-MRSA and CA-MRSA are significantly different. HCA-MRSA usually affects the elderly and those who are immuno-compromised, particularly those with surgical or other wounds or who have indwelling catheters. For CA-MRSA, those at particular risk appear to be younger, generally healthy people who practice contact sports or other activities that put them at higher risk of acquiring skin cuts and abrasions. US experience suggests that CA-MRSA may be more virulent than other strains and is easily transmissible within households and community settings (e.g., schools, day care centers, sport teams) where skin-to-skin contact or sharing of contaminated towels and sport equipment are vehicles for person-to-person transmission.

The extent to which people may be exposed to pathogens through frequent close contact with domestic pets is reviewed in section 1.1.1.

**1.3.2 Other skin and wound pathogens**

*P. aeruginosa*

Some skin infections attributable to *P. aeruginosa* are more likely to be encountered in community settings. These include folliculitis and the green nail syndromes following recreational exposure to water sources such as hot tubs, Jacuzzis and swimming pools, and septic arthritis in injecting drug users. Zichichi *et al.* reported 14 cases of *P. aeruginosa*...
folliculitis after shower/bath exposure. In all cases, *P. aeruginosa* was isolated from lesional skin. In 3 families, *P. aeruginosa* was isolated in the well water. In further 3 families, *P. aeruginosa* was isolated from bathroom and kitchen components.

**Herpes simplex virus**
Humans are the only known reservoir of herpes simplex virus 1 (HSV). It is most commonly spread by oral secretions, and can be shed by persons with or without symptoms. HSV can be recovered from the skin for up to 2 hours after inoculating the hands with the virus. It was found that the virus is more readily transmitted from moist drops than from drops which had been allowed to dry, although touching dried virus-containing droplets on the skin with moistened fingers results in transmission. Infectious HSV has been recovered from environmental surfaces, such as doorknobs and toilet seats, but virus detection rapidly decreases with drying. Turner *et al.* examined 9 adults with virus-positive herpes labialis. The virus was detected in the anterior oral pool of seven (78%) and on the hands of six (67%); HSV isolated from patients with oral lesions were found to survive for up to 3 hours on cloth as well as 2 hours on skin, and 4 hours on plastic. Nerurker *et al.* also found that HSV survived for up to 4 hours on plastic surfaces.

**Varicella-zoster virus**
A recent study demonstrated the rapid and broad contamination of the environment with varicella-zoster virus (VZV) when a family member acquired the disease. Eight days after onset of the index case VZV DNA was detected in both samples from the patient and on the surfaces of an air-conditioning filter, a table, television channel push-buttons and a door handle. The virus was also detected on the hands of the parents and the children. Two siblings developed the disease 18 days after onset of the index case.

Another study by Yoshikawa *et al.* (2001) showed that rapid and widespread VZV DNA contamination may occur with a patient with zoster (shingles). Positive surfaces for VZV DNA from the room environment of a patient with zoster included the back of a chair, table, door-knob and the air conditioner filter.

### 1.4 Chain of Transmission of Eye and Ear Infections
Conjunctivitis is a very common eye condition in the community, and is an inflammation of the conjunctivae, the mucous membranes covering the white of the eyes and the inner side of the eyelids. Bacterial conjunctivitis is caused by strains of *staphylococci*, *streptococci* or *haemophilus* which may come from the patient’s own skin or upper respiratory tract or from another infected person. Viral conjunctivitis is often associated with the common cold and may be caused by adenoviruses. Viral conjunctivitis can spread rapidly from person-to-person, between people and may cause an epidemic of conjunctivitis. *Chlamydia trachomatis* may also be a cause of conjunctivitis. Babies and small children are particularly susceptible to infective conjunctivitis and can develop severe forms of the condition. One of the most important pathogens in kerato-conjunctivitis associated with contact lenses is *P. aeruginosa* where unhygienic behaviour is a risk factor.

A number of studies carried out in ophthalmology clinics have demonstrated the role of hand hygiene in preventing the transmission of adenoviral keratoconjunctivitis. Jernigan *et al.* showed that the hands of physician and patients remained culture-positive for the incriminated adenovirus even after washing hands with soap and water and drying them with a paper towel. Azar *et al.* recovered infectious adenoviruses from the hands of 46% (12/26) of the patients with epidemic keratoconjunctivitis indicating the potential for virus transfer to hospital personnel through casual hand contact.
Otitis externa attributable to *P. aeruginosa* is more likely to be encountered in community settings. It can manifest as severe, potentially life-threatening malignant otitis externa in patients with diabetes and immune-compromised individuals. Tjen *et al.* (2007) reviewed *Pasteurella multocida* meningitis and otitis media infections transmitted by contact with household pets. Tjen reports that animal exposure is reported in 89% of cases of *P. multocida* meningitis, the majority without known bites or scratches, whilst Otitis media has been documented or strongly suspected in 24% of cases.

2. **CLOTHING AND HOUSEHOLD LINENS AS VECTORS FOR TRANSMISSION OF INFECTION**

Recently, there has been renewed interest in the role of clothing and household linens in spread of infectious disease in the home, particularly in relation to their potential role in transmission of MRSA and *Clostridium difficile*, but also because of concerns about the increasing numbers of people in the general community who are more susceptible to infection. There is also concern regarding the availability of detergents active at ambient water temperatures and about how well washing techniques at lower temperatures reduce or eliminate pathogens. There is evidence to show that transfer of pathogens can occur between contaminated and clean laundry during the washing cycle. The infection transmission risks associated with clothing and household linens are assessed in a separate IFH report.

3. **AUDITS OF MICROBIAL CONTAMINATION IN THE DOMESTIC ENVIRONMENT**

Over the last 30 years a whole range of studies have been carried out to evaluate the distribution of microorganisms in the domestic environment (Finch *et al.* 1978, Scott *et al.* 1982, Speirs *et al.* 1995, Josephson *et al.* 1997, Rusin *et al.* 1998, Tierney *et al.* 2002, Ojima *et al.* 2002, Toshima *et al.* 2002, Sharp *et al.* 2003, Rice *et al.* 2003, Haysom *et al.* 2005, Scott *et al.* 2009). The majority of these audit studies have been carried out in developed country situations including the UK, Japan and the US, but recently studies have begun to appear which look at contamination in homes in developing country situations such as Mexico and Cambodia (Chaidez and Gerba 2000, Carasco *et al.* 2008, Medrano-Felix *et al.* 2010, Sinclair and Gerba 2010). These studies differ from those described earlier in this review, in that there was no attempt to recruit homes where there was a known infected person.

The studies looked for a range of organisms including pathogens such as *Salmonella*, *Campylobacter* and norovirus, and potential pathogens such as *P. aeruginosa* and *S. aureus* (including MRSA). In many or most studies, the presence of *E. coli*, coliforms and/or *Enterococcus faecalis* was evaluated as an indicator of residual faecal contamination from humans or animals, or from raw foods such as meat or poultry. Although many/most species of *E. coli* are not normally pathogenic to the healthy adult, they are regarded as indicators of poor hygiene.

Surprisingly, given their importance, relatively few studies looked at contamination of hands during normal daily activities, most studies focussed on contamination of environmental sites.

3.1 **AUDIT STUDIES OF CONTAMINATION OF ENVIRONMENTAL SITES AND SURFACES IN THE HOME**

The studies, as summarised below, indicate that wet sites such as kitchen sink areas (particularly sink surfaces, draining board, U-tubes), toilets and nappy buckets are most
commonly associated with heavy contamination and the occurrence of *E. coli* and coliforms. Almost universally, dishcloths and other wet cleaning utensils were also found to be frequently and heavily contaminated. For these “reservoir” sites, typically, from 10% up to as much as 30% of samples were contaminated with these species. Counts varied significantly, but in some cases, particularly for dishcloths and dish sponges, counts up to 10^7 cfu per sample were obtained. These results suggest that, in the kitchen, wet areas such as sinks, waste traps, cleaning cloths etc can act as semi-permanent sources or reservoirs which harbour and encourage the establishment of free-living bacterial populations. Similarly, in the bathroom or toilet, although enteric bacteria probably originate from the toilet or directly from humans, baths, basins, cleaning cloths and face cloths may form semi-permanent reservoirs of bacteria. These conclusions are supported by laboratory studies which demonstrate the ability of Gram-negative species such as *E. coli*, *Klebsiella* spp. and *Pseudomonas* to grow to substantial numbers in samples of sink U-tube and toilet water, and in wet cloths. Additionally, although less frequently, potentially harmful organisms are quite often isolated from hand and food contact surfaces in the bathroom and toilet as well as the kitchen, although the numbers are usually relatively small.

Haysom and Sharp studied changes in contamination levels at five key sites in 10 UK domestic kitchens during a period of 24 hours. Colony counts and *Enterobacteriaceae* counts varied during the day, peaking after meal preparation and generally falling overnight. Contamination levels were lower in vegetarian than in non-vegetarian households.

*Enterobacteriaceae* spp. isolated in the 1982 study of 200 UK homes by Scott *et al.* included *Klebsiella, Enterobacter, Citrobacter, Proteus* and *E. coli*. *Salmonella* and *Campylobacter* were not isolated. A similar pattern was also reported by Finch *et al.* (1978) and Speirs *et al.* (1995). In Josephson’s study, of 10 US homes sampled over a period of 19 months, *Salmonella* was isolated once (from a sponge) and *Campylobacter* twice (from sinks). Tierney *et al.* (2002) sampled the sink, draining board and tap surfaces in 35 kitchens in Ireland; both *E. coli* and *Salmonella* were isolated; isolation rates ranged from 12-50% for *E. coli* and 8-30% for *salmonella*. By contrast, in a study of 100 dishcloths and sponges from domestic kitchens, Hilton and Austin (2000) did not detect the presence of *Salmonella* or *Campylobacter* in any samples. The fact that in many of the audit studies, primary pathogens such as *Salmonella* and *Campylobacter* were not isolated, should not be taken as an indication that these organisms do not occur in the home; it must be borne in mind that the number of homes surveyed was relatively small in global terms, and the homes were evaluated at random under "normal" conditions. From an investigation of 140 sponges, and from 56 dishcloths from US homes, Enriquez *et al.* however reported that, although the most common bacteria were *Enterobacteriaceae* and *Pseudomonas* spp., *Salmonella* spp. was identified in 15% of sponges and 14% of dishcloths. Rice *et al.* also reported frequent isolations of *Salmonella* from the contents of household vacuum cleaner bags. A total of 16 bags from 79 bags were found to be positive for *S. enterica*. Contamination however was associated with occupational exposure to *Salmonella*, such as cattle farms with known salmonellosis. None of the 12 out of 79 of the samples which were taken from homes where occupants had no exposure to livestock or exposure to *S. enterica* in the workplace were found to be positive for *S. enterica*. Chaidez and Gerba also reported that the most frequently occurring enterobacteria in a survey of 50 cleaning tools from Mexican domestic kitchens was *Salmonella* and *Klebsiella pneumoniae*, isolated from 9.8% and 4.9% of sponges respectively. In a 2009 study of 32 surfaces in kitchens, bathrooms, and living areas in 35 homes of healthcare and non–healthcare workers in Boston USA, Scott *et al.* obtained 2 isolates of *Salmonella* spp., one from the toilet bowl and one from the bathroom tub. *Shigella* spp. was isolated on 1 occasion from the kitchen counter top, but *Escherichia* spp. was rarely isolated.
In a survey of 213 homes, Listeria spp. were found in about 47.4% of homes and were recovered from wet sites such as kitchen sinks, dishcloths and washing up brushes, the refrigerator and the toothbrush. Spiers et al. (1995) isolated Listeria monocytogenes from fridge surfaces in 2.2% of homes. Yersinia enterocolitica was also isolated from the sink area in 4.2% of homes, and Bacillus cereus from 10.9% of homes. A UK study also found 84% of dishcloth samples contaminated with Listeria spp. A study in Portugal showed that Listeria monocytogenes was present in 3/68 domestic refrigerators. L. grayi and L. innocua were isolated from four and one refrigerators, respectively.

In their study of 86 Tokyo Metropolitan households involving around 100 sites in each home, Ojima et al. found S. aureus at most sites in 1 or more homes. Highest isolation rates were from sinks, drains, floors showerheads, futons and pillows where isolation rates of 10% or more were recorded. Maximum counts were mostly of the order of around 100 cfu per sample. S. aureus was detected on the arms of 5.4% of housewives and 4.0% of children. It was detected on items in households with carriers and households without carriers at statistically different rates of 10.7% and 3.5% respectively. Enriquez et al. (1997) recorded the presence of S. aureus in 20% of household sponges and 19% of dishcloths. Hilton and Austin (2000) sampled 100 dishcloths and sponges from domestic kitchens and isolated S. aureus from 4% of sponge-type cloths, ranging from $10^2$ to $4 \times 10^4$ cfu/ml. The total viable count from all cloth types ranged from 20 to $6 \times 10^8$ cfu/ml. Scott et al. sampled a total of 32 surfaces in kitchens, bathrooms, and living areas in 35 homes of healthcare and non-healthcare workers in Boston USA, each with a child in diapers and either a cat or dog in the home. S. aureus was found in 34 of the 35 homes (97%) and was isolated from all surfaces in 1 or more homes, with the exception of the kitchen chopping board and the child training pot. MRSA was isolated from 9 of 35 homes (26%) and was found on kitchen and bathroom sinks, countertops, kitchen faucet handle, kitchen drain, dish sponge/cloth, dish towel, tub, infant high chair tray, and pet food dish.

In their study of homes in the Boston area, Scott et al. also found P. aeruginosa in 4% of 35 homes where it was isolated from wet sites such as sinks and dishcloths but also from dry sites such as a worktop and chopping board. Ojima et al. reported that detection rates for P. aeruginosa were on the whole, low, but this spp. was found on items where coliforms were detected, such as kitchen drains, dishwashing tubs, dishwashing sponges, sinks and cleaning sponges and floors. Counts were generally less than 100 cfu per sample.

In a 2010 study Egert et al. reported an evaluation of the microbial composition of biofilms in domestic toilets by molecular means. Only 15 genera (representing 121 sequences affiliated with Acidobacteria, Actinobacteria, Bacteroidetes, Planctomycetes and Proteobacteria) occurred in at least half of the samples or contributed at least 10% of the sequences in a single biofilm. They concluded that virtually all ‘typical’ clones were closely related to bacteria or to sequences obtained from environmental sources, implicating that the flushing water is the main source of recruitment.

In June 2011, a new study was published that investigated the rubber sealing on the doors of domestic dishwashers. The study found Exophiala dermatitidis and Exophiala phaeomuriformisin in around 30% of 189 domestic dishwashers sampled in multiple locations across the world. The authors verbally reported that they had also found the organism on plates and cutlery taken from the dishwashers. Although the organism is known to be an opportunistic pathogen (can cause systemic disease in humans and frequently colonises the lungs of patients with cystic fibrosis) no incidents of infection from dishwashers were reported. Exophiala is a fungus widely distributed in soil, plants, water and decaying wood material. The somewhat odd spectrum of main sources of isolation (fruit surfaces, steam baths, faeces and human tissue) suggests that a hitherto unknown, quite specific natural niche must be concerned. Consistent occurrence in steam rooms of public bathing...
facilities suggests that the artificial environment of the steam bath provides a novel environmental opportunity for this fungus.

A recent study sampled 118 hand-touched surfaces in buses, trains, stations, hotels and public areas of hospital in central London and cultured MSSA from 8% of the sites but did not find MRSA (Otter and French 2009). Over the period 1999–2003 Reynolds et al. carried out an evaluation of “public” surfaces. They evaluated 1,061 environmental surfaces from shopping, day-care, and office environments, personal items, and miscellaneous activities (i.e., gymnasiums, airports, movie theatres, restaurants, etc.), in four US cities. Samples were analysed for faecal and total coliform bacteria, and biochemical markers. Biochemical markers, i.e., haemoglobin (blood marker), amylase (mucus, saliva, sweat, and urine marker), and urea (urine and sweat marker) were detected on 3%, 15% and 6% of the surfaces, respectively. Protein (general hygiene marker) was present on 26% of surfaces. Surfaces from children's playground equipment and day-care centers were the most frequently contaminated. Half and one-third of the sites positive for biochemical markers were also positive for total and faecal coliforms, respectively. Artificial contamination of public surfaces with an invisible fluorescent tracer showed that contamination from outside surfaces was transferred to 86% of exposed individual's hands and 82% later tracked the tracer to their home or personal belongings.

3.2 Audit Studies of Contamination of Mobile Phones, Computer Keyboards ETC

A number of investigations have been carried out to evaluate the potential for transmission of infection via mobile phones. The majority of these were mobile phones of healthcare workers (HCWs) working in hospitals. The studies were conducted in the US and Israel, UK, Saudi Arabia and India. Isolates from mobile phones of HCW included S. aureus (both MRSA and MSSA), E. coli, Klebsiella pneumoniae, P. aeruginosa and E. faecalis. Goldblatt et al. reported that one-fifth of cellular telephones examined were found to harbor pathogenic microorganisms, whilst Sadat-Ali et al. reported that (43.6%) HCWs carried infective organisms on their cell phones. O'Connor et al. studied 100 municipal public telephones cited in Belfast, Ireland during the summer of 2006. Phones were sampled for the presence of MRSA, but no isolates were obtained.

Anderson et al. investigated the keyboards of multiple-user (student) and single-user (staff) computers located on a university campus. Contamination levels on multiple-user computer keyboards was significantly greater than on single-user keyboards, and the number of keyboards harbouring potential pathogens was also greater for multiple-user computers. Overall, a greater number of different types of microorganisms were detected on the keyboards of the multiple-user computers. Forty-seven percent of multiple-user keyboards were found to be contaminated with S. aureus, compared to only 20% of the single-user keyboards. In one multiple-user laboratory, 60% of keyboards contained either S. aureus, E. coli and/or E. faecalis. Investigation of microbial contamination of computer keyboards in hospital settings is also reviewed by Lu et al. (2009). Kassem et al. (2007) found 8% of the 24 university computer keyboards were MRSA positive although they did not characterize the isolates. In contrast, in a second university study, no MRSA were identified from 70 frequently used environmental surfaces, although MSSA was isolated in computer keyboards, telephone mouthpieces and an elevator button of a large Midwestern United States urban university (Brook et al. 2009). Brook et al. (2009) examined 70 frequently used environmental surfaces in a university of 25,000 individuals for contamination of S. aureus and MRSA from 420 samples taken from student
desktops, computer keyboards, telephone mouthpieces, water fountains, photocopy keypads, vending machines and elevators buttons over a 3-week period in 2007. *Staphylococcus aureus* was isolated from computer keyboards, telephones and elevator buttons; however, no MRSA strains were isolated.

Tekerekoglu report a 2011 cross-sectional study of the bacterial colonization on the mobile phones (MPs) used by patients, patients’ companions, visitors, and healthcare workers (HCWs). Significantly higher rates of pathogens (39.6% vs 20.6%, respectively) were found in MPs of patients versus the HCWs’. There were also more multidrug pathogens in the patents’ MPs including MRSA, extended-spectrum β-lactamase-producing *E. coli*, and Klebsiella spp.437

In a study of 60 rented DVDs obtained from 5 local DVD rental shops in Tripoli city,438 *S. aureus* was detected on 35 (58.3%), *S epidermidis* on 20 (33.3%) and *P. aeruginosa* on 3.

Messina et al. conducted a study to assess keyboard contamination, comparing results from 15 shared keyboards and 15 nonshared keyboards of 30 computers in use at the University of Siena.439 Microbes were recovered from all keyboards, with counts ranging from 6 cfu/key to 430 cfu/key. Mould was not found on 8 keyboards, but was detected on all other keyboards up to a maximum of 120 cfu/key. Yeast was found on 17 keyboards up to a maximum of 420 cfu/key. Staphylococci were found on all keyboards but one at counts up to 120 cfu/key. Typing revealed *S. aureus*, *S epidermidis*, and *Micrococcus spp*. *Enterococcus* was found on only 7 keys, including 6 shared keyboards, and was typed as *E avium* (1-31 cfu/key) (possibly related to presence of pigeons on windowsills). *Pseudomonas* was not detected on any keyboard. *S aureus* was significantly more common on shared keyboards than on nonshared keyboards (P= .03). Greater growth of *Staphylococcus* was found on keyboards of users who ate at their desks.

3.3 Audit Studies of Children’s Toys

Considering the potential infection risks from contaminated children’s toys, which are not only frequent hand contact surfaces, but also carry the risk that they may come into contact with children’s mouths, relatively few studies have been carried out to determine the levels of contamination which can be found on these items:

- Hughes et al.(1986)440 described a prospective study of 39 sterilized teddy bears. The bears all became colonized with bacteria, fungi, or both within 1 week of being given to children in the hospital.
- Studies by Van et al.(1991)441 and Pickering et al.(1986)442 demonstrated contamination of hands, toys, and other classroom objects with faecal coliforms in a day-care setting. It was found that contamination increased during outbreaks of diarrhoea.
- In 2000 Davies et al.361 carried out a survey of toys in the cots of infants in a neonatal intensive care unit in a hospital in Melbourne, Australia over a 4-week period (86 cultures from 34 toys of 19 infants). Bacteria were grown from 84/86 samples (98%): 13 of the cultures grew MRSA, 4 group B streptococcus, 3 *S aureus*, 3 nonhemolytic streptococci, 3 group D streptococci, 4 a-hemolytic streptococci, and 2 coliforms. None grew fungi. Colonization rates did not differ with cot type, presence of humidity, toy size or fiber length, or the fluffiness score. Eight (42%) of infants had positive blood cultures and 5/8 of the isolates (63%) were of the same type as that colonizing their toy.
- In a 2002 study in New Zealand of hard toys (Merriman et al.)443 from general practitioners’ waiting rooms relatively low levels of contamination were found, with only
13.5% of 30 toys showing any coliform counts. There were no hard toys with heavy contamination by coliforms or other bacteria (1 toy only had a coliform count >10³). Soft toys were far more likely to be contaminated, with 20% of toys showing moderate to heavy coliform contamination (>10³ per toy) and 90% showing moderate to heavy bacterial contamination (10³ – 10⁵ per toy).

- Hanrahan et al. (2004) found that eliminating toys in the neonatal intensive care unit decreased the rates of nosocomial infections from 4.6 to 1.99 per 1000 patient-days over a six-month evaluation period.

- In 2004, Avila-Aguero et al. reported a study to determine whether toys were contaminated with potentially pathogenic bacteria when they arrived in the hospital, and whether they were contaminated in the hospital. After a first culture, toys were cleaned with 4% chlorhexidine and water and were immediately re-cultured. Following cultures were collected on days 5 to 7, 10 to 15, and every week until the owner-patient was discharged. All first cultures were positive for at least 1 pathogen: 55 (78%) coagulase-negative Staphylococcus (CNS); 26 (37%) Bacillus spp; 13 (18%) S. aureus; 8 (11%) alpha-hemolytic Streptococcus; 5 (9%), Pseudomonas spp; 2 (3%) Stenotrophomonas maltophilia, and 6 (11%) other gram-negative organisms. After toys were cleaned, subsequent cultures showed significant decreases in bacterial growth rates. Because some patients were discharged, additional cultures were obtained for only 31 toys.

- In a 2007/8 study by Naesens et al. of 57 toys of 57 infants from two neonatal intensive care units in a hospital in Belgium were analysed for their microbial load. Before washing, 13/57 toys (23%) were positive for potential pathogens (8 for S. aureus, 3 Enterococcus spp., 1 Klebsiella pneumoniae and 1 P. aeruginosa). Postwashing cultures resulted in 5/57 (9%) positive cultures (4 revealed Enterococcus spp., 1 S. aureus), which was a significant decrease compared with the pre-wash cultures.

Other studies of contamination of toys are reported by Van et al. 1991, Suviste et al. 1996 and McKay et al. 2000.

In 2011 Chaidez et al. reported studies of contamination of children’s toys during play. In a pilot study involving 12 children who had played in parks, sidewalks etc., the presence of faecal coliforms was detected on hands and toys together with hepatitis A virus and Giardia lamblia. In an intervention study with 40 children, faecal coliforms were found on toys and hands. S aureus and K. pneumoniae was found on hands at concentrations up to 2.4x10⁴ and 1x10⁴ per toy. On toys, E. coli and K. pneumoniae was found at concentrations up to 2.4x10² and 2.7x10⁴ per toy. Salmonella spp. were also present on toys, whilst G lamblia was found on toys and hands.

3.4 STUDIES IN DEVELOPING COUNTRY SITUATIONS

As stated above, a number of studies are now being published to examine households in developing country situations, and to determine whether, and to what extent levels and types of contamination are different.

Carrasco et al. studied 135 households in Ciudad Juarez, Mexico, and El Paso, Texas. Five different kitchen surfaces and head of households’ hands were sampled. Sponge/dishcloth samples were the most commonly contaminated, followed by countertops and cutting boards. Isolation rates for wet sponges and sink faucet handles were 51% and 27%, respectively for households in Mexico compared with 25% and 14% for households in Texas, but these differences were not deemed statistically significant. Faecal coliforms were
recovered respectively from 13% and 5% of child care givers hands. This indicator was moderately associated with self-reported failure to wash hands after visiting the toilet.

Medrano-Felix et al. 2010\textsuperscript{417} carried out a study to identify and quantify the presence of E. coli, S. aureus, Salmonella, hepatitis A and norovirus in households in the city of Culiacan, Mexico. Eleven sites in kitchen, bathroom, pet and children’s areas of two groups of 30 homes were sampled weekly for 6 weeks. One group (controls) were asked to continue their normal cleaning and disinfection routine, whilst the other (intervention) group were given specific training about cleaning and disinfection procedures. E. coli and S. aureus were detected in both groups of homes. The frequency of isolation of these species was not recorded, but the authors reported that the occurrence and concentration of bacteria in the intervention households was less than in the control households. For E. coli, mean cfu log counts per 900cm\textsuperscript{2} ranged from 0.5 to 4.0, with maximum counts between 7.0 and 10.0 being recorded. For S. aureus mean cfu log counts per 900cm\textsuperscript{2} ranged from 0.2 to 1.0, with maximum counts between 6.0 and 8.0 being recorded. A total of 720 samples (360 kitchen sponges and 360 dishcloths) from test and control group homes were tested for the presence of Salmonella, hepatitis A and norovirus. Salmonella was present in 5 (1.38\%) and 8 (2.22\%) of the sponges and dishcloths analysed from both disinfection and control group households, ranging from 300 to 110 000 MPN as minimum and maximum values. Several of the isolated serotypes have been associated with foodborne outbreaks. Two samples were positive for HAV, but norovirus was never detected.

In a paper published in 2010, Sinclair and Gerba\textsuperscript{51} set out to establish whether households that have met the MDG metrics in a developing country by having an improved latrine, have different concentrations of microbes than households in industrialized countries. To this end they monitored faecal coliforms, total coliforms, E. coli and heterotrophic plate count bacteria on household surfaces in 8 homes that possess improved latrines (i.e. a pour-flush latrine) in a rural village of Cambodia, and compared the results with similar data from homes in the US\textsuperscript{408} and Japan.\textsuperscript{410} Surfaces which were sampled included the dipping ladle for sink water, the table or counter for food preparation, the floor surface near kitchen sink, the cutting board, the handle of the ladle for anal cleansing, the top of toilet (squat style) and the floor surface around the base of the toilet. Faecal coliform levels in Cambodia were highest on moist locations such as the plastic ladle used for sink water, the toilet seat surface and the cutting board surface. For E. coli mean log cfu per 4 cm\textsuperscript{2} ranged from 0.5 to 4.0 with highest counts of up to 4 logs found on the top of the squat toilet, the wash basin and the floor around the toilet and the well. Faecal coliform levels were 100-fold higher than that for equivalent surfaces in the US and Japanese studies. They found that the top of the squat-style toilet was highly contaminated with faecal coliforms. These ceramic pour-flush bowls have two positions on either side of the toilet bowl for the user's feet. Although made from the same smooth ceramic material as the bowl, the tread positions have grooves where water can pool allowing the area to be moister than the surrounding floor.

On the basis of the evidence which suggests that surfaces can have a significant role in transmission of infections, the authors conclude that their results indicate that a latrine barrier alone is only partially effective for household sanitation. For complete sanitation, multiple environmental barriers may be necessary. When compared to homes in Cambodia, homes in industrialized countries (US and Japan) have additional environmental barriers that may control surface contamination including the chlorinated water distribution system, a solid waste disposal system, a more elaborate home construction with easily washable surfaces and cleaning product availability. Homes in these countries also have indoor climate control systems and lower relative humidity than tropical Cambodia. The authors suggest that efforts should be made to include as many pathogen control points as possible in hygiene and sanitation improvement programmes.
All eight houses sampled have similar stilt-house construction with elevated living and sleeping quarters. Five of the eight houses had a kitchen attached to the upper level, while the remaining houses had their kitchen area in an improvised zone under the house. Houses were constructed with wooden walls and tile or corrugated metal roofs. These latrines were built with a cement septic tank and PVC plumbing. Latrines and bathrooms were kept relatively clean, but no soap or other cleaning material was seen with the exception of powdered laundry detergent at one house. Dishes are washed with plastic scrub brush in large plastic basins with water, which was obtained from the onsite well. The dishes are then air-dried on a rack and sometimes wiped with a rag designated for the kitchen. There was a plastic ladle cup, which is used to transfer water to the dish washing basins. Although no pets were reported, many pigs, chickens, stray dogs and cats were seen in the all of the house yards. *Escherichia coli* and enterococci on hands can be significantly increased by various household activities, including those involving the use of soap and water.

In order to study mechanisms of hand contamination with faecal indicator bacteria on mothers’ hands, Pickering *et al.* carried out a household observational study combined with repeated microbiological hand rinse sampling among 119 mothers in Dar es Salaam, Tanzania.\textsuperscript{451} Hand rinse samples were analysed for enterococci and *Escherichia coli*, and selected samples were analysed for genetic markers of *Bacteroidales*, enterovirus and pathogenic *E. coli*. Using the toilet, cleaning up a child’s faeces, sweeping, cleaning dishes, preparing food and bathing all increased faecal indicator bacterial levels on hands. Geometric mean increases in cfu per two hands ranged from 50 (cleaning dishes) to 6310 (food preparation). Multivariate modelling of faecal indicator bacteria as a function of activities recently performed shows that food handling, exiting the household premises and longer time since last handwashing with soap were positively associated with bacterial levels on hands, while bathing was negatively associated. Genetic markers of *Bacteroidales*, enterovirus and pathogenic *E. coli* were each detected on a subset of mothers’ hands. Pickering *et al.* also studied the association between hand contamination and stored water quality within households.\textsuperscript{452} This study measured levels of *E. coli*, fecal streptococci, and occurrence of the general *Bacteroidales* faecal DNA marker in source water, in stored water, and on hands in 334 households among communities in Dar es Salaam, where residents use non-networked water sources. Faecal contamination levels on hands of mothers and children were positively correlated to fecal contamination in stored drinking water within households. Household characteristics associated with hand contamination included mother’s educational attainment, use of an improved toilet, an infant in the household, and dissatisfaction with the quantity of water available for hygiene. In addition, fecal contamination on hands was associated with the prevalence of gastrointestinal and respiratory symptoms within a household.

In a study in developing country situations Luby *et al.*\textsuperscript{453} studied 30 housing compounds: 10 received handwashing promotion with free soap, 10 received handwashing promotion with free waterless hand sanitizer and 10 were non-intervention controls. Fieldworkers assessed handwashing behaviour by structured observation but also collected hand rinse specimens. Hand rinse samples were tested for thermotolerant coliforms and faecal streptococci and *Clostridium perfringens*. The authors reasoned that the high variability of hand microbiology assessments involving the most common indicator organisms, thermotolerant coliforms, *E. coli*, and faecal streptococci have limited usefulness in evaluating handwashing interventions. By contrast *C. perfringens* is a potential alternative biomarker of faecal contamination because it persists in the environment longer than *E. coli* and so may provide a more stable indicator of faecal contamination. Although the data indicate that coliforms, faecal streptococci and *C. perfringens* were isolated from hands in significant numbers (from 10 to $10^5$) cfu, unfortunately the data was not presented in a manner which allowed assessment of the frequency occurrence and concentrations of these organisms relative to hand sampling carried out in developed country situations.
3.5 Audit Studies of Hand Contamination Normal Daily Living

Considering the central role of hand hygiene, it is perhaps surprising that relatively few studies have been carried out to audit hand contamination during normal daily activities. In 2003, Aiello et al.\textsuperscript{339} reported a prevalence study comparing the types of bacterial flora on the hands of individuals in the community. Hand cultures were obtained from 204 homemakers (defined as the person (usually the mother) who is the primary person responsible for arranging childcare, cooking, cleaning etc) during a home visit. There 32 homemakers with S. aureus on their hands. The five most prevalent species of bacteria found on the hands of the 204 homemakers were: \textit{Pseudomonas fluorescens/putida} (59), \textit{Staphylococcus warneri} (56), \textit{Klebsiella pneumoniae} (44), S. aureus (32), and \textit{Enterobacter cloacae} (26), \textit{E. faecalis} (20%). \textit{P. aeruginosa} was not found on any hands.

In 2010, Judah et al.\textsuperscript{454} analysed swabs taken from the hands of 409 commuters at train stations across the UK. Most common were Enterococcus in 22% of samples, followed by \textit{E. coli} in 9%, Klebsiella 2.5, Enterobacter 0.3%. In another study\textsuperscript{455} 20 volunteers were taken to a large, frequently visited British museum, or asked to travel on a bus or the underground. They were asked to deliberately wipe their hands over hand contact surfaces such as handrails, door handles and seats with the aim of contaminating their hands with whatever bacteria were present. Out of 160 samples taken, sampling of hands showed that the frequency of occurrence of different species was Enterococcus spp. (29%), \textit{Enterobacter amnigenus} 14%, \textit{Enterobacter cloacae} 13%, \textit{Shigella} 1% Klebsiella spp. 3%. \textit{Staphylococcus} spp. were not isolated. \textit{E. coli} was isolated once from 160 samples taken from a repeat experiment in which volunteers washed their hands before sampling.

Hand contamination studies in developing countries are described in the previous section 3.4.

4. Air as a Source of Fungal Pathogen and Bacterial Endotoxin Exposure in the Home

Fungi (moulds) in indoor environments are a potential problem. They can be responsible for infections, cause allergic responses, deteriorate/damage surfaces and cause unpleasant odours. Moulds produce millions of spores, which, due to their small size (average size 1–5 \(\mu\)m) easily stay air-borne and may be breathed deep into the airways. Air-borne fungi are usually associated with damp conditions, poor ventilation or closed air systems. Primary sites of fungal growth are inanimate surfaces, including carpets and soft furnishings.\textsuperscript{17}

The home provides reservoirs for opportunistic fungi that mostly cause infection in the immuno-compromised community living at home. Infections caused by common indoor moulds, such as \textit{Aspergillus, Penicillium, Fusarium, Rhizopus} and \textit{Alternaria}, are increasing in HIV-infected and other immunodeficient patients.\textsuperscript{456} Some fungi are pathogenic to healthy humans, causing superficial infections (mycoses), where the fungus grows on body surfaces such as the feet, skin, hair and nails, as well as the oral or vaginal mucosa. They are spread by direct contact and are highly contagious and easily spread to other individuals. Infections within the body (deep mycoses) are rare in healthy humans but people with impaired immune functions (e.g. cancer patients receiving chemotherapy or people with AIDS) are at significant risk. They can be acquired by inhalation of spores or by entry through wounds.\textsuperscript{456,457}
There have been a number of studies investigating fungal species which can be found in the home. In one study, spores of *Penicillium* spp. and *Cladosporium* spp. were isolated on every occasion from at least one room in all homes. Aspergillus spp. and other fungi as well as yeasts were also isolated. Total airborne mould counts ranged from 0–41000 cfu/m³ but were usually in the range 50–1500 cfu/m³.

Visible mould was found in 46% of households in a cross-sectional study in Glasgow, Edinburgh and London. In a survey in central Scotland, the main fungus isolated from the indoor air was *Penicillium* spp., with *Cladosporium* spp. being the next common. Pink and cream yeasts were also isolated from the air in >90% of houses, with *Rhodotorula* and *Sporobolomyces* being the main ones. Higher airborne mould counts (1000–2000 cfu/m³) were found in homes with visible mould. The fungi isolated from the air were similar to homes surveyed in Europe, North America, Taiwan and Canada in which *Penicillium*, *Cladosporium* and *Aspergillus* also predominated. A study of homes in Berlin showed 63% having large amounts of viable fungal propagules and/or visible fungal growth. *Penicillium*, *Cladosporium*, *Aspergillus*, *Mycelia sterilia* and yeasts were prominent. In one study in Australia, visible mould growth was present in every house at some time during the study.

*Aspergillus niger* can grow in the topsoil of houseplants. In hospitals and homes, the soil from a wide range of potted plants was found to be a major source of *A. fumigatus*, as well as *A. niger* and *A. flavus*. Bacteria, moulds and mildews may be found in air conditioning equipment, humidifier reservoirs, dehumidifier drip pans and shower heads.

Fungal contamination of soft furnishings in the home has been documented in publications by Cole and co-workers. Levels of fungal contamination in carpets and upholstery have been shown to approach or exceed 100,000 cfu/gram and consist of potential aeroallergens, such as *Cladosporium*, *Alternaria* and *Penicillium*. The predominating fungal contaminants recovered from upholstered furniture include *Cladosporium*, *Alternaria*, *Penicillium*, *Aureobasidium* and cream yeast. Other fungi recovered include *Aspergillus versicolor*, *Rhodotorula*, *Aspergillus fumigatus*, *Aspergillus flavus*, *Paecilomyces*, *Trichoderma*, *Phialophora*, *Rhizopus*, *Ulocladium*, *Fusarium* and *Stachybotrys*.

Studies over the last decade have focused on the link between airborne bacteria and fungi, associated with poor housing, and the incidence of respiratory allergies, such as asthma. Fungal infections in the home and the role of hygiene in preventing fungal infections are reviewed in more detail in a 2004 IFH review. Some further examples are as follows:

- In an Australian study of houses with visible mould growth at some time during the study, asthma, atopy and respiratory symptoms in children were significantly associated with indoor exposure in winter to fungal spores. Penicillium exposure was a risk factor for asthma, while *Aspergillus* exposure was a risk factor for atopy.
- An analysis of data collected in the winter of 1993-1994 in the framework of the PEACE study (Pollution Effects on Asthmatic Children in Europe) showed that peak flow variability was positively related to self reported moulds in homes of European children with chronic respiratory symptoms.
- A high rate of morbidity related primarily to the upper airways, skin and mucous membranes was found in children who had been living in indoor environments with high levels of fungi. Also, the results of a sentinel case investigation of a family living in an apartment with widespread visible fungal growth (predominantly *Cladosporium* and toxigenic *Stachybotrys chartarum*) showed a marked improvement in their health after exposure to the fungi ceased.
- Participants of an international Workshop held at Alexandria, Virginia, April 1998 concluded that exposure to moulds may constitute a health threat resulting in
respiratory symptoms, increased incidence of infections, skin symptoms or allergy. They advise that paediatricians and allergists should obtain information about mould and dampness in the home environment when examining children with chronic respiratory symptoms, recurrent infections or persistent fatigue and headache.\(^{472}\)

- Kilpeläinen\(e\) et al. (2001) in a study involving 10,667 Finnish students aged 18-25 years, found that living in traditional student homes with mOULDy and damp walls not only increased the risk of asthma, but students had a greater chance of repeated colds. The strongest statistical association was found between exposure to visible mould and asthma and common colds.\(^{473}\)

- Zureik\(e\) et al. (2002) studied over 1100 adults to see if severity of asthma is increased due to airborne moulds present on walls of their homes. Three out of four people were sensitive to at least one allergen. Two out of three people were sensitive to 2 or more allergens. Almost 1 in 5 was allergic to \(\textit{Alternaria alternata}\) or \(\textit{Cladosporium herbarum}\). Hence, it was concluded that people sensitive to mould were more likely to have a severe form of asthma. This may be because mould spores can reach the lower airways.\(^{474}\)

- Surveillance data from 8 European cities showed that dampness and mould were associated with depression, independent of individual and housing characteristics. This association was independently mediated by perception of control over one’s home and by physical health.\(^{475}\)

- There is also an increasing risk in normal subjects dwelling in such homes which can contribute to the risk of developing asthma and chronic obstructive lung diseases due to the potential inhalation risk of airborne endotoxin particularly during the winter and summer seasons.\(^{476}\)

- Mobin\(e\) et al. (2011) carried out a study to determine the fungal species in toothbrushes of residents of a neighborhood on the east side of Pittsburgh, USA.\(^{477}\) Fifty toothbrushes were divided into two groups: group A comprised 30 toothbrushes used by the residents and group B (control group) 20 new toothbrushes. Seventeen fungal species were identified in group A, all of which were considered opportunistic and may cause health problems mainly in immunocompromised patients. The species most frequently found were: \(\textit{Candida albicans}\), \(\textit{Aspergillus niger}\), \(\textit{Penicillium citrinum}\), \(\textit{Geotrichum candidum}\), \(\textit{Aspergillus fumigatus}\) and \(\textit{Cladosporium oxysporum}\).

- In 2011 Tischer\(e\) et al. reported a systematic review of studies of children from eight European birth cohorts which suggested that a mouldy home environment in early life is associated with an increased risk of asthma particularly in young children and allergic rhinitis symptoms in school-age children.\(^{478}\) They analysed data from 31,742 children from eight ongoing European birth cohorts. Results showed that exposure to visible mould and/or dampness during first 2 years of life was associated with an increased risk of developing asthma: there was a significant association with early asthma symptoms in meta-analyses of four cohorts [0–2 years: adjusted odds ratios (aOR), 1.39 (95%CI, 1.05–1.84)] and with asthma later in childhood in six cohorts [6–8 years: aOR, 1.09(95%CI, 0.90–1.32) and 3–10 years: aOR, 1.10 (95%CI, 0.90–1.34)]. A statistically significant association was observed in six cohorts with symptoms of allergic rhinitis at school age [6–8 years: aOR, 1.12 (1.02–1.23)] and at any time point between 3 and 10 years [aOR, 1.18 (1.09–1.28)].

**5. ASSESSMENT OF THE CAUSAL LINK BETWEEN HYGIENE AND INFECTIOUS DISEASES USING DATA FROM INTERVENTION AND OBSERVATIONAL STUDIES**

Significant insights into the sources and routes of spread of infectious diseases in the home come from epidemiological studies. These include intervention studies in which the impact of
different hygiene measures on disease incidence within a population is evaluated. It also includes observational studies in which case and control populations are investigated in relation to disease rates (self-reported or assessed according to criteria such as absenteeism) and questioned about hygiene practices. The data is then used to identify risk factors. Although surveillance provides information on modes of transmission, it is biased towards investigation of outbreaks and gives only a limited picture of how sporadic person-to-person transmission occurs in community and home environments.

5.1 Observational Studies of the Impact of Hygiene on Infectious Diseases

In the following section, observational studies assessing the causal link between hygiene and infection are categorized according to whether they looked at overall rates of infection, groups of infections e.g., GI or RT, or specific pathogens e.g., salmonella.

5.1.1 Hygiene and Infectious Intestinal Diseases

Food borne infection in the home results from one, or a combination of the following factors: inadequate cooking, inadequate storage of food, or cross contamination during handling of contaminated food. One of the difficulties in developing good kitchen hygiene practice is understanding the relative extent of the risk from each of these components. From a 1990 study, Roberts (1990)\textsuperscript{479} concluded that, although most food-borne outbreaks result from poor temperature control of raw and cooked foods, many are associated with cross contamination. This review suggested that cross contamination is implicated in about 6% of outbreaks and poor hand hygiene in about 4% of outbreaks. Another report (Roberts 1986)\textsuperscript{480} suggests that cross-contamination is a contributory factor in up to 14% of outbreaks of Salmonella. Ryan et al. (1996)\textsuperscript{481} estimated that poor hygiene involving hands and other surfaces is a contributory factor in up to 39% of domestic food poisoning outbreaks. In an evaluation of reported outbreaks linked to UK households for 1992-1999, Gillespie et al.\textsuperscript{482} estimated that, of the 85% of outbreaks designated as foodborne, cross contamination was implicated in 20% of outbreaks compared with 30 and 31% for outbreaks where inadequate storage and cooking were thought to be the cause. Gillespie et al. expressed concern that most of the reported outbreaks were linked to home catering, thus not necessarily representative of normal daily routine.

A number of early surveys of the day-care centre environment demonstrate increased risk of diarrhoea associated with faecal contamination levels of hands and environmental surfaces.\textsuperscript{483,484,485,486,487,488} Researchers were able to demonstrate that toys had the highest coliform levels, and that hand contamination of children and adults strongly affected diarrhoea incidence. Laborde et al. (1993)\textsuperscript{488} also demonstrated a correlation between contamination levels and increased risk of disease.

Salmonella

A number of investigations of salmonella outbreaks are reported which showed that spread via hands, environmental surfaces, cleaning cloths and household linens was a, or the, causative factor:

- In 1981, Palmer et al.\textsuperscript{489} reported an outbreak of Salmonella typhimurium infection among healthy students in a university hall of residence. The first phase of the outbreak was due to food contamination, while the second phase was best explained by person-to-person spread. In 13 out of 18 residential blocks there was only one toilet. Soiling of the toilet environment must have occurred. All 12 students ill during the second phase of the outbreak had used the toilet in a block where students ill in
the first phase were also living. The last case in the outbreak did not eat any contaminated food or use the residence hall but had emptied a commode used by a severely affected student and disposed of soiled sheets, indicating that infection was via an environmental source.

- After a hospital outbreak of *S. typhimurium*, organisms were isolated from ward dust and from sputum of patients, indicating that aerial spread can occur. Several laundry workers and domestic staff became infected when their only contact was with contaminated bed linen.

- Sanborn (1963) described several outbreaks of gastroenteritis in which contaminated surfaces were involved. In one outbreak at a naval station, *S. typhimurium* was isolated from patients and from a cutting board on which turkey had been carved. The majority of patients had eaten turkey. The organism was isolated from the chopping board 12 days after the turkey had been carved, despite being cleaned following use. Another outbreak aboard a ship, due to *Salmonella chester*, occurred in 2 phases. Roast pork was the suspect vehicle in phase 1, while turkey sandwiches were the suspect vehicle in phase 2. Both foods had been carved on a cutting board placed on a table used to thaw frozen turkeys. The juices from the thawing turkeys apparently contaminated the cutting board.

- Following an outbreak of food poisoning in a public house, *Salmonella enteritidis* was isolated from environmental sites in the kitchen, including a cleaning cloth. Surfaces were cleaned using a reusable cleaning cloth. Pre-cooked foods, which were possible vehicles of infection, were thought to have been contaminated after being brought into the kitchen, suggesting cross contamination may have played a part. Several sites were contaminated with *Salmonella* 9 days after the outbreak, suggesting cleaning had not been done properly. After thorough cleaning repeat sampling was negative, but 1 of the 2 joints between work surfaces was still positive.

- An investigation of an outbreak of diarrhoea due to *Salmonella berta* linked it to unpasteurised cheese produced on a farm. Cases increased weekly following weekends when the cheese was sold at markets. A review of the cheese-making process at the farm showed several opportunities for contamination. The cheese was made by ripening curds in buckets for a few days. Chicken carcasses had also been soaked in 2 buckets overnight, with 1 bucket then used for ripening curds without being adequately disinfected. *S. berta* was isolated from faecal specimens, cheese from case homes and a curd sample from the farm. One chicken carcass also yielded *S. berta*.

- Schutze et al. (1999) studied 50 homes where children under 4 years were infected with *Salmonella* spp. The study was carried out in Aransas, USA where case rates for *salmonella* were higher than the national average. In 34% of homes there was also illness in other family members. The data indicate that environmental sources, infected family members and pets, appeared to be much more significant risk factors for development of salmonellosis in these children than contaminated foods.

The literature also reports a number of case-control studies in which transmission via hands and surfaces were identified as risk factors. It is interesting that, in 6 of the following 9 reports, contact with animals was identified as the likely source:

- Following a 1998 outbreak of diarrhoea in children attending a Komodo dragon exhibit at a zoo, caused by *Salmonella enteritidis*, a case-control study was conducted with 39 confirmed and 26 suspected cases. No patients and 2 controls reported touching a dragon; however, 83% of patients but only 52% of controls touched the barrier surrounding the dragon pen (odds ratio = 4.0). Washing hands after the visit was highly protective (OR = 0.14). Cultures from patients, a dragon, and the exhibit barriers yielded *Salmonella enteritidis*.

- Parry et al. (2002) sampled kitchen dishcloths and refrigerators for *Salmonella* spp.,
total Enterobacteriaceae and total aerobic colony counts in homes of subjects who had suffered sporadic *Salmonella* infection (cases) as compared with control domestic kitchens. *Salmonella* spp. were isolated from 12/125 (10%) case dishcloths and 4/81 (5%) control dishcloths, but the result was not statistically different. All 4 controls with positive cloths had handled chicken in the previous weeks and 3 had handled eggs. In 6/12 case households with a *Salmonella* positive dishcloth, the strain was the same phage type as the clinical isolate; in 4 a different strain was isolated. *Salmonella* was isolated from 1 out of 137 (0.7%) case refrigerators compared to 3 out of 96 (3%) control refrigerators. It was concluded that the presence of *Salmonella* in the domestic kitchen is necessary, but not sufficient, to result in transmission of foodborne illness, and there are further risk factors not identified by a study of this type which increase transmission risks.

- In previous study, Parry *et al.* (2002) found no evidence of differences in food consumption and food handling practices, opportunities for cross contamination and refrigerator temperature control in 99 households in Wales in 1997/8 with a case of *Salmonella* food poisoning, against control households. Cases were more likely to have purchased free-range eggs in the preceding week and handled frozen chicken.

- Kohl *et al.* (2002) report that, in the US, about 90% of *Salmonella* infections are sporadic. They studied the risk for sporadic salmonellosis among 115 persons aged >15 years reported in Louisiana, USA, compared with 115 age-matched controls. Although consumption of food items likely to contain *Salmonella* was not associated with illness, inconsistent handwashing between preparation of meat and non-meat items was associated with illness (aOR 8.3).

- Marcus *et al.* (2007) conducted a case-control study (218 cases and 742 controls) of sporadic *Salmonella enteritidis* infection in 5 US Foodborne Diseases Active Surveillance Network (FoodNet) sites. Eating chicken prepared outside the home and undercooked eggs inside the home, and contact with birds and reptiles were associated with infection.

- Centers for Disease Control and Prevention (CDC) reported cases of Salmonellosis in the US associated with a range of animals including pet turtles, reptiles and chicks.

- During 1996-7, Mermin *et al.* estimated the burden of reptile- and amphibian-associated *Salmonella* infections in Minnesota, Oregon California, Connecticut, and Georgia (501 cases, 9047 controls). Reptile and amphibian contact was associated with infection with serogroup B or D *Salmonella* (multivariable odds ratio 1.6; *P* < .009) and infection with non-serogroup B or D *Salmonella* (OR, 4.2; *P* < .001). The population attributable fraction for reptile or amphibian contact was 6% for sporadic *Salmonella* infections and 11% for persons >21 years old. They estimated that reptile and amphibian exposure is associated with apprx 4,000 *Salmonella* infections annually in the US.

- A large case-case study in England between 2004 and 2007 indicated that reptile exposure is a rare but significant risk factor for *Salmonella* infection, with higher risk in children <5 years old. Among the *Salmonella* serotypes found in people exposed to reptiles, several non-*Enteritidis*, non-*Typhimurium* serotypes were identified.

**Campylobacter**

A number of outbreaks of *Campylobacter* are reported, where studies suggested that spread via hands, environmental surfaces and cleaning cloths was a, or the, causative factor:

- Cross-contamination of food with *Campylobacter jejuni* from raw chicken was cited as the cause of an outbreak of enteritis from eating at a restaurant. Inspection of the kitchen showed the food preparation area to be too small to separate raw poultry and other foods adequately during preparation. The cook had cut up raw chicken before preparing salads and lasagne (which were statistically associated with illness). The...
lettuce or lasagne was probably contaminated with *C. jejuni* from raw chicken through unwashed or inadequately washed hands, cooking utensils or the countertop.

- A review by Pebody *et al.* (1997) reported general outbreaks of *Campylobacter* infection in England and Wales indicating that some foodborne outbreaks were related to the handling and consumption of poultry and cross contamination from other foods.

The literature also reports a number of case-control studies in which transmission via hands and surfaces were identified as risk factors. Again in 4 (but not in 2) of these 6 reports, contact with animals was identified as the likely source:

- Neimann *et al.* (2003) did a case control study (282 cases and 319 controls) in Denmark during 1996–7. Consumption of undercooked poultry (OR 4.5; 8.2), red meat at a barbecue, or grapes (OR 1.6; 2.8), and drinking unpasteurized milk (OR 2.3; 11.8) were identified as risk factors for sporadic *Campylobacter* infection. Frequent consumption of pork chops (OR 4.4) and daily contact with domestic animals and pets were identified as risk factors in one of the two models only.

- A 2001 case-control study in children aged 0-35 months (81 cases, 144 controls) in Australia showed that ownership of pet puppies (adjusted OR16.58) and pet chickens (OR 11.80), and consumption of mayonnaise (OR 4.13) were risk factors for infection.

- By contrast, in a UK case-control study aimed at identifying risk factors for intestinal infection with *Campylobacter jejuni* involving subjects with diarrhea occurring in community cohorts or presenting to General Practitioners with *Campylobacter jejuni* in stools, there was no significant risk associated with consumption of chicken other than in restaurants, nor with reported domestic kitchen hygiene practices. Pets or other animals were not identified as risk factors and most cases remained unexplained. They suggested that infection with low numbers of micro-organisms, and individual susceptibility may play a greater role in causation of *Campylobacter* infection than previously thought. They also concluded that, in mild, sporadic cases, infection may result from cross contamination from kitchen hygiene practices usually regarded as acceptable and that chicken may be a less important vehicle of infection for sporadic cases than for outbreaks.

- In 1989 and 1990, Kapperud *et al.* performed a case-control study designed to identify risk factors for sporadic *Campylobacter* infections in Norway. Risk factors found to be associated with illness included consumption of sausages at a barbecue (OR 7.64; *P* = 0.005), daily contact with a dog (OR =4.26; *P* = 0.024), and eating of poultry brought into the house raw (frozen or refrigerated) (OR =3.20; *P* = 0.024).

- In contrast, a case-control study by Danis *et al.* conducted in Ireland showed that although factors such as eating chicken were risk factors for sporadic *Campylobacter* infections, contact with pet cats, dogs and other was not.

### Norovirus

A number of norovirus outbreaks have been reported for which person to person transmission via the environment (both via hands and surfaces and also by aerosol transmission) or via food was implicated as the route of transmission:

- Following a wedding reception, an outbreak of norovirus gastroenteritis affected 50% of guests. The previous day, a kitchen assistant had vomited in a sink that was subsequently used for preparing vegetables eaten by the wedding guests.

- The causal agent of recurrent outbreaks of gastroenteritis on a cruise ship was found to be norovirus. There had been at least 10 outbreaks of gastroenteritis aboard the ship in the previous 2 years. Thorough inspections and cleaning of the ship between cruises were not sufficient to stop the outbreaks. The likely modes of transmission were person-to-person contact or surface contamination by aerosol droplets from infectious stool or vomitus in the communal bathrooms.
• Although direct evidence is lacking, this and other outbreaks reported in cruise ships in which recurrent waves of infection occurred in successive cohorts of guests strongly suggests transmission of norovirus via environmental sites and surfaces.512,513
• An outbreak of norovirus gastroenteritis in an elderly care unit of a hospital spread rapidly within and between wards, affecting both patients and staff. Analysis of risk exposure showed areas where patients had vomited to be the most significant factor for the spread of norovirus to staff.514
• Cheesbrough et al. 1997515 reported that 2 carpet fitters became ill after removing a carpet from a hospital ward 13 days after the last case in rotavirus outbreak. Routine daily vacuuming since the outbreak had not removed the virus.
• During a norovirus outbreak in a long stay ward for the mentally ill, 36 environmental samples were collected on the affected ward of which 11 (30%) were positive by RT-PCR. Positive swabs were from lockers, curtains and commodes and were confined to the immediate environment of the affected patients.516
• The potential for environmental spread of norovirus was demonstrated in a prolonged hotel outbreak in successive cohorts of guests.211 Environmental sampling demonstrated widespread dissemination of the virus on hand contact and other surfaces. From the patterns of infection, it was concluded that although infectious aerosols were probably the main route of dissemination of infection within a particular cohort of guests, contact with contaminated fomites was the most likely factor responsible for maintaining the outbreak by forming the link between successive cohorts.
• Evans et al.517 investigated a 1999 outbreak of norovirus which affected more than 3000 people who attended a UK concert hall over a 5 day period. The index case was a concert attendee who vomited in the auditorium and in an adjacent toilet. Illness occurred among 8/15 school parties who attended the following day. Illness affected 257/1229 (20.9%) of the children, but attack rate by school was 0.6 to 75%. Children who sat on the same auditorium level as the index case were more likely to be ill than those seated elsewhere (RR 7.1, p=<0.001).
• Data from 2 norovirus outbreaks in 2000 and 2003 indicate how infection can result from direct inhalation of infected particles of vomit by people immediately adjacent to the person who vomits. The potential for airborne transmission was demonstrated in studies in a restaurant and a primary school, where close proximity to infected persons in the immediate aftermath of a vomiting attack was found to be a risk factor.518,519
• Investigation of a 2008 norovirus outbreak in the US identified insufficiently cleaned computer keyboards as a probable risk factor for a school-based outbreak.520
• In a case-control study carried out in the Netherlands, De Wit et al. identified risk factors, modes of transmission, and opportunities for prevention gastroenteritis due to norovirus, Sapporo-like virus (SLV), and rotavirus. The main risk factor for viral gastroenteritis was contact with other persons with gastroenteritis, supporting the hypothesis that these viruses are mainly transmitted from person to person. However, for NV gastroenteritis, foodborne transmission also seems to play an important role.521
• Jones et al. (2007)214 reported an outbreak which affected 74% of guests on 3 consecutive houseboat trips. An environmental investigation identified norovirus RNA on 71% of surfaces in bathrooms, kitchens, and door handles.
• During an outbreak in a long-term care facility, norovirus RNA was identified on 5 of 10 environmental sites collected after disinfection, suggesting widespread persistent contamination. Positive sites included an elevator call button used only by staff. The outbreak resolved following a second, more thorough facilitywide disinfection.213
• Nicolay et al. 2011 investigated a cluster of 4 gastroenteritis cases among people who attended a family lunch in a Dublin hotel in 2009.522 Consumption of egg mayonnaise, turkey with stuffing or chicken sandwiches were each associated with increased risk of gastroenteritis: (risk ratio (RR): 2.3; 95% CI: 1.4–3.9), (RR: 1.9; 95% CI: 1.2–3.2), (RR:
Further investigations suggested that the ready to eat sandwiches had most likely been contaminated during preparation, by three asymptomatic kitchen food handlers who had used the same toilets. All eight cases and three asymptomatic food handlers on duty at the lunch tested positive for norovirus.

Although the data suggest that both aerosol, and hand and surface transmission contribute to spread of norovirus infection, there are no data to indicate the relative importance of these two routes.

**Rotavirus**

Outside the hospital environment, rotavirus outbreaks are most usually reported for young children in day-care centers. Ekanem et al. (1983) concluded that contamination of hands and classroom objects plays a role in transmission in day-care centers. Astroviruses and enteric adenoviruses have been associated with gastroenteritis outbreaks in schools, paediatric hospital wards and nursing homes. Rotavirus shows a distinct winter peak. Low humidity and crowding indoors associated with winter may be factors in the spread of this virus. One-third of parents whose children are infected with rotavirus become ill indicating that transmission takes place in the home between family members.

In the Netherlands case-control study by De Wit et al., as described above, the main risk factor for rotavirus as well as norovirus gastroenteritis was contact with other persons with gastroenteritis, supporting the hypothesis that these viruses are mainly transmitted from person to person.

A number of investigations are reported for which cross-contamination from person to person was implicated as the route of transmission of rotavirus:

- A US study revealed that rotaviruses infected one or more members in 51% of families, including 28% of children and 13% of adults. Some adults acquired rotavirus infections a few days after their children’s illnesses, suggesting that children rather than the parents brought infection into the home.
- Rodriguez et al. (1979) found rotavirus infection in 55% of adult family contacts of children hospitalised with gastroenteritis.
- In a community study in New Zealand, in families with an index case of rotavirus infection, children were more frequently infected than adults. Once a family member became infected, probability of cross infection was high.

**Escherichia coli**

A number of *E. coli* outbreaks have been reported for which cross-contamination was implicated as the route of transmission:

- Linton et al. (1977) demonstrated that *E. coli* strains from chicken carcasses became part of the majority coliform flora of one volunteer who had handled, cooked and eaten the chickens at home. None of the strains had been detected in the faecal flora prior to handling the chicken. The strains were isolated from faecal specimens taken the day after the chicken was handled, prepared and cooked, but before it was eaten. This indicates that it was handling of the uncooked chicken that provided the opportunity for transmission of *E. coli* rather than the eating of the cooked chicken. The strains of *E. coli* from the chicken also remained in the faecal flora for about 10 days.
- Mead et al. (1997) conducted a case-control study to identify sources of infection and contributing practices to sporadic outbreaks of *E. coli* O157:H7. Illness was strongly associated with having consumed a hamburger in the previous week, with 80% of hamburgers being prepared at home. Case households were more likely to report not washing their hands or work surfaces being in contact with raw beef, and
were more likely to report placing cooked hamburgers back onto unwashed plates previously in contact with raw beef. Transmission was believed to have occur more often when the hands of food preparers were allowed to cross-contaminate other food and utensils. The authors concluded that 34% of infections could have been avoided by adequate hand hygiene.

- **Varma et al.** carried out a case control study to determine the risk factors for E. coli O157 infection during an outbreak at a county fair in Ohio, in August 2001. Case-patients were more likely than controls to have visited building A (a multipurpose community facility on the fairgrounds). Among visitors to building A, illness was independently associated with attending a dance in the building, handling sawdust from the floor, or eating and/or drinking in the building. Twenty-four (44%) of 54 specimens from building A 6 weeks after the fair grew Shiga toxin-producing E. coli O157. Isolates from sawdust, rafters, and other surfaces were identical by molecular fingerprinting to patient isolates. Sawdust specimens collected 42 weeks after the fair also grew the same E. coli O157 strain.

- **Rangel et al.** reviewed *E. coli* O157 outbreaks in the US from 1982–2002
  
  - Outbreak settings included 40 (80%) child daycare centers; 5 (10%) individual residences; 3 (6%) communities 1 (2%) school, and 1 (2%) residential facility. Transmission route for 183 (52%) was foodborne, 74 (21%) unknown, 50 (14%) person-to-person, 31 (9%) waterborne, 11 (3%) animal contact, and 1 (0.3%) laboratory-related.
  
  - In a study of sporadic E. coli O157 infections in Wales, Parry and Salmon (1998) calculated that the household transmission rate from an index case to be 4–14%, although many of the secondary cases were asymptomatic.
  
  - In a 2011 report, Friedrich review cases of E. coli O104 in Germany Netherland and France which were due to secondary person-to-person transmission within households or associated with an infected food handler.

Investigations involving other bacterial and viral enteric pathogens are as follows:

**Listeria**

- *Listeria monocytogenes* was the causal agent of an outbreak of gastroenteritis among supper guests at a private home. The rice salad was deemed the most likely vehicle since the attack rate was 90% for those who ate rice salad. The salad had been prepared 24 hours in advance and stored at room temperature. *Listeria monocytogenes* was also isolated from other foods left over from the supper, and from the blender and the freezer in the home of the cook indicating that cross-contamination from kitchen surfaces or utensils may have played a role in this outbreak.

**Helicobacter pylori**

- A Japanese study examined the relationship between persistent *Helicobacter pylori* infection, and factors such as sanitary conditions or home environment during childhood. Almost 6000 participants completed a questionnaire and *H. pylori* antibody test. The authors concluded that drinking water, type of toilet, residential area, number of people in the house and birth order showed significant correlation with *H. pylori* infection.

- Perry et al. (2006) examined household members in California, USA for *H. pylori* infection. Among 1,752 person considered uninfected at baseline, 30 new infections occurred. The risk for definite or probable new infection increased by 4.8-fold upon exposure to an infected household member. Of probable/definite new infections, 75% were attributable to exposure to an infected person. The authors suggest that person-to-person transmission of *H. pylori* is most commonly implicated with faecal/oral,
oral/oral, or gastric/oral pathways; infection is associated with conditions of crowding and poor hygiene and intrafamilial clustering.

**Hepatitis A**

- Rajaratnam *et al.* describe an outbreak of hepatitis A (HAV) associated with a Middle school involved 23 cases. The probable source was a male pupil infected by a sibling who had contracted hepatitis A while abroad on holiday. A questionnaire survey and salivary IgG and IgM anti-HAV testing of the pupils demonstrated a statistically significant association between infection and the use of a changing room toilet for defecation. An inspection of the school showed that toilets lacked toilet paper, soap and hand towels.

- An outbreak of HAV was associated with a public house whose barman had chronic diarrhoea and had served drinks while incubating HAV himself. Fomite transmission by contamination of glasses was the likely route of spread.

- Investigation of community outbreaks of HAV show that people involved in nappy-changing in day-care centers often handle food. HAV may be acquired from children who are excreting HAV, the majority of whom are asymptomatic. A significant percentage (23–52%) of household contacts of index cases with HAV infection, are at risk of acquiring infection. Higher rates of infection in children (71–80%) compared with parents (29%) suggest that child play activity is a risk factor for transmission in homes.

**Shigella sonnei dysentery**

Poor surface hygiene has been implicated in the spread of *Shigella* infection. In 1992 there was an epidemic outbreak of dysentery caused by *Shigella sonnei*. Some 17,000 cases of dysentery were reported for England and Wales in 1992 compared with 2313 in 1990. Transmission of *Shigella* is via the faecal–oral route and it is recognised that prevention requires careful attention to hand hygiene and cleaning of washbasins, toilets and surrounding areas. Outbreaks are often centered on nursery schools, etc., but there is also substantial evidence for spread within the home. The infectious dose is very small and young children are implicated in the spread of shigellosis to their families.

**Cryptosporidium**

*Cryptosporidium*, a common cause of diarrhea, has been associated with sporadic and epidemic diarrhoea in child-care settings with evidence for secondary transmission to household and other close contacts. Transmission from pets has also been recorded.

**Gastrointestinal infections linked to petting farms**

Gormley *et al.* 2011 reviewed 55 outbreaks of infectious intestinal disease associated with petting farms in England and Wales as reported to the UK Health Protection Agency during 1992–2009. Verocytotoxin-producing *Escherichia coli* O157 (VTEC O157) caused 30 (55%) of these outbreaks (244 persons were affected [range 2–93, mean 8 persons] and 84 were hospitalized); *Salmonella enterica* serovar Typhimurium definitive phage type 104 caused 2 (3%) of the outbreaks. A total of 23 (42%) petting farm outbreaks were caused by *Cryptosporidium* spp. (1,078 persons were affected [range 2–541, mean 45 persons] and 29 were hospitalized). Contributory factors reported in the cryptosporidiosis outbreaks included direct contact with preweaned lambs, calves, kids, or animal faeces (e.g., diarrhea in lambs, a recognized risk factor for cryptosporidiosis; 11/23 [48%]) and inadequate hand washing facilities (7/23 [30%]). Of outbreaks in which hand washing facilities were inadequate, thumb sucking by children was also noted in 1; in another, alcohol-based hand gels and sanitizers, which are ineffective against *Cryptosporidium* spp., were used.
With overall regard to infectious intestinal diseases, the difficulties of drawing general conclusions from case-control studies about the role of environmental hygiene in preventing GI infections involving several pathogens is illustrated by the study of Stenberg et al. The study evaluated 14 published studies (11 case-control studies, 2 cross-sectional surveys, and 1 randomised control trial (some described in more detail above)) in order to assess whether household kitchen practices contribute to development of diarrhoea. Exposures identified were related to kitchen hygiene and cleanliness or food preparation and storage practices. Outcomes studied were self-reported diarrhoea with no identified pathogen, or diarrhoea involving a known pathogen. The study also included reanalysis of the UK IID study investigating associations between self-reported diarrhoea and poor domestic kitchen hygiene. Overall, the authors concluded that the data does not support the hypothesis that poor environmental hygiene in the domestic kitchen is a risk factor for Salmonella, Campylobacter or self-reported diarrhoea although there is evidence that poor kitchen hygiene may be a risk factor for Enterohemorrhagic E. coli. Although some variables in the reanalysis of the UK IID study were statistically significant, no obvious trend was seen. Importantly, the study which did not distinguish between the various infectious agents (Salmonella, Campylobacter, norovirus and rotavirus) for which the sources and routes of transmission are likely to be quite different. The study also looked mostly at kitchen hygiene practices, whereas a large proportion of disease may have resulted from person-to-person transmission outside the kitchen, not involving food handling; most diarrhoeal diseases in developed nations are probably due to viruses which are largely transmitted from person-to-person. The authors also concurred that they did not list all potential risk factors, which may have caused under-ascertainment of negative relative to positive outcomes. Overall, the authors concluded that no unequivocal conclusions about the impact of kitchen hygiene on diarrhoeal disease could be drawn from their study.

Similarly, Mitakakis et al. studied 600 families (cases and controls) to identify whether dietary intake and food-handling and storage practices in the home were risk factors for gastroenteritis. No association with food-handling and storage practices was detected. However cases were more likely to have a baby in nappies in the house.

5.1.2 Hygiene and respiratory tract infections
A number of case-control studies are reported which assess the impact of hygiene measures in preventing the spread of viral RT infections:

- St. Sauver et al. (1998) studied prevalence of respiratory illness in children attending daycare homes. Never or rarely washing hands by both children and carers, using shared cloth towels rather than disposable paper towels and washing of sleeping mats less than once a week were associated with higher frequency of respiratory infection.

- Jefferson et al. (2009) assessed 6 case-control studies which assessed the impact of public health measures to curb the spread of severe acute respiratory syndrome (SARS) during February to June 2003 in China, Singapore, and Vietnam. Studies reported that disinfection of living quarters was highly effective in preventing the spread of severe acute respiratory syndrome (odds ratio 0.30, 95% confidence interval 0.23 to 0.39, one study); handwashing for a minimum of 11 times daily prevented most cases (0.45, 0.36 to 0.57; all six studies), wearing simple masks was highly effective (0.32, 0.25 to 0.40; five studies), wearing N95 masks was even more effective (0.09, 0.03 to 0.30; two studies), wearing gloves was effective (0.43, 0.29 to 0.65; three studies), wearing gowns was also effective (0.23, 0.14 to 0.37; four studies). All approaches combined achieved high effectiveness (0.09, 0.02 to 0.35; two studies).

- In one of the case-control studies included above, Lau et al. analysed data from 1,192 patients with probable SARS reported in Hong Kong. Multivariate analysis
showed that having visited mainland China, hospitals, or the Amoy Gardens were risk factors (OR 1.95 to 7.63). Mask use in public venues (OR 0.36), frequent hand washing (OR 0.58), and disinfecting the living quarters (OR 0.41) were also significant protective factors.

5.1.3 Hygiene and skin and wound infections

**S. aureus** and MRSA

A range of MRSA outbreaks related to the home and community have been evaluated where transmission via hands and environmental surfaces has been identified as a likely cause of transmission. These are also reviewed elsewhere. In addition, a small number of instances are recorded where the home environment was cited as a causative factor:

- In studies of HCWs colonised with MRSA, the HCW was treated to eradicate the organism, but subsequently became recolonised. In each case, MRSA was isolated from environmental surfaces in the home of the HCW, including door handles, a computer desk shelf and computer joystick, linens, furniture, and in some cases also from other family members and family pets.

- A number of cases are reported where family members in the home of an infected person have become colonised. Hollis et al. found that transmission of the MRSA strain from an index case to two siblings and the mother occurred at least three times, and one family member was colonised for up to 7 months or more.

- The potential for HCWs acquiring PVL-MRSA in the community with onward transmission to patients or fellow HCWs was demonstrated during investigation of a fatal PVL-MRSA infection in a Filipino healthcare worker (HCW, case 1) in the UK. Both household members (partner and child) were identified as asymptomatic carriers (cases 2 and 3). From analysis of blood cultures from 5 patients on the ward where case 1 had worked, one patient with an MRSA strain indistinguishable from the outbreak clone was identified (case 4). Screening of HCWs who worked on the ward with case 1 and where case 4 had been admitted revealed the outbreak clone in another HCW (case 5). Cases 1 and 5 had previously shared accommodation and had cared for case 4. Case 5 lived in a household with partner and child. Both were identified as carriers (cases 6 and 7). Case 6 was a HCW who worked on a different ward. Overall, representatives of the same lineage were identified in 16 individuals in community and hospital. Infections likely to be caused by PVL-MRSA had occurred in 12 cases of which 9 worked as nursing staff in the hospital. Eight of these were linked socially.

In 2006, Turabelidze et al. reported a case-control study, involving 55 culture-confirmed cases of MRSA in a US prison examining risk factors for MRSA infection with a focus on personal hygiene. It was found that the risk for MRSA infection increased with lower frequency of hand washing per day and showers per week. Patients were also less likely than controls to wash personal items (80.0% vs. 88.8%) or bed linens (26.7% vs. 52.5%) themselves instead of using the prison laundry. When personal hygiene factors were examined for cases and controls, patients were more likely than controls to share personal products (e.g. cosmetic items, lotion, bedding, toothpaste, headphones), especially nail clippers (26.7% vs. 10%) and shampoo (13.3% vs. 1.3%), with other inmates. To evaluate an overall effect of personal hygiene practice on MRSA infection, a composite hygiene score was created on the basis of the sum of scores of 3 hygiene practices, including frequency of hand washing per day, frequency of showering per week, and sharing personal items shared with other inmates. A significantly higher proportion of case-patients than controls had lower
Experience in the US suggests that CA-MRSA is easily transmissible not only within families but also on a larger scale in community settings such as prisons, schools and sports teams. For CA-MRSA, those at particular risk appear to be younger, generally healthy people who practice contact sports or other activities that put them at higher risk of acquiring skin cuts and abrasions. Skin-to-skin contact (including intact skin) and indirect contact with contaminated objects such as towels, sheets and sport equipment are seen as the primary vehicles of transmission; Johnson cite risk factors for spread of CA-MRSA as close skin-to-skin contact, cuts and abrasions, shared contaminated items or surfaces, poor hygiene and crowded living conditions. A 2008 study by Archibald et al. investigated a cluster of MRSA infections in college football players. Risk factors included a history of recurrent skin infections and contact with the skin lesions of persons outside college.

Uhlemman et al. 2011 carried out a community-based study (95 case and 95 controls) which indicated that environmental colonization may contribute to the community spread of epidemic strains such as USA300. Case patients presented with CA-MRSA infections to a New York hospital. Age-matched controls without infections were randomly selected. During a home visit, case and control subjects completed a questionnaire, nasal swabs were collected from index respondents and household members and standardized environmental surfaces were swabbed. Among case households, 53 (56%) were environmentally contaminated with S. aureus, compared to 36 (38%) control households (p = .02). MRSA was detected on fomites in 30 (32%) case households and 5 (5%; p,.001) control households. More case patients, 20 (21%) were nasally colonized with MRSA. In a subgroup analysis, the clinical isolate (predominantly USA300), was more commonly detected on environmental surfaces in case households with recurrent MRSA infections (16/36, 44%) than those without (14/58, 24%, p = .04).

Mycobacteria
Infections with Mycobacterium avium and M. fortuitum have been linked to inadequately sanitised domestic hot tubs in both healthy and immune-compromised individuals. A community-based outbreak of infection with M. fortuitum was associated with contamination of a foot-bath at a nail salon.

Streptococcus
Clusters of Group A streptococcal infections in family, hospital and nursing home settings have been reported by Schwartz et al. A report of a nursing home outbreak of Group A streptococcal infection involved infected skin lesions among residents. One of 3 throat swabs from staff members complaining of a sore throat yielded the same organism. As some infected lesions followed falls on the nursing home carpet, samples were taken which indicated widespread occurrence of the outbreak strain on carpets and furnishings. In comparison there was no evidence of environmental contamination in a “control” nursing home which was also sampled. Repeat environmental sampling after cleaning measures had been implemented showed decreased streptococcal contamination and no further cases of infection were reported among staff and residents.

5.1.4 Hygiene and fungal infections
Fungal contamination in homes and hospitals has been implicated as the cause of infection or increased prevalence of infection:
- The presence of the fungus Stachybotrys atra in a house in Chicago was implicated in an outbreak of illness among the occupants. The symptoms of the illness only
ceased following the removal of the fungus.

- Mould growth on a floor and underside of linoleum was the cause of more severe respiratory symptoms in patients returning home from hospital and they only recovered after treatment of the mouldy area.\textsuperscript{560}

- In Finland, visible mould was reported in 3.7% of homes, and 5.5% reported mould odour.\textsuperscript{561} Increased prevalence of respiratory infections and respiratory symptoms was recorded in homes reporting dampness or mould.

### 5.1.5 Home hygiene and overall rate of infection

Larson and Duarte\textsuperscript{50} examined the relationship between prevalence of non-specific infections and home hygiene practices amongst household members. The study involved 398 households in New York. Infections investigated were defined as 2 or more members of the same household with the same symptoms that included fever, cough, cold, diarrhoea, vomiting, sore throat, skin infection or other infection. Only 2 specific “targeted” practices, using a communal laundry and not using bleach in communal laundering, were predictive of increased risk of infection. For the remaining practices there was no evidence of an association with infection risk. Other hygiene practices studied were mostly cleaning practices such as daily personal bathing or showering, daily cleaning of bathrooms and toilets, frequent changing of dish-sponges, or use/non use of antimicrobial cleaning products for these activities.

### 5.2. Assessments of the causal link between hygiene and infectious diseases using data from intervention studies

One of the most important aspects of intervention studies is that they give a quantitative estimate of the extent to which hygiene measures can reduce infection rates. However, apart from hand hygiene and household water treatment, very few intervention studies have been carried out to assess the impact of procedures such as surface hygiene, cleaning cloth hygiene or laundry hygiene, as used in the home. Even for hand hygiene, most studies have involved settings such as schools or day-care centres rather than the home.

#### 5.2.1 Intervention studies assessing the impact of hand hygiene on gastrointestinal, respiratory tract and skin and wound infection

**Impact of hand hygiene on gastrointestinal disease**

From a systematic review of hand washing intervention studies carried out in 2007 (\textbf{Table 4}), Bloomfield, Aiello \textit{et al.} \textsuperscript{4} estimated that the range of reduction in the incidence of infectious intestinal diseases was between -13% to 79% for developing countries and between -10% and 57% for developed countries. Of the studies that were statistically significant (7/11 and 3/5), reductions in GI infection ranged from 26–79% and 48–57% for developing and developed countries, respectively. In the same review it was estimated that the range of reduction in the incidence of infectious intestinal diseases by use of an alcohol hand sanitizer was between 0 and 59% for developed countries. Of the studies that were statistically significant (3/4), reductions in GI infection ranged from 20–50%.
Table 4 – Data from intervention studies on the impact of hand hygiene on respiratory and gastrointestinal infections

<table>
<thead>
<tr>
<th>Type of infection</th>
<th>Area of study</th>
<th>Risk reduction from hand washing with soap</th>
<th>Use of alcohol hand sanitizer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Range (No. of statistically significant studies (range))</td>
<td>Range (No. of statistically significant studies (range))</td>
</tr>
<tr>
<td>Gastro-intestinal</td>
<td>Developed</td>
<td>-10 to 57% (3/5 studies 48 to 57%)</td>
<td>0 to 59% (3/4 studies 20-50%)</td>
</tr>
<tr>
<td></td>
<td>Developing</td>
<td>-13% to 79% (7/11 26% to 79%)</td>
<td></td>
</tr>
<tr>
<td>Respiratory</td>
<td>Developed and</td>
<td>5% to 53% (2/6 studies 20%-51%)</td>
<td>-6 to 26% (2/4 studies 13–26%)</td>
</tr>
</tbody>
</table>

In a 2009 study by Nicholson et al., a 10 month study was carried out to evaluate the impact of handwashing with soap on the incidence of diarrhoea, acute respiratory infections (ARIs), and eye infections.31 The study involved 1,656 families across 70 communities in Mumbai, India. Half of the families were provided with soap along with education about the importance of handwashing at 5 key occasions: before eating meals, when bathing and after using the toilet. At the end of the trial, children aged approximately 5 years old in the intervention group had 25% fewer episodes of diarrhoea than those in the control group, with similar reductions in children in other age groups and adults, ranging from 21.4% to 24.7%. Furthermore, due to the reduction in the number of episodes of disease there was a 40% increase in school attendance during the trial.

The strong causal relationship between hand hygiene and GI disease risk has been demonstrated by a range of systematic evaluations of data from intervention studies.562, 563, 564 These studies were carried out using data from both developed and developing countries. Individual studies on the impact of hand hygiene on GI infections are described in more detail in IFH review papers on the effectiveness of hygiene procedures.4, 9 In most cases, these studies assessed the overall impact on diarrhoea, but in some cases the impact of hand hygiene on specific infections such as Shigella, rotavirus or norovirus was investigated. Some of these studies looked at the impact of handwashing, whilst others evaluated use of alcohol hand sanitizers.

In the most recent reviews Waddington et al. 200932 concluded that handwashing with soap lead to an estimated 31% reduction in child diarrhoea morbidity. Analysis by sub-group suggested that provision of soap is more effective in reducing diarrhoea morbidity than education campaigns alone. In a 2010 review, Cairncross et al. proposed a diarrhoea risk reduction of 48% associated with handwashing with soap.33 However they concluded that most of the evidence is of poor quality and more trials are needed, although they commented on the consistency of the results across various study designs and pathogens.

Impact of hand hygiene on respiratory disease
A range of intervention studies have been carried out which indicate a significant link between hand hygiene and spread of RT infections. Individual studies on the impact of hand hygiene on RT infections are described in more detail in the IFH review paper on the effectiveness of hygiene procedures.4, 9 Some of these studies evaluate the impact of handwashing, whilst other studied use of alcohol hand sanitizers.
Some of the earlier studies evaluated the impact of hygiene in interrupting the transmission of "experimental" rhinovirus colds:

- Gwaltney et al. (1980) showed that aqueous iodine (2%) applied to fingers was effective in blocking hand transmission of experimental rhinovirus infection. None of the 8 volunteers became infected when exposed to rhinovirus immediately after treatment of fingers with iodine whilst all of 7 subjects treated with a placebo preparation became infected. One of 10 volunteers became infected when exposed 2 hour after treatment of fingers with iodine, compared with 6 of 10 who became infected in the control group. Virus was recovered from three (11%) of 27 hand rinses from volunteers using iodine and from 11 (41%) of 27 hand rinses from volunteers using the placebo preparation.

- In a 4-year trial, Hendley and Gwaltney (1988) studied the impact of prophylactic treatment of mothers' fingers with iodine on RT infections. When illness occurred in the family, mothers were instructed to dip their fingers in iodine first thing in the morning, then every 3-4 hours or after activities that washed the iodine from the skin. Secondary attack rates in mothers were 7% in the iodine group and 20% in placebo families. No infections occurred in mothers after 11 exposures to an index case with infection in the iodine group, compared with 5 infections after 16 exposures in the placebo group.

In 2007, Aiello et al. carried out a systematic review of hand hygiene intervention studies carried out to assess the impact on RT infections. Based on these studies, Table 4 summarises the results of community-based interventions (i.e. excluding healthcare-related and military settings). Most studies were conducted in economically developed countries (83%, 5/6). Reduction in illness due to handwashing ranged from 5–53%, but only 33% (2/6) of studies were statistically significant. In the same review it was estimated that the range of reduction in the incidence of respiratory infections by use of an alcohol hand sanitizer was between -6 and 26%. Of the studies that were statistically significant (3/4), reductions in GI infection ranged from 13-26%. Rabie and Curtis in 2006 also published a review of hand hygiene studies involving RT infections. They reported that hand hygiene (hand washing, education, and waterless hand sanitizers) can reduce the risk of respiratory infection by 16% (95% CI: 11-21%). These investigators have now updated their estimate with two further, more recent, studies which, when all studies are taken together, give a pooled impact on respiratory infection of 23%. In a more recent 2008 study, Aiello et al., estimated that the reduction in respiratory illness associated with the pooled effects of hand hygiene (hand washing with soap, use of alcohol handrubs) was 21%.

In the 2009 study by Nicholson et al. of the impact of handwashing with soap on diarrhoea, acute respiratory infections (ARIs), and eye infections in 1,656 families in Mumbai, India (described in more detail above), a 15% reduction in the number of episodes of ARI was observed in children aged approximately 5 years in the intervention group.

In 2009, Jefferson et al. reported a systematic review of 58 intervention and observational studies on the impact of physical interventions to interrupt the spread of viral respiratory tract infections. The authors concluded that “hygiene and physical measures, such as handwashing, wearing masks and isolating potentially infected patients, are highly effective in preventing the spread of viral infections. The results show that regular handwashing (more than 10 times a day) and wearing masks, gloves and gowns were effective individually against all forms of acute infectious respiratory disease, and were even more effective when combined. The highest quality trials suggested that spread of respiratory viruses can best be prevented by hygienic measures in younger children and within households. They also concluded that “the incremental effect of adding virucidal or antiseptics to normal handwashing to reduce respiratory disease remains uncertain”.

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Impact of hand hygiene on skin, wound and eye infections

Although skin, wound and eye infections are common in the home and community, and are transmitted from person-to-person, other than for *S. aureus* infections, there is little intervention study data on the impact of hand hygiene.

Perhaps the most convincing evidence for hand transmission of *S. aureus* comes from a US controlled trial in 1962 comparing the effect of no handwashing with antiseptic handwashing on the acquisition of *S. aureus* in infants in a hospital nursery. Infants cared for by nurses who did not wash their hands after handling an index infant colonised with *S. aureus* acquired the organism significantly (*p*<0.05) more often and more rapidly than infants cared for by nurses who used hexachlorophene to cleanse their hands between infant contacts.567

In two studies carried out in Pakistan, Luby *et al.*30, 289 studied the impact of hand washing with soap on impetigo. Impetigo is a skin infection caused by *S. aureus* which is frequently found as part of the normal body flora. In the 2002 study30 involving 162 households, it was found that, children had a 25% lower incidence of impetigo (-52% to -16%) compared with controls (no hand washing promotion). In the 2005289 study involving 600 households, it was found that, compared with controls, children younger than 15 years in households with plain soap had a 34% lower incidence of impetigo (-52% to -16%).

In a more recent study by Nicholson *et al.*31 on the impact of handwashing with soap on diarrhoea, acute respiratory infections (ARIs), and eye infections in families across Mumbai, India (described in more detail above), a 46% reduction in the number of episodes of eye infections was observed in children aged approximately 5 years old.

5.2.2 Impact of safe faeces disposal, and household water treatment and safe storage on diarrhoeal disease

In a 1991 review Esrey *et al.* examined a total of 144 studies to examine the impact of improved water supply and sanitation facilities on ascariasis, diarrhea, dracunculiasis, hook worm, schistomiosis and trachoma.568 The median reduction in morbidity for diarrhea, trachoma and ascariasis induced by water supply and/or sanitation was 26%, 27% and 29% respectively. The same for schistomiosis was 77%.

A 2005 systematic review by Fewtrell *et al.*563 concluded that diarrhoeal episodes can be reduced by 39% via household water treatment and safe storage. The link between household water storage, handling and point-of-use treatment and its effectiveness in reducing the burden of diarrhoeal diseases is also reviewed in a 2006 IFH report.5 The results of intervention studies showing that safe excreta disposal and improved water supply are effective in preventing diarrhoeal diseases are more recently reviewed in a 2008 WHO report,569 and two Cochrane reviews, a 2009 review on water supply570 and a 2010 review on improved sanitation.571 One of the key findings of the Cochrane review on water is that the effectiveness of household interventions is significantly greater than those at the source.

In the most recent reviews, Waddington *et al.*32 found results that were generally consistent with previous reviews, suggesting that, water quality interventions and safe excreta disposal interventions on average effect respectively a 42% and 37% relative reduction in child diarrhoea morbidity. The pooled meta-analysis suggested that sanitation and/or hygiene do exert additional impact on diarrhoea morbidity when combined with either water supply or water quality interventions. In a 2010 review, Cairncross *et al.* propose a diarrhoea risk reduction of 17 and 36%, associated respectively, with improved water quality and excreta disposal.33 However they concluded that most of the evidence is of poor quality and more
trials are needed, although they commented on the consistency of the results across various study designs and pathogens.

5.2.3 Impact of environmental/surface hygiene procedures applied to hand-contact, food-contact and other critical contact surfaces

Although most of the interventions studies summarised above, measured only the impact of hand hygiene, in some studies hand hygiene was combined with other measures. In some studies, hand hygiene promotion was combined with hygiene education, whilst in a few others hand hygiene was combined with cleaning and/or disinfection of environmental surfaces. In these studies however, no attempt was made to assess the separate effects of one intervention relative to another, and thereby rank their importance. In some studies, the impact of hygiene on groups of infections (e.g., respiratory tract infection), whilst in others the impact on specific infections (e.g. norovirus, C. difficile, MRSA) was assessed:

- Krilov et al. (1996) reported an intervention study in a preschool daycare centre for children with Down syndrome enrolled in a school-based early intervention program. Through a series of questionnaires, the number and types of infections in the children were chronicled for a year before and a year after the implementation of an intervention program. Intervention measures included reinforcing handwashing procedures and education of staff and families on issues of infection control including surface cleaning and disinfection and disinfection of toys. Compliance with these measures was monitored. During the interventional year the median number of illnesses/child/month decreased significantly from the baseline year (0.70 vs 0.53, \( P < 0.05 \)), with a trend toward a decrease in the number of respiratory illnesses (0.67 vs 0.42, \( P < 0.07 \)). Significant decreases were also seen in the median number of physician visits (0.50 vs 0.33, \( P < 0.05 \)), courses of antibiotics administered (0.33 vs 0.28, \( P < 0.05 \)), and days of school missed as a result of RT illness (0.75 vs 0.40, \( P < 0.05 \)).

- Uhari and Mottonen (1999) reported a 15 month randomised controlled trial to evaluate a programme for reducing infection transmission in 20 US child daycare centres. Most of the infections that did occur were viral. The programme included increased handwashing, cleaning of the daycare centers and regular washing of toys. Both the children and the personnel in the program centers had significantly fewer infections than those in control centers, the reduction being 9% (\( P < 0.002 \)) among 3-year-old children and 8% (\( P = 0.049 \)) among older children. The children at the program centers received 24% fewer prescriptions of antimicrobials (\( P < 0.001 \)). Likewise, there were 2.5 man-year fewer absences from work on the part of parents because of a child's illness during 1 year in the program centers, a 24% difference (\( P < 0.001 \)).

Since 2007, 3 new intervention studies (one in the home and two in schools) have been reported, which assessed the effect of promotion of environmental cleaning with or without hand hygiene, on rates of GI, RT, and skin and eye infections:

- In a household study carried out in South Africa in 2007 by Cole et al., the effects of intensive hand and environmental hygiene education alone and in combination with use of hygiene products (soap, surface cleaner/disinfectant, and antiseptic) were assessed. Four communities (685 households) participated: two of government (RDP) housing (indoor tap/flush toilet) and two of informal (INF) housing (communal tap/latrines). Illness symptoms were monitored weekly and reinforced disease-prevention behaviours established through participatory learning focusing on handwashing/bathing with soap, cleaning toilet and food surfaces, and treating skin problems with antiseptic. RDP and INF communities were located in 2 areas, with one
area receiving education and products (intervention), and the other receiving education only. Illness data were gathered from Jun-Nov 2006 (baseline), and for the same 2007 period following education and product introduction and the percentage reduction in illness calculated.

**Table 5** – Incidence and reduction in gastrointestinal, respiratory and skin disease in hygiene intervention and control households in government and informal housing communities

<table>
<thead>
<tr>
<th>Incidence and reduction in gastrointestinal, respiratory and skin disease</th>
<th>Gastrointestinal</th>
<th>Respiratory</th>
<th>Skin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction</td>
<td>Reduction difference</td>
<td>Reduction</td>
<td>Reduction difference</td>
</tr>
<tr>
<td><strong>Formal housing</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Education + products</td>
<td>78.6%</td>
<td>14.0%</td>
<td>74.2%</td>
</tr>
<tr>
<td>Education only</td>
<td>64.6%</td>
<td>49.6%</td>
<td></td>
</tr>
<tr>
<td><strong>Informal housing</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Education + products</td>
<td>77.4%</td>
<td>11.3%</td>
<td>57.4%</td>
</tr>
<tr>
<td>Education only</td>
<td>66.1%</td>
<td>19.6%</td>
<td></td>
</tr>
</tbody>
</table>

Table 5 indicates that hygiene promotion produced a significant reduction in rates of infection. Calculation of hazard ratios (HR) using proportional hazard models indicated that RDP controls were more likely to experience GI (HR=1.27, CI: 1.10-1.46), RT (1.25, CI 1.08-1.43) and skin (HR=1.26, CI: 1.10-1.44) illnesses than intervention counterparts. INF controls were more likely to experience GI (HR=1.43, CI: 1.26-1.62), RT (HR=1.26, CI: 1.11-1.44) and skin (HR=1.46, CI: 1.29-1.66) infections than intervention counterparts.

- In 2008, Sandora et al.\(^{37}\) reported a cluster-randomised, controlled trial at an elementary school in the USA. Intervention classrooms (285 students) received alcohol hand sanitizer and quaternary ammonium wipes to disinfect classroom surfaces daily for 8 weeks; control classrooms followed usual hand-washing and cleaning practices. Absenteeism rates for GI illness were significantly lower in the intervention-group; 24% of students in the control group missed ≥1 day because of GI illness, compared with 16% of students in the intervention group. Absenteeism rates for respiratory illness were not significantly different between groups. After adjusting for race, health status, family size, and current hand-sanitizer use in the home, the absenteeism rate for GI was significantly lower in the intervention group compared with the control group [rate ratio: 0.91 \((P < 0.01)\)]. The adjusted absenteeism rate ratio for respiratory illness was 1.10 \((P < 0.12)\). Of interest is the fact that swabs of environmental surfaces were also taken which showed that norovirus was present on 29% of surfaces evaluated in control classrooms. In the intervention classrooms this was reduced to 9%.

- Bright et al.(2009)\(^{23}\) carried out a 6 week intervention study of the impact of hygiene in 6 (3 intervention, 3 control, 148 students) classrooms in a school in Seattle, USA. For the intervention group, test surfaces were cleaned with a disinfectant wipe each morning before arrival of students. Surfaces were sampled in the afternoon on 4 study days, and mean heterotrophic bacterial counts determined. Teachers collected information on the incidence of GI and RT illnesses (self-reported coughing, sneezing, fever, headache, sinus problems, sore throat, vomiting, abdominal pain, diarrhoea) leading to absenteeism. Although there was a reduction in the bacterial counts in intervention classrooms, the results were not statistically significant. Water fountain toggles, pencil sharpeners, computer keyboards, and faucet handles were the most
bacterially contaminated. Influenza A virus and norovirus was also detected on 24% (13 of 54) and 16.4% (9 of 55) of control classroom surfaces, respectively. During 2 weeks prior to the viral sampling date, from 3 to 6 children had been absent from control classrooms due to illness. Despite no significant reduction in bacterial counts on surfaces, children in control classrooms were 2.32 times more likely to become ill than children in intervention classrooms \((p=0.026, 95\% \text{ CI} \ 1.03–5.28)\). In control classrooms, 26 of 74 children (35.1%) became ill (either GI or RT symptoms) with a total of 57 days absent, whilst 14 of 74 children (18.9%) became ill in the intervention classrooms with 22 days absence.

**Impact of hygiene measures on gastrointestinal diseases**

In the section above, 3 intervention studies (one in the home and two in schools) are reported, which assessed the effect of promotion of environmental cleaning with or without hand hygiene, on rates of GI infections:

- The South Africa household study by Cole et al.\(^{36}\) (Table 5) showed that hand and environmental hygiene education alone or combined with use of hygiene products could produce, respectively, up to 64.6% and 78.6% reduction in the incidence of GI infection.
- The US study of Sandora et al.\(^{37}\) in elementary school settings showed that absenteeism rates for GI illnesses were significantly lower in classrooms where students used alcohol hand sanitzers and surface disinfectants compared with control classrooms that followed usual hand-washing and cleaning practices. Adjusted and unadjusted absenteeism rate ratios were 0.91 and 0.86 respectively for intervention compared with the control groups.
- The US classroom study of Bright et al.\(^{23}\) showed that children in control classrooms were 2.32 times more likely to become ill than children in intervention classrooms \((P=0.026, 95\% \text{ CI} \ 1.03–5.28)\) where surfaces were cleaned with a disinfectant wipe each morning before arrival of students. In control classrooms, 35.1% of children became ill (either GI or RT symptoms) with a total of 57 days absent, whilst 18.9% became ill in the intervention classrooms with 22 days absence. There was no attempt to distinguish the impact on respiratory compared with GI infections.

Three further studies indicate that surface hygiene (in one study this was combined with handwashing promotion) has a significant impact in reducing spread of norovirus infection:

- Following recurrent and consecutive norovirus outbreaks on a cruise ship, the ship was cleaned and disinfected at the end of the fourth cruise.\(^5\) Fewer than 10 cases presented on subsequent cruises compared to195 cases during the fourth cruise. Control measures included cleaning and disinfection of cabins, crew and staff quarters and communal bathrooms and steam cleaning of soft furnishings.
- During a hospital outbreak of norovirus, the attack rate among patients decreased in several wards following implementation of environmental hygiene procedures.\(^4\) Infection control measures included cleaning and hypochlorite disinfection (ward floors, toilet areas, toilet seats, taps and spillages of vomit and faeces) to reduce environmental contamination. Disinfection was applied to places contaminated with vomit or faeces and for general disinfection of ward floors and toilets areas.
- Heijne et al. analysed norovirus outbreaks in 7 camps at an international scouting jamboree in the Netherlands. Implementation of hygiene measures such as washing hands, thoroughly cleaning contaminated surfaces, avoiding contact between sick and healthy persons, and requesting caretakers and cleaning staff to wear gloves and aprons coincided with an 84.8% reduction in the reproduction number.\(^5\)

The potential for transfer of rotavirus infections via surfaces and hands is shown in an intervention study by Ward et al.\(^{1991}\).\(^4\) These workers examined transfer of rotavirus from
contaminated surfaces to the mouth and from surfaces to hands to the mouth. All volunteers who licked rotavirus contaminated plates became infected. Of those individuals who touched the virus-contaminated plates with their fingers and put the fingers to their mouths, about half became infected. It was found that 13 out of 14 adult subjects who consumed rotavirus (10^3 focus forming units) became infected.

The 2006 IFH review\textsuperscript{8} summarises the results of 6 intervention studies indicating the positive impact of environmental cleaning and hygiene on infection risks associated with \textit{C. difficile}. In more recent hospital intervention studies by Hacek \textit{et al.}\textsuperscript{573} and Abderrahmane \textit{et al.}\textsuperscript{574} report reduction in nosocomial rates of \textit{C difficile} infection associated with targeted cleaning of the environment using hypochlorite disinfectant. Salgado \textit{et al.}(2009)\textsuperscript{575} also report control of an outbreak without a change in antibiotic policy as a result of enhanced cleaning with bleach, and soap and water hand hygiene when caring for patients. Although these studies were carried out in hospitals they indicate the potential for transmission in the home where good hygiene practice is not observed.

**Impact on respiratory tract infections**

Gwaltney and Hendley (1982)\textsuperscript{263} examined the impact of surface disinfection on transfer of experimental rhinovirus infection in 4 studies by having recipients handle surfaces previously contaminated by infected donors and then touch their nasal and conjunctival mucosa. Five (50\%) of 10 recipients developed infection after exposure to virus-contaminated coffee cup handles and 9 (56\%) of 18 became infected after exposure to contaminated plastic tiles. Spraying contaminated tiles with disinfectant reduced recovery of virus from the tiles from 42\% (20/47) to 8\% (2/26) and the rate of detection of virus on fingers touching the tiles was reduced from 61\% (28/46) with unsprayed tiles to 21\% (11/53) with sprayed tiles. Fifty-six percent (9/16) of recipients exposed to untreated tiles became infected while 35\% (7/20) touching only sprayed tiles became infected with rhinovirus.

Three more recent intervention studies (one in the home and two in schools), as described above, are reported, which assessed the effect of promotion of environmental cleaning with or without hand hygiene, on rates of RT infections:

- The South Africa study in household settings by Cole \textit{et al.}\textsuperscript{36} (Table 5), showed that hand and environmental hygiene education, alone or combined with use of hygiene products, produced, respectively, up to 26.4\% and 65.5\% reduction in incidence of RT infections.
- The US study of Sandora \textit{et al.}\textsuperscript{37} in elementary school settings showed that absenteeism rates for RT illnesses were not significantly lower in classrooms where students used alcohol hand sanitisers and surface disinfectants compared with control classrooms that followed usual hand-washing and cleaning practices. Adjusted and unadjusted absenteeism rate ratios were 1.10 and 1.07 respectively for intervention compared with the control groups.
- The US classroom study of Bright \textit{et al.}\textsuperscript{23} showed that children in control classrooms were 2.32 times more likely to become ill than children in intervention classrooms \((P = 0.026, 95\% \text{ CI} 1.03–5.28)\) where surfaces were cleaned with a disinfectant wipe each morning before arrival of students. In control classrooms, 35.1\% of children became ill (either GI or RT symptoms) with a total of 57 days absent, whilst 18.9\% became ill in the intervention classrooms with 22 days absence. There was no attempt to distinguish the impact on respiratory compared with GI infections.

In 2009, Jefferson \textit{et al.}\textsuperscript{48} reported a systematic review of 58 epidemiological studies on the impact of physical interventions to interrupt the spread of viral respiratory tract infections. None of the intervention studies assessed the impact of surface hygiene.
Impact on skin infection

In the South Africa study in household settings by Cole et al.\textsuperscript{36} (Table 5), it was found that intensive hygiene education alone (participatory learning focusing on handwashing/bathing with soap, cleaning toilet and food surfaces, and treating skin problems with antiseptic) and in combination with use of hygiene products could produce, respectively, up to 26.4% and 65.5% reduction in the incidence of skin infection.

In studies\textsuperscript{45,46,47} in the homes of healthcare workers (HCWs) colonised with MRSA, the HCW was treated to eradicate the organism, but subsequently became re-colonised. In each case, MRSA was isolated from environmental surfaces (pillows, bed linen, brushes, cosmetics and hand contact surfaces and household dust) in the home. In each case, the problem was finally terminated only after thorough cleaning of the home environment.

A hospital intervention study by Dancer et al.\textsuperscript{41} indicates that enhanced hygiene of near patient hand contact surfaces can reduce transmission of MRSA. In this study, an additional cleaner was introduced into 2 wards, with each ward receiving enhanced cleaning for 6 months. Enhanced cleaning was associated with a 32.5% reduction in microbial contamination rates at handtouch sites. Near-patient sites (lockers, overbed tables and beds) were more frequently contaminated with MRSA/S. aureus than sites further from the patient. Genotyping identified indistinguishable strains from handtouch sites and patients, supporting the possibility that patients acquired MRSA from environmental sources. There was a 26.6% reduction in new MRSA infections on wards receiving extra cleaning, despite higher MRSA patient-days and bed occupancy rates during enhanced cleaning periods. Adjusting for MRSA patient-days and based on 9 new MRSA infections seen during routine cleaning, they expected 13 new infections during enhanced cleaning periods rather than the 4 that actually occurred. Clusters of new MRSA infections were identified 2 to 4 weeks after the cleaner left both wards.

This is one of a number of studies which indicate the impact of environmental cleaning and hygiene on infection risks associated with MRSA.\textsuperscript{576,577,578} Although these studies were carried out in hospitals they indicate the potential for transmission of MRSA in the home in situations where good surface hygiene practice is not observed.

Elias et al.\textsuperscript{96} describe a community-based intervention to manage an outbreak of community-associated MRSA skin infections in a US Midwestern county jail. A systematic investigation conducted by a family medicine residency program identified 64 total cases and 19 MRSA cases between January 1 and December 31, 2007. Even though they could not separate the effect of individual interventions, based on the data, factors identified as contributing to MRSA transmission included inadequate surveillance, lack of antibacterial soap, and a defective laundry process.

Higashyami et al. (2011) investigated dissemination of community-associated MRSA (CA-MRSA) strains among healthy students in a Japanese boarding school, which frequently caused skin infection.\textsuperscript{579} Of 21 patients with skin disease, in whom MRSA strains were isolated, MRSA colonization rates in 3 selected groups ranged from 7.6% to 36.6%. Genetic analysis revealed dissemination of a PVL-positive SCCmec IVc clone (41/47 isolates in total). Risk factors for CA-MRSA infection included skin damage, frequent-contact sports, inadequate hygiene, sharing of equipment or clothing, scratching insect bites, hot and humid weather, and crowded dormitory rooms containing 6-10 students. Among the 50 contact points, one PVL-positive MRSA strain was isolated from a toilet seat. MSSA strains were also isolated from tatami mats in the judo facility, mats from the wrestling club, and a strength-training machine. Based on these risk factors, students were educated about SSTIs and hygiene practices and alcohol-based handrub dispensers were installed. Rates of skin disease and MRSA carriage decreased significantly after infection controls were introduced.
Some of the best evidence that contaminated surfaces are involved in transmission of infection in hospitals, comes from relatively recent findings that admission to a room when the prior room occupant was infected or colonised with a pathogen increases their risk of acquisition. These data are review by Otter et al. 2011 and include studies involving MRSA, C. difficile and P aeruginosa.

6. USE OF QUANTITATIVE MICROBIAL RISK ASSESSMENT (QMRA) TO EVALUATE THE HEALTH IMPACT OF HYGIENE

Although intervention studies yield quantitative data on health impact, the reliability of estimates is difficult to confirm. On the other hand, data from in vivo and in vitro tests can be used to quantify the impact of hygiene procedures on transmission of infectious agents, but give no assessment of how contamination reduction on hands correlates with health impact. In an attempt to overcome this problem, Haas et al. have applied techniques of Quantitative Microbial Risk Assessment (QMRA) to estimate the relative health benefits resulting from the use of hygiene procedures with different efficacies. This involves using microbiological data from the published literature, related to each stage of the infection transmission cycle to calculate infection risk. The investigators used this approach to compare the impact of different hand hygiene procedures in preventing transference of E. coli and E. coli O157:H7 from hand-to-mouth following hand contact with ground beef during food preparation. Data on the density of pathogens in ground beef, transference from beef to hands, removal by handwashing or alcohol hand sanitiser (AHS), rate of transfer from hand-to-mouth and infectivity of ingested pathogens were obtained from the literature, and, after screening for data quality, used to develop probability distributions. With some plausible assumptions, it was assessed that, assuming that there are 100 million individuals in the United States each of whom handles ground beef once per month, this results in 1.2 x 10^9 contacts per year. Assuming that 10% of these individuals contact hand-to-mouth after handling ground beef, this amounts to 1.2 x 10^8 incidents per year. For E. coli O157:H7, it was assessed (Table 6) that if no handwashing is done this would result in 0.7 infections per year. By contrast, if all individuals washed their hands with soap following contact with ground beef, producing a 0.3 log reduction on hands, this would result in an estimated 0.014 infections per year, equating to a 98% median risk reduction compared with no handwashing. If all individuals used a hand hygiene process, following contact with ground beef, producing a 4.3 log reduction on hands (i.e. they used an AHS), this would then result in an estimated 0.00005 infections per year, equating to a 99.9996% median risk reduction for use of the AHS compared with handwashing.

<table>
<thead>
<tr>
<th></th>
<th>No handwashing</th>
<th>Handwashing</th>
<th>Use of alcohol hand rub</th>
</tr>
</thead>
<tbody>
<tr>
<td>Log reduction on hands</td>
<td></td>
<td>0.7</td>
<td>4.3</td>
</tr>
<tr>
<td>Mean</td>
<td>1.39 x 10^{-2}</td>
<td>1.25 x 10^{-2}</td>
<td>1.15 x 10^{-2}</td>
</tr>
<tr>
<td>Median</td>
<td>5.98 x 10^{-9}</td>
<td>1.18 x 10^{-10}</td>
<td>3.71 x 10^{-13}</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>7.79 x 10^{-2}</td>
<td>7.52 x 10^{-2}</td>
<td>7.26 x 10^{-2}</td>
</tr>
</tbody>
</table>

This follows on from an earlier study by Haas et al. to calculate ID risks associated with hand-to-mouth transfer after diaper changing of a baby infected with Shigella. Based on this model, it was calculated that the probability of acquiring infection was between 24/100 and 91/100 for those who used handwashing with soap after changing diapers. This was based on panel test data indicating that the mean log reduction of S. marcescens on hands due to
handwashing is 2.56. The authors calculated that, by using a hand hygiene formulation which increased the log reduction in release of bacteria from hands to 2.91, the infection risk would be reduced to between 15/100 and 90/100.

In another study, Gibson et al.\textsuperscript{115} applied QMRA to estimate the relative infection risks associated with fabrics laundered with detergent alone or with detergent plus bleach. The study modelled transference of \textit{Shigella} from hand-to-mouth following hand contact with laundered clothing. Rose and Haas\textsuperscript{583} have also applied QMRA as a means to assess the potential impact of antibacterial soap use on skin infection with \textit{S. aureus}.

Risk modelling is a promising approach, but has limitations because of the multifactorial nature of infection transmission and paucity of data to specify model parameters. What the data does illustrate however is how a quantifiable increase in the log reduction, for example, an increase from a 2.5 to a 3.5 log reduction on hands can translate into a significant decrease in the risk of infection transmission within a national population. More information and data on QMRA can be found on the Quantitative Microbial Risk Assessment Wiki site (QMRAwiki) at: http://wiki.camra.msu.edu/index.php?title=Table_of_Recommended_Best-Fit_Parameters. QMRAwiki is the QMRA community’s portal for current quantitative information and knowledge developed for the Quantitative Microbial Risk Assessment (QMRA) field. It is an evolving repository for QMRA knowledge and data available to the risk analysis community.

To study the potential effectiveness of a targeted disinfection program for food preparation in household kitchens, Duff et al.\textsuperscript{584} developed a computer-based model in which published literature and expert opinion for US, Canada and UK was used to estimate the cost of the program, the number of cases of \textit{Salmonella}, \textit{Campylobacter}, and \textit{E. coli} O157 infections prevented. The model estimated that approximately 80,000 infections could be prevented annually in US homes, resulting in $138 million in direct medical cost savings, 15,845 quality-adjusted life-years (QALYs) gained, as against $788 million in programme costs. Results were similar for households in Canada and the UK. Evaluating the program for households with high-risk members showed a more favourable cost-effectiveness.
REFERENCES


36 Cole E, Hawkley M. Health impact of a comprehensive family hygiene promotion in peri-urban Cape Town, South Africa in children under five. 13th Annual International Congress on Infectious Diseases, 2009 (also being prepared for publication).


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57 Dancer SJ. Control of transmission of infection in hospitals requires more than clean hands. Infect Control Hosp Epidemiol. 2010 Sep;31(9):958-60.


68 Waterkeyn J. Hygiene behaviour change through the Community Health Club approach. Lambert, Saarbrücken, Germany, 2010.


Starr J. Hospital acquired infection. Control measures for Clostridium difficile need to extend into the community. BMJ. 2007 Apr 7;334(7596):708.


European Food Safety Authority (2011) Scientific Opinion on an update on the present knowledge on the occurrence and control of foodborne viruses. EFSA Journal 2011;9(7):2190


Reiling, J. (2000). Dissemination of bacteria from the mouth during speaking, coughing and otherwise. JAMA 284,156.


Tackling MRSA in animals and humans. (2005).*Veterinary Record* **157**, 671-672.


Pan, Angelo; Battisti, Antonio; Zoncada, Alessia; Bernieri, Francesco; Boldini, Massimo; Franco, Ale. (2009). Community-acquired methicillin-resistant *Staphylococcus aureus* ST398 infection, Italy. *Emerging Infectious Diseases* **15**, 845-846.


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