The infection risks associated with clothing and household linens in home and everyday life settings, and the role of laundry

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Other data, more recently published, on the infection risks associated with clothing and household linens 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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1. INTRODUCTION

The evidence presented in the 2009 IFH review on the global burden of hygiene-related diseases[1] shows that infection outbreaks in the home and everyday life settings, particularly gastrointestinal (GI) infections, respiratory infections (RT), and skin, wound and eye infections, continue to exact a heavy toll on the health and prosperity of the global community. As discussed in more detail in this review, 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. norovirus infections) remain at unacceptably high levels, much of this food-borne infection occurring in private homes.
- Evidence now suggests that respiratory hygiene plays a significant part in limiting the spread of respiratory infections such as colds and influenza.
- New pathogens (including antimicrobial resistant strains such as the community-acquired Panton Valentine Leukocidin-producing strains of methicillin resistant *Staphylococcus aureus* (MRSA PVL CA-MRSA)) 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.

At the same time:

- Social and demographic trends mean that people with reduced immunity to infection make up an increasing proportion of the population (currently up to 20%). The largest proportions are the elderly. It also includes the very young and patients discharged from hospital, taking immunosuppressive 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 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 are demanding 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 food borne 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 healthcare costs.
- Technological and policy changes are being introduced to reduce costs and/or environmental effects without regard to the potential impact on disease risks.

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 burden of infectious diseases. Increased homecare is one approach to reducing health spending, but healthcare agencies increasingly recognise that gains are likely to be undermined by inadequate infection control at home.
Recently, there has been renewed interest in the role of clothing and household linens in

spread of infectious disease, particularly in relation to their potential role in transmission of Methicillin Resistant *Staphylococcus aureus* (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. In most of the households of the lower middle class and poorer sections of the community, particularly in developing countries, washing machines are not generally used. There is evidence to show that transfer of pathogens can occur between contaminated and clean laundry during the washing cycle. Previously, it was common to dry laundry outdoors, where an added microbiocidal effect was achieved from sunlight. Clothes and linens were also ironed damp so that steam penetrating the fabric caused reductions of microbial load. The practice of ironing has largely disappeared in many households with the use of wrinkle-resistant fabrics. On the positive side however, clothes dryer have added a margin of safety because, depending on the temperature and the length of the drying time, they reduce the numbers of viable microorganisms on fabrics being dried. Another gap in our knowledge is the effect of changing fabric compositions on retention, survival and release of microbes, both during normal daily activities and/or during the laundering process.

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. Risk management is 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 hospital settings.[2] 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 disease agents can spread further.

The object of this paper is to review the infection risks associated with clothing and household linens such as towels, bed linen and so on. This includes data on how, and to what extent, these items become contaminated with pathogenic organisms and how they survive and are spread. This is reviewed together with data on the extent to which we are exposed to these agents in our daily lives. The paper also reviews epidemiological data and data from quantitative risk modeling techniques assessing the link between laundry hygiene and infectious disease risk. The extent of the risks associated with clothing etc is also assessed in relation to risks associated with other surfaces such as the hands, hand and food contact surfaces and so on.

This report is based on the database of published literature accumulated by IFH since 1997, together with data identified from google scholar and PubMed database searches using combinations of search terms including infection, hygiene, cleaning, cross contamination together with laundry, clothing, bedlinens, pillows, together with viruses, fungi, bacteria, Tinea and Candida. Publications were also searched for references to other relevant published data. Evidence assessing the effectiveness of hygiene procedures such as laundry in breaking the chain of infection is reviewed in a separate IFH report.[3]

2. DEVELOPING A RISK-BASED APPROACH TO HOME HYGIENE

As stated above, the aim of targeted hygiene is to maximise protection against infectious diseases by breaking the chain of infection transmission. As specified by Aiello and Larson[4], 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. Indications are that the hands are probably the single most important infection transmission route because, in all cases they come into direct contact with the known portal of entry for pathogens (the mouth, nose and conjunctiva of the eyes), and are thus the key last line of defense. 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 a wound), 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). The likely routes of transmission via clothing and household linens are shown in Figure 1.

The criteria (and methodology) for assessing the association between hygiene practices and infectious disease risk reduction have been reviewed by Aiello, Larson and co-workers.[4,5,6] Applying standard approaches, they set out a range of criteria for inferring a causal link (and the relative importance of individual "component causes") between hygiene practice and infectious disease reduction.[4] They postulate that, establishing the health impact of an intervention such as hand or laundry hygiene, requires examination of data related to a range of criteria which should include the strength, consistency, specificity and temporality (cause and effect) of the association, together with data on plausibility (microbiological or behavioral rationale). Other factors which should be taken into account 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), 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).

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 epidemiological data from intervention or other studies to quantify the impact on infectious disease burdens. Although a range of intervention studies have been carried out assessing the impact of hand hygiene and household water treatment on disease rates, by contrast relatively few studies have been carried out to assess the impact of other hygiene procedures such as surface hygiene, cleaning cloth hygiene or laundry hygiene. Even for hand hygiene, where intervention or case control studies have been performed, they have mostly involved schools or day-care centres rather than the home and everyday life settings.

Assessing the impact of hygiene practices, such as laundry hygiene, either in combination with or separate from hand hygiene or surface hygiene, is difficult because of multiplicity and close interdependence of the various routes of infection transmission, and the extreme difficulties in controlling variables. It also stems from the very large population sizes required to produce a significant result which tends to make the cost of such studies prohibitive. Transmission of infectious diseases involves many different pathogens each with multiple interdependent routes of spread, making it difficult to determine the separate effects of different interventions. 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 habits of the people who make up 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 laundry hygiene.

By contrast with intervention and observational studies, there is now a large body of microbiological data showing the extent to which infectious disease agents enter the home, how they survive and are spread around the home environment, the extent to which we are exposed to these agents in our daily lives, and what is known about their infectivity (infectious doses). Although these 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 the resulting contamination reduction translates into a reduction in disease burden. Risk modeling techniques now offer the possibility to perform such assessments but this approach is also open to challenge.

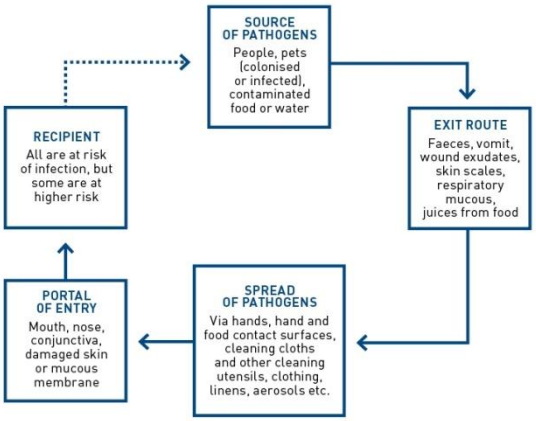
Currently, there is a tendency to demand that data from intervention studies should take precedence over data from other sources in formulating public health policy. Although there are those who still adhere to this, it is increasingly accepted that, since transmission of pathogens is so complex, infection control policies and guidelines must be based on the totality of the evidence including microbiological as well as epidemiological data. This is particularly important for home hygiene, for which little or no intervention data is present, which separately assesses the effects of specific hygiene procedures (hand washing, surface hygiene, laundry, washing and bathing etc). The "total" microbiological and epidemiological data used by IFH in the development of the targeted approach to home hygiene (apart from the data on clothing and household linens which is presented here) is reviewed in detail in the 2011 IFH report "The chain of Infection transmission in the home and everyday life settings and the role of hygiene in reducing the risk of infection"[7] In 2010/11, IFH set out to update the 2002 IFH report which reviews the "total" data on the causal link between hygiene (including hygiene related to clothing and household linens) and infectious diseases rates in home and everyday life settings. Because of the significant amount of data related to fabric hygiene, and the current concerns about infection risks associated with fabrics, it was decided to present this data in this separate report.

2.1 THE IFH TARGETED APPROACH TO HOME HYGIENE

As described in more detail in the 2011 IFH report on the chain of infection transmission, the IFH risk approach to hygiene starts from the principle that pathogens are introduced continually into the home, by people (who may have infection or may be asymptomatic carriers), food and domestic animals, but also sometimes in water, via insects, or via the air. 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 a primary reservoir of infection; although species are mostly those which represent a risk to vulnerable groups, primary pathogens can also be present.

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. To an extent, we can limit the exit and entry of pathogens from and into the body, but the link that we have most control over is that related to the "spread of pathogens".

Figure 2 – The chain of infection transmission in home.



To carry out a risk assessment, sites and surfaces in the home have been categorized into 6 groups: reservoir sites, reservoir/disseminators, hands, hand and food contact surfaces, clothing and household linens, and other surfaces. Risk assessment is then based on 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 site is highly contaminated, unless there is a probability of transfer from that site, the risk of infection transmission is low. From this, it is possible to determine the "critical control points" for preventing spread of infection.

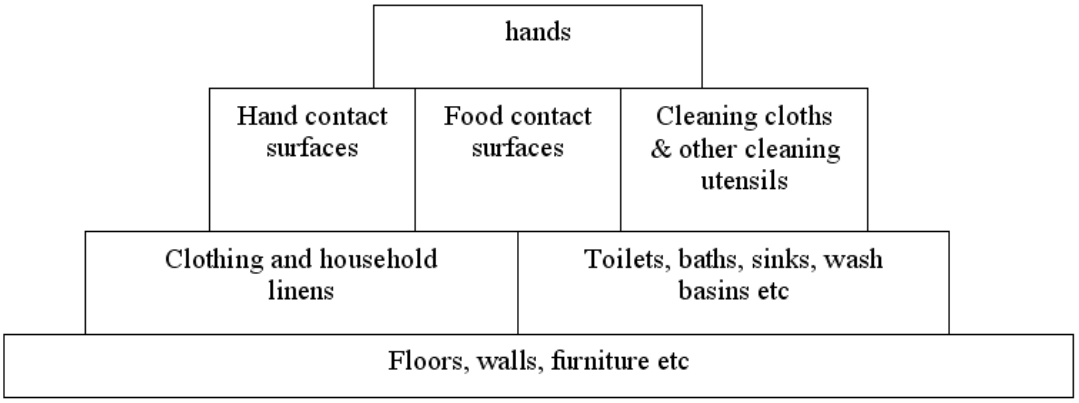
Overall the data suggest that:

- For reservoir sites such as the sink waste pipes or toilets, although the probability of significant contamination (i.e. with potentially pathogenic bacteria 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 settle on contact surfaces around the toilet).
- For reservoir sites such as wet cleaning cloths, not only is there 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, e.g. particularly following contact with contaminated food, people, pets or other contaminated surfaces such as door-, 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, again, although the probability of significant contamination is less, it is still significant, particularly following contact with an infected source (people, raw contaminated food or domestic animals). Since there is a risk of spread from these surfaces, it is important that, for items that particularly come into direct contact with body surfaces, laundering 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*, and fungi that survive dry conditions. Because the risks of transfer and exposure are relatively low, these surfaces are considered low risk, but where there is a 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.

Overall, this approach allows us to rank sites and surfaces (Figure 3) according to the level of potential infection transmission risk.

Figure 3 – Ranking of sites and surfaces in the home based on risk of transmission of infections



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, in other cases transmission involves a combination of control points including hand and food contact surfaces, cleaning cloths and other cleaning utensils. 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. Although this is a useful rule of thumb ranking, it is not a constant. For example, although risks from toilets, sinks, floors etc, relate mainly to the relatively lower risk of transfer from these sites to hands, hand and food contact surfaces and cloths, risks can increase substantially where an infected family member has fluid diarrhea, or where floor surfaces are contaminated with vomit or faeces. Similarly, risks of transmission via clothing and household linens increases where one family member has a skin or wound infection.

3. TRANSMISSION OF INFECTION VIA CLOTHING, HOUSEHOLD LINENS AND LAUNDRY

Clothing and household linens (sheets, pillows and towels etc) have the potential to act as vehicles for spread of infection in home and everyday life settings. The potential routes of spread are shown in Figure 1. This can occur where family members, or others, share bed linen or share towels (not only in the home but elsewhere e.g. in sports changing rooms). Clothes have the potential, just as any other hand contact site, to be a component in the chain of infection transmission during normal daily activities. There are also 2 additional points where clothing etc can spread infection. The first is where contaminated items are handled before and during laundering. Secondly, if the laundry process fails to eliminate contamination, this can then be spread to other items in the laundry load. If laundry is left damp, this encourages microbial survival and there is the chance for growth of residual micro-organisms, such that clothes can then become a source of microbes.

Infectious agents that have the potential for spread via clothing etc include enteric bacteria such as *Salmonella, Shigella, Campylobacter, E. coli* (including *E. coli* O157) and *C. difficile* and respiratory and enteric viral strains such as norovirus, rotavirus, adenovirus and astrovirus. It also includes respiratory (cold and flu) viruses such as rhinovirus, influenza virus, respiratory syncytial virus etc. The risks from skin pathogens are mainly associated with *S. aureus* (including MRSA), yeasts (such as *Candida albicans*) together with dermatophyte fungal strains such as Tinea pedis (athlete's foot) and Tinea corporis (ringworm) and viral strains such as herpes.

The available data assessing infection risks associated with each stage of the infection transmission cycle involving clothing and household linens is outlined below.

3.1 SOURCES OF CONTAMINATION ON CLOTHING AND HOUSEHOLD LINENS

Within the home, the primary sources of contamination on clothing are from the wearers own body flora, from handling of contaminated food and from contact with other people or household pets. Whereas organisms shed via skin scales or via faeces will mainly contaminate underclothing in contact with the skin, contamination from e.g. nasal secretions or from contaminated food or from nursing care of infected family members is more likely on outer clothing.

The potential for spread of pathogens to clothing etc from infected sources (people, contaminated food, domestic animals) in relatively high numbers is shown by data as reviewed in the 2011 IFH report.[7] Data presented in this report show that an infected person can shed large number of enteric pathogens in their faeces (up to 10^{10}-10^{11} per gram). Gibson *et al.* estimate that, of the 100 to 500 g of faeces excreted per day by the average American, approximately 0.1 g of residual faecal material remains on the undergarment of any person.[8] Up to 10^{7} infectious influenza particles per ml may be found in nasal secretions. People who carry *S. aureus* can shed the organism in large numbers during normal daily activities, most usually associated with skin scales. It is estimated that around 10^{6} skin squames containing viable organisms are shed daily from normal skin.[9] Investigation in hospitals, as reviewed by Tammerlin (2000)[10], show that clothing act as a barrier to dispersal, from which it must be concluded that these organisms are retained on the inner surfaces of underclothing. It is possible that transmission of contamination onto clothing and household linens from contaminated sources occurs not by direct contact, but via the hands, but apart from 2 studies using laboratory models[11,12] which indicate the potential for this to occur, no useful studies of the risk of transfer via hands to clothing were identified.

3.2 OCCURRENCE OF PATHOGENS ON CLOTHING AND HOUSEHOLD LINENS

The potential for infection transmission via clothing and household linens is shown by a range of field studies carried out to assess microbial contamination on clothing during daily wear and household linens during use. The majority of these studies have been carried out in hospital settings in situations where there are patients known to be infected with organisms such as *S. aureus* (including MRSA), *C. difficile*, etc. These studies show that in this situation, the causative pathogens are quite frequently isolated from clothing (either that of the patient or of the medical staff caring for them) and bed linens. It must be concluded however that the same potential for infection transmission must occur in the home where a family member is carrying and shedding pathogenic organisms. There are also a number of reports where clothing and linen in hospitals, and in the general community, were sampled at

random. These studies show that the most common isolates are species such as *staphylococci*, *micrococci*, *corynebacteria* etc which are part of the normal skin flora. Gram negative pathogens are also reported, but less frequently (probably because they need a moist environment for survival), although a number of studies show that spp. such as *Salmonella, P. aeruginosa* are sometimes found on clothing and household linens, although probably in small numbers.

3.2.1 Contamination of clothing etc in healthcare facilities where there are patients infected with MRSA and C. difficile

In particular, a large number of published studies show that, in hospital settings (but also including one study of a patient discharged from hospital into the home) where there are patients known to be infected or colonized with *S. aureus* (including MRSA), the organisms are frequently isolated from the bed linen and clothing of patients, and the clothing of medical personnel. Although it is assumed that *C. difficile* has the potential for transmission via clothing etc, there are relatively few similar studies to confirm this:

- Colbeck *et al.*[13] studied patients suffering from *S. aureus* infections in a Canadian hospital. *S. aureus* was isolated from sheets of 11/12 infected patients.
- In a 1957 UK hospital study, Frisby *et al.*[14] found that, of 115 blankets sampled, scanty growth of *S. aureus* was obtained from 18 (15.7%) blankets. Of 850 patients, 366 (43%) gave *S. aureus*, 272 (32%) of these being nasal carriers, 193 (23%) rectal carriers, and 99 (12%) both nasal and rectal carriers.
- In a UK hospital study Speers *et al.* (1969)[15] found considerable contamination of nurses' uniforms with *S. aureus*. Nasal carriage by the nurses was rare and most isolates appeared to have come from a minority of patients who were *S. aureus* carriers. Dressing a septic wound resulted in heavy contamination of nurses uniforms.
- Lidwell *et al.* (1974)[16] carried out a study in a single-bed patient-room of a UK hospital. During bed-making, strains of *S. aureus*, carried on the nurses' external clothing were often transferred to the patients' bedclothes and their hands. Dispersal of *S. aureus* from nurses' clothing to patients was also demonstrated by Hambreus (1973).[17]
- Reiss-levy and McAllister reported isolation of MRSA from the pillows of an infected patient in Australia.[18]
- In a 1983 study Babb *et al.*[19] sampled cotton gowns and plastic aprons from nurses in a UK hospital. Patients were admitted to the ward if they were particularly susceptible to infection, e.g. immunosuppressed, or had communicable infections, or if they were potential heavy dispersers of *S. aureus* (e.g. with eczematous lesions), or were carrying with highly resistant strains. It also included those with Group A streptococcal infections and those with diarrhoea and vomiting (e.g. *Salmonella*, *Shigella* infections). *S. aureus* was isolated, usually in small numbers, from cotton gowns (12.6%), plastic aprons (9.2%) and nurses' uniforms (1.5%). Larger numbers of *S. aureus* were isolated after close contact with a heavy disperser. Gram-negative bacilli were infrequently isolated.
- Perry *et al.* (2001)[20] studied 57 staff in a UK hospital. At the time, MRSA-positive patients were present on 7/8 wards. Of the uniforms sampled prior to commencement of duty, bacteria most commonly detected were MRSA and *C. difficile* on 7 uniforms each. Three staff had not worn clean uniforms and it was notable that they were all positive for large numbers of MRSA at the commencement of the shift. At the end of duty, the bacteria most often detected were *C. difficile* (11 uniforms) and MRSA (8 uniforms). The level of contamination recovered from the uniforms using a slit sampler varied from 1 to 100 colonies, but, for MRSA, some counts of >500 cfu (colony forming unit) were obtained.

- The potential for spread from linens was demonstrated by Shiomori *et al.* (2002)[21] who determined numbers of surface and airborne MRSA before, during and after bedmaking for 13 inpatients with MRSA infection or colonisation in a Japanese hospital. Airborne contamination was significantly higher 15 min after bedmaking than during the resting period, although differences in counts after 30 min were not significant. MRSA was also found on surfaces including floors, bed sheets and clothing, and from the patient's hands.
- In 2009 Gaspard *et al.*[22] evaluated MRSA contamination of healthcare workers'' uniforms in three geriatric long term care facilities. MRSA colonisation rates for patients in these units was known to be 15.2% to 18%. Over 500 samples were taken from uniforms and their pockets and these samples showed a high level of MRSA contamination.
- Trillis *et al.* in 2008 found that 42% of privacy curtains in a US hospital 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.[23]
- In 2009, Treakle *et al.*[24] studied staff in a large US teaching hospital to investigate the prevalence of contamination of white coats with pathogens, such as methicillin-sensitive *S. aureus* and MRSA. This facility had a colonization prevalence of 25% *S. aureus* (7% MRSA) among recently admitted non-ICU patients. Coats were sampled on lapels, pockets, and cuffs. Of 149 white coats, 34 (23%) were contaminated with *S. aureus*, of which 6 (18%) were MRSA. About 70% of participants reported that they laundered their own white coats.
- Other hospital studies in which MRSA was isolated from clothing mattresses pillows and bedding in situations where there was a patient infected with MRSA are described by Blythe *et al.* (1998)[25], Rampling *et al.* (2001)[26], Sexton *et al.* (2006).[27]

In addition, Kim *et al.*[28] evaluated *C. difficile* in the home of a patient discharged from hospital. They found that 12.2% of environmental surfaces were positive for *C. difficile*, but although surfaces such as floors and furniture were found to be contaminated, samples from linens and soiled clothing were negative for *C. difficile.*

3.2.2 Contamination of clothing etc in healthcare facilities where there are patients infected with other species

A number of studies in outpatient settings report contamination of clothing associated with patients infected with other bacterial and viral species:

- Environmental contamination with *Burkholderia cepacia*, a potential respiratory pathogen in cystic fibrosis (CF) patients was studied before, during and after physiotherapy in 8 CF patients.[29] Thirty-nine (40%) of 97 air samples were positive for *B. cepacia* and counts ranged from 1-63 cfu/m^3. *B. cepacia* was not recovered from sinks or horizontal surfaces but the pillows of three patients were positive.
- In a UK cystic fibrosis centre Panagea *et al.*[30] evaluated samples from staff, patients and the environment (drains, bath tubs, showers, dry surfaces, respiratory equipment and air) in the inpatient ward and outpatient clinic for presence of *P. aeruginosa*, an organism that colonizes most CF patients. *P. aeruginosa* was isolated from patients' hands, clothes and bed linen, but was short-lived.
- Bergeron *et al.*[31] sampled genital human papillomavirus-related lesions occurring in 74 patients and their underwear. Human papillomavirus DNA was found in 54 of 74 (72%) lesions and 13 of 74 (17%) swabs from the underwear. Recurrence rates in patients with

and without positive underwear swabs were 61% and 29% ($p<0.05$), respectively.

- Tanaka *et al.*[32] (2006) report a study in Japan of a patient with Tinea pedis caused by *Trichophyton mentagrophytes*. Samples were taken using rodac contact plates (65mm diameter) from the inner and outer surfaces of socks and stockings immediately after removal following 8 hours wear, and 24h after removal. Of 8 samples taken 25% of outer surfaces and 100% of inner surfaces were found to be contaminated. Mean colony counts per contact area were: immediately after wear, outer side = 0.4, inner side = 190; after 24 hours, outer side = 0.3, inner side = 289. Two other studies also review reports of isolation of dermatophytes from shoes, socks and shower stalls,[33,34] whilst a third study reports isolation of dermatophytes from bath mats.[35]

3.2.3 Contamination of clothing etc in healthcare facilities with no identified source of infection

A number of other studies have been carried out in healthcare facilities, to examine clothing etc sampled at random (i.e. in the absence of an identified source of infection). Although the frequency of isolation was less, nevertheless, pathogenic bacteria, viruses and fungi were sometimes isolated, indicating the ability of these organisms to survive on essentially dry surfaces of clothing etc. The studies show that the most frequently isolated spp. are those resistant to desiccation such as *S. aureus*, but Gram-negative species were also sometimes found. In particular, the data show the relatively high frequency of isolation of *S. aureus* (including MRSA) in hospitals, even where there is no identified infected source:

- Howe *et al.* (1961)[36] evaluated *S. aureus* contamination of blankets in a US hospital ward over a 3 month period where, initially, there were no identified cases of infection. *S. aureus* was isolated from 46% of 234 blankets sampled. Isolation rates increased from 2% to 34% during the 3 month period. Contamination levels were about 10 colonies per contact plate. During the study, *S. aureus* infections developed on 3 patients, but no isolates of *S. aureus* were obtained from their blankets and there was no evidence that the infections were related to contaminated blankets.
- Blaser *et al.* (1984)[37] examined soiled sheets and terry items taken from a laundry in a US hospital. The total bacterial bioburden was of the order of 10^6-10^8 cfu/100 sq cm, but most of these were non-pathogenic species. Of 345, species isolated the frequency of isolation of pathogenic species was: *E.coli* 52, *P. aeruginosa* 36, and *S. aureus* 5. Fungal organisms were present in concentrations of about 1.2 log less than bacteria. Of 16 fungal isolates which were identified, 10 were *Candida albicans.*
- Smith *et al.* (1987)[38] reported a study of soiled hospital linen (terry towelling and sheets). Total counts of around 10^7-10^8 per 100 sq cm were recovered. Gram positive isolates include *S. aureus* (2 isolates) and *Enterococcus* (6 isolates). Gram negative spp. which were isolated included *E. coli* (11 isolates), and *Klebsiella*, *Serratia*, *Enterobacter* and *Proteus* spp. (139 isolates). *P. aeruginosa* was also isolated (6 isolates).
- Wong *et al.* (1991)[39] sampled the white coats of 100 randomly selected doctors in a UK hospital. A total of 42 isolates of *S. aureus* were found on the coats of 29 individuals and were more likely to be isolated from the cuff and pocket than the back. Gram negative bacilli were frequently seen but were environmental strains which are rarely associated with disease. *S. aureus* was isolated from the noses of 12/25 (48%) individuals whose white coats yielded *S. aureus*. Of 32 strains of *S. aureus* isolated from 25 individuals, 11 strains had the same phage type as those found in the subject's nose (35%).
- Loh *et al.* (2000)[40] carried out a random survey of 100 medical students at a London Medical School. All students wore cotton and polyester white coats and all were bacteriologically contaminated to varying degrees. Most isolates were normal skin commensals such as *Staphylococcus* spp. (from all the students), *Acinetobacter* spp. (7 students), and diphtheroids (12 students). Of 5 *S. aureus* isolates, none were MRSA. Gram-negative organisms were rarely seen (3 students) and those identified were environmental strains rarely associated with significant infections, e.g. *Alcaligenes* spp.
- Pilonetto *et al*. (2004)[41] analysed samples from the cuffs and abdominal region of hospital gowns. Pathogens were isolated from 48% (15/31) of the gowns. Of the isolated pathogens, 61% (11/18) were *S. aureus,* none of which were MRSA. No *E. coli* or *Pseudomonas* spp. was detected. The authors suggest that the lower number of Gram negative organisms was due in part to their poor ability to attach to fabrics. They found a significant (p=0.027) increase in total bacteria from the beginning to the end of a work shift, with average counts increasing from 2.2 to 4.9 cfu/cm^2.

- Bureau-Chalot *et al.* (2004)[42] examined the microbiological quality of linen and linen rooms in short-term care units in France. MRSA was isolated from 3/160 sample from environmental surfaces, but none of the 46 samples from linens (sheets and pyjamas) were positive for MRSA.
- Malnick *et al.* (2008)[43] sampled pyjamas and bed sheets (10 sq cm) before and after overnight usage by 18 patients in an Israel hospital. The area swabbed corresponded to the surfaces in contact with the patient's back. Isolates included *Enterococcus faecalis* (9 patients), coagulase-negative *staphylococci* (18 patients), *S. aureus* (7 patients, 5 isolates were MRSA), *Proteus mirabilis* (1 patients), *Bacillus* spp. (16 patients), *Corynebacterium* spp. (1 patient), *E. coli* (2 patients), and *P. aeruginosa* (1 patient).
- Analysis of swabs taken from the cuffs and pocket mouths of physicians' white coats in an acute care hospital in Nigeria showed that 91.3% of the coats had bacterial contamination[44] which included diphtheroids, *S. aureus* and Gram-negative bacilli. Lower contamination rates were found on coats <1 year old and coats laundered daily.

3.2.4 Contamination of clothing and household linens in home and community settings

Investigations carried out in home and everyday life settings are as follows:

- In their study of 200 UK homes, Scott and Bloomfield (1982)[45] evaluated contamination from bathroom towels. The frequency of isolation for various organisms was *S. aureus* 3.6%, *E. coli* 2.6% and *P. aeruginosa*: 0.5%. The proportion of towels which showed total counts of >100 cfu per rodac contact plate was 27%.
- In homes where there is an MRSA carrier, MRSA was isolated from laundered items (personal communication from Martin Exner, May 2001).
- In their study of 86 Japanese households Ojima *et al.* (2002)[46] evaluated contamination from kitchen hand and counter towels, and bathroom and toilet handtowels. The frequency of isolation was, for coliforms 0-8% (60% for counter towels), *E. coli* 0-2.5%, *P. aeruginosa*: 0% (6.2% for counter towels) and *S. aureus*: 2.6-7.4%. Counts were mostly between 1 and 9 cfu/10 sq cm, but counts of 10-1000 were sometimes recorded.
- Home-laundering in Japan is unique among many countries as leftover bath water is used for laundering the next day. Tabata *et al.*[47] carried out an investigation of various articles. *Staphylococcus* spp. were isolated from every sample of children's underwear, bath towels and kitchen rags (mean levels 10^3–10^4/sq cm), and also from the washing machine and leftover bath water. Coliform bacteria (mean levels 10^2-10^4/sq cm) were found in 21/27 samples and *E. coli* ($1.5x10^1$ in underwear up to 10^5 in dishrags) was found in 3/27 samples. *Staphylococcus* spp. and coliforms were isolated from washing machines and bathwater, and *E. coli* was also isolated from bathwater. *Shigella* and *Salmonella* were not found in any samples.
- In studies carried out in North and South Metropolitan areas of the US, Robinton *et al.*[48] examined the contamination of cotton towels in places used by the public. These were public washroom facilities in gasoline stations, restaurants, airports, bus and railroad stations, and similar establishments. Towels were sampled by pressing them onto rodac agar plates (sq cm). It was found that 70% of samples were contaminated with 1 or more cfu, 15% had >100 cfu per rodac contact plate and 7% of the samples had more than 300 cfu per plate. Samples yielded *S. epidermidis* (23% of samples), *Corynebacteria* (19%) and *Micrococci* (13%). *S. aureus* was isolated on two samples from cloth towels. No coliforms or other Gram negative spp. was found.

3.2.5 Contamination of clothing and household linens with Candida albicans

Although Ossowoski *et al.*[49] report that "in patients with vulvovaginal candidiasis, garments may be contaminated with fungi leading to reinfection" we were not able to identify reports to confirm this. The potential for contamination of clothing and re-infection with *Candida* is shown in a study by Andrioli *et al*. In this study, a total of 286 samples of vaginal fluid of women with and without clinical suspicion attending health units in Brazil were collected (121 cases, 165 controls). A total of 47.9% of the women were confirmed of candidiasis by the laboratory tests. Among control patients, 78.2% were vulvovaginal candidiasis negative. *Candida albicans* was the prevalent strain in 74.5% of the cases.[50]

3.3 LABORATORY STUDIES ON SURVIVAL OF PATHOGENS ON CLOTHING AND HOUSEHOLD LINENS

The potential for survival and spread of pathogens transferred from a human, animal, food or other source onto clothing or household linens is shown by various laboratory studies. These studies show that survival varies considerably between different microbial strains and depends on factors such as temperature and relative humidity and type of fabric. Most particularly it depends upon the inoculum size, increasing with increasing inoculum.

These studies show that Gram positive spp. such as *S. aureus* and fungal spp. can survive long periods (several days to months) on fabrics. Although, Gram negative spp. such as *Serratia marcescens* and *P. aeruginosa* are less resistant than Gram positives to drying, survival is still sufficient to allow transfer to hands and other surfaces. Relatively less data is available for fungi and viruses, but these similarly suggest the potential for transfer via fabrics. In studies, where survival on fabrics was compared with survival on non-porous surfaces, they suggest that survival times are generally less on porous surfaces.

3.3.1 Survival of bacterial strains on clothing and household linens

- Spicer (1959) found that *Shigella sonnei* could remain viable on cotton threads for 7-10 days at cool temperatures.[51]
- Wilkoff *et al.* (1969)[52] reported that a *S. aureus* isolate lived 1 week on cotton and 2 weeks on terry cloth. In these studies, wool (blanket and gabardine), cotton (sheeting), terry cloth and knit jersey were exposed to *S. aureus* (approx 10^7–10^8 per 6.54 sq cm swatch) by direct contact, and exposure to aerosol and virus containing dust.[53,54] Fabrics were stored at 25°C at 35 and 78% RH (relative humidity). Persistence time on fabrics at 35% RH was substantially longer when fabrics were contaminated by exposure to aerosolized cultures or to dust than when contaminated by direct contact. At 78% RH, populations persisted for shorter periods of time. Cotton wash-and-wear fabric was the material on which *S. aureus* persisted for the shortest time. The organism retained its virulence for mice after recovery from wool gabardine swatches, held 4 and 6 weeks in 35% and 78% RH.
- Using the same method, Wilkoff *et al.* (1969)[55] evaluated survival of *Salmonella typhimurium* on fabrics. Persistence time of *S. typhimurium* on fabrics held in 35% RH was substantially longer when the fabrics were contaminated by direct contact or exposure to contaminated dust than when exposed to aerosolized cultures. Populations persisted for 24 weeks at relatively high population densities on wool gabardine, cotton sheeting, cotton knit jersey and cotton terry cloth exposed by direct contact and stored at 35% RH. In 78% RH, bacteria persisted on the fabrics for shorter time periods regardless of mode of contamination or fabric type. The organism retained its virulence for mice after recovery from wool gabardine held 8 weeks in 35 or 78% RH, and from

cotton terry cloth held 6 weeks in the same humidities.

- Ghione *et al.* (1989)[56] showed that the adherence of *Bacillus megaterium* spores to cotton terry cloth and plain cotton is higher than to cotton-polyester fabrics, and that adherence is enhanced by the presence of organic and inorganic encrustation deposited when fabrics are washed without adequate detergents.
- Scott and Bloomfield (1990)[66] studied survival of bacteria on cleaning cloth fabric (dry woven J cloths) inoculated with relatively low numbers (around 120 cfu/sq cm) and stored at RT at 60% RH for 48 h. Laboratory strains (Is) of *E. coli, Klebsiella aerogenes, P. aeruginosa*; *Salmonella abony* and *S. aureus, together* with wild type (wt) environmental strains of *E. coli, Salmonella* spp. and *S. aureus* were investigated. Numbers of organisms on clean cloths declined over the drying period but, with the exception of *K. pneumoniae* (wt) and *S. aureus* (wt), recovery at 4 h was greater than 20 cfu/25 sq cm. At 24 h, recovery levels were generally <20 cfu/25 sq cm, but for *K. aerogenes* (Is) and *P. aeruginosa* (Is), there was regrowth of residual survivors. Soiled cloths showed higher survival rates, with only *S. aureus* (Is and wt), *Salmonella* spp. (Is and wt) and *E. coli* (Is) reduced to less than 20 cfu/25 sq cm at 4 h. For the other species, although there was a reduction at 4 h, regrowth of residual survivors occurred within 24 h.
- Neeley and Maley (2000)[57] determined the survival of 22 Gram-positive bacteria on 100% cotton (clothing), 100% cotton terry (towels), 60% cotton/40% polyester blend (scrub suits and lab coats), 100% polyester (privacy drapes). Swatches were inoculated with 10^4-10^5 cfu. All isolates survived for at least 1 day, and some survived for more than 90 days on the various materials. Smaller inocula (10^2) survived for shorter times, but still generally for days. Test strains were *Enterococcus faecalis, Enterococcus faecium, Enterococcus casseliflavus*, *Enterococcus gallinarum,* coagulase-negative *staphylococci* and *S. aureus* (methicillin sensitive and methicillin resistant).
- Neeley (2000)[58] also determined survival of 7 Gram-negative species on 100% cotton (clothing), 100% cotton terry (towels), 60% cotton/40% polyester blend (scrub suits and lab coats) and 100% polyester (privacy drapes). At 10^2 cfu/swatch, bacteria survived from less than 1 h or less (*P. aeruginosa*, *E. coli*) to 2-6 days (*K. pneumonia*, *Enterobacter* spp.). At 10^4 and 10^5 inoculum size, survival ranged from than 2-4 hours (*P. aeruginosa*, *P. mirabilis*) to 10-50 days (*K. pneumonia*, *Enterobacter* spp.).
- Huang *et al.* (2006)[59] found that 2 hospital isolates of MRSA inoculated onto polyester cloth curtain fabric (inoculum size not stated) survived for up to 9 days.
- Van der Reijden *et al* (2009)[60] studied survival of *S. aureus, Serratia marcescens* and *P. aeruginosa* on swatches from unused dental polycotton coats (65% polyester, 35% cotton) which were soaked in 1 ml of suspension containing $3.7x10^5$ - $3.64x10^6$ cfu/ml of the test strain. Immediately after inoculation of *S. aureus* only $5.92x10^2$ cfu (0.16%) survived. The number of viable cells decreased further to $1.70x10^2$ (0.046%) after 1 h and $5.2x10^1$ (0.014%) after 24 h. For *S. marcescens* and *P. aeruginosa* rate of decrease in viability was more rapid with no recovery after 8 and 3 h respectively.

3.3.2 Survival of viral strains on clothing and household linens

- Sidwell and co-workers (1966)[53,54] exposed wool (blanket and gabardine), cotton (sheeting, terry cloth and knit jersey) to vaccinia and poliovirus (to represent enveloped and non enveloped viruses) (approx. 10^5–10^9 per 5 cm swatch) by direct contact, aerosol and virus containing dust. Fabrics were stored at 25°C at 35 and 78% RH. Persistence varied considerably depending on the type of fabric, humidity and method of exposure. Although there was generally a 5 or more log reduction within the first 24

hours, the virus persisted for relatively long periods (up to 14 weeks) on wool and cotton fabrics, particularly if stored at low humidity, but only 1 day or less on a “wash and wear” fabric. Similar results were obtained with poliovirus, with high concentrations of the virus remaining over 5 months on wool blanket material, but only 3-5 days on cotton fabrics. On the wash and wear fabric, persistence was only 1 day.

- Hall et al. (1980)61 investigated survival of respiratory syncytial virus (RSV) through contact with environmental surfaces contaminated by RSV-infected nasal secretions. RSV in freshly obtained infant secretions was recovered from countertops for up to 6 h, from cloth gowns and paper tissue for 30-45 min, and from skin for up to 20 min.
- Turner *et al.* (1982)[62] examined 9 adults with virus-positive herpes labialis, herpesvirus. The virus was detected in the anterior oral pool of 7 (78%) and on the hands of 6 (67%). Herpesviruses isolated from patients with oral lesions were found to survive for as long as 3 h on cloth as well as 2 h on skin, and 4 h on plastic.
- Bean *et al.*[63] studied the survival of influenza virus on cloth (Cotton pyjamas and handkerchief) paper and tissues as well as plastic and stainless steel surfaces inoculated with about 10^5 $TCID_{50}$ of influenza A and influenza B virus. Although viability declined rapidly, viruses survived for 8-12 h on fabrics and tissues, but up to 24-48 h on hard surfaces.
- Brady *et al.* (1990)[64] examined survival of parainfluenza virus (PIV) on nonabsorptive (stainless steel, laminated plastic, skin) and absorptive (hospital gown and laboratory coat) surfaces, at room temperature. The inoculum size was approx. 10^3 per 2 sq cm sample. Persistence on stainless steel was greater than on fabrics, but all 3 PIV strains survived for up to 4 h.

3.3.3 Survival of fungal strains on clothing and household linens

- Neely and Orloff (2001)[65] examined survival of *Candida* spp., *Aspergillus* spp., a *Fusarium* spp., a *Mucor* spp., and a *Paecilomyces* spp. on hospital fabrics (100% smooth cotton (clothing), 100% cotton terry (towels, washcloths), 60% cotton–40% polyester blends (scrub suits, lab coats, clothes), 100% polyester (privacy curtains). Survival was variable, depending on fungal species and type of material, with most fungi surviving at least 1 day but many living for weeks. In general, *Aspergillus* and *Mucor* survived longer (median=26.0 days) than *Candida*, *Fusarium*, and *Paecilomyces* (median = 5.0 days). There was also a tendency for the fungi to be viable longer on 100% synthetic materials (polyester) than on fabrics with natural fibre content (cotton, terry, and blends).

3.4 LABORATORY STUDIES ON SPREAD OF PATHOGENS VIA CLOTHING AND HOUSEHOLD LINENS

Various laboratory studies have been carried out which demonstrate significant transfer of bacteria, viruses and fungi to hands or other surfaces (including clean fabrics) as a result of contact with contaminated fabrics. By contrast only 2 studies[11,12] could be identified which assessed the extent of transfer of pathogens from contaminated hands (in this case wet hands) to fabrics. The studies suggest that the extent of transfer varies considerably depending on a range of factors. The study of Mackintosh and Hoffman[12] suggests that transfer rates from contaminated clothing to hands may be higher for Gram negative than Gram positive species. **In particular, all studies clearly indicate that the number of organisms transmitted is significantly higher if donor’s fabric or hands are wet.**

3.4.1 Investigations on transfer of bacterial species from clothing etc

Investigations on transfer of bacterial species are as follows:

- Marples and Towers (1979)[11] studied transfer from fabrics artificially contaminated with *Staphylococcus saprophyticus* (approx. 5x10^3 cfu/sq cm) to clean recipient fabrics via hands (estimated hand contact area 60 cm^2, contact time not stated). When donor fabrics were moist, 10% of cells passed onto the hands, but this fell to 0.05% when the inoculum dried. Transfer from wet hands to the recipient fabric was 85%, but in the complete model (fabric to hands to fabric) only 0.06% of cells were transferred.
- Using the same model, Mackintosh and Hoffman (1984)[12] evaluated transfer of *S. saprophyticus, P. aeruginosa, S. pyogenes, E. coli, K. aerogenes* and *Serratia* spp. *S. saprophyticus* transferred from moist contaminated fabrics (10^5- 10^6 cfu/sq cm, 10s contact time) to hands at the highest rate (1.67% of the count/cm^2 on donor fabrics). Gram-negative spp. transferred to the hand at lower rates (0.3-0.5 %). *S. pyogenes* transferred poorly (0.021%). Transfer from moist hands to recipient fabrics, occurred at a much higher efficiency than for moist fabrics to hands, presumably as a result of the superficial location of the acquired contamination; *S. saprophyticus* transferred less readily from wet hands to fabrics (17%) than the Gram-negative organisms (76-86%). Complete transfer, from fabric to hands to fabric, were rated as between 0.01% for *S. pyogenes* to 0.37% for *S. saprophyticus.*
- Scott and Bloomfield (1990)[66] studied transfer from fabrics (dry woven J cloths) to finger tips. Cloths were inoculated with around 10^3 cfu/25 sq cm and stored at RT at 60% RH. Transfer of organisms (wild type strains of *E. coli* and *S. aureus,* and a laboratory strain of *Klebsiella aerogenes)* to fingertips (30s contact) to cloths was determined at time 0 and 1, 4 and 24**.** Table 1 shows that, at 0, 1 and 4 h transference was of the order of 50-100 cfu for *S. aureus and K. aerogenes,* but only 3-8 cfu for *E. coli.* Increases in numbers on cloths over 4-48 h due to regrowth of residual survivors was accompanied by increased transfer.

Table 1 – Transfer of fingers from a soiled cloth to the fingers or work surface

	Number of colony-forming units recovered per 25 cm² contact plate											
	Fingertip						Laminate surface					
	Escherichia coli•		*Klebsiella aerogenes*†		*Staphylococcus aureus*•		*Escherichia coli*•		*Klebsiella aerogenes*†		*Staphylococcus aureus*•	
Total inoculum per 25 cm² cloth	976		714		2976		976		714		2976	
Recovery times (h)												
0	5	8	48	92	101	113	31	37	41	43	35	31
1	5	7	60	34	77	153	22	31	34	39	28	27
4	4	3	41	24	91	57	20	22	22	24	8	8
24	T	T	T	T	T	T	T	T	T	T	T	T
48	T	T	T	T	T	T	T	T	T	T	T	T

† Laboratory strains; • wild type strains; T, too numerous to count.

- Sattar *et al.* (2001)[67] examined transfer of *S. aureus* from contaminated fabrics to hands and contaminated fabrics to fabrics. Test pieces of the fabrics {100% cotton and 50% cotton/50% polyester (poly cotton)}, 1 cm in diameter were seeded with about 10^5 cfu of *S. aureus* contained in 5% foetal bovine serum as soil load. Transfer from fabric to fabric

and from fabrics to fingerpads (with or without friction) was performed by 10s contact. Table 2 shows that about 0.4% and 1.0% of the inoculum were transferred from moist donor cotton and polycotton samples to dry fingerpads. Bacterial transfer from dry and remoistened donor fabrics was always lower than from moist fabrics. Friction increased transfer from fabrics to fingerpads by as much as fivefold. Bacterial transfer from poly cotton was consistently higher than that from all-cotton material. Transfer from moist donor fabrics to dry fabric was 0.02% and 0.12% for polycotton and cotton, respectively, but the numbers of bacteria transferred from dry donor to dry recipient fabrics was "barely detectable". Sattar *et al.* suggested that the ease with which bacteria were released from polycotton compared with cotton may be due to the higher hydrophobic nature which reduced the ability of the bacterial cells to penetrate into the fibres.

Table 2 - Transfer of *S. aureus* from contaminated fabrics to fingerpads and sterile fabrics (Sattar *et al.* 2001)

Recipient	% cfu* transferred from inoculated donor fabrics to**					
	Cotton which was:			Polycotton which was:		
	Moistened	Dry	Remoistened	Moistened	Dry	Remoistened
Dry fingerpads	0.4% (0.15%)	Ud (0.01%)	0.05% (0.02%)	1.0% (0.2%)	Ud Ud	0.1% (0.05%)
Moist fingerpads	0.4% (0.25%)	0.1% (0.05%)	0.2% (0.1%)	2.7% (1.8%)	0.1% (0.15%)	0.3% (0.2%)
Dry fabric	0.02%	Ud	-	0.12%	0.02%	-
Moist fabric	0.02%	0.02%	-	0.08%	0.09%	-

*approximated from bar chart data **data for transfer with friction in parentheses; ud = undetectable contamination

- In further studies published in 2002 Gerba and co-workers[68] examined transfer to hands after touching or handling moist surfaces inoculated with a pooled culture of a Gram-positive bacterium (*Micrococcus luteus*), a Gram negative bacterium (*Serratia rubidea*) and bacteriophage PRD-1. Activities included wringing out a dishcloth, turning on/off a kitchen faucet (tap), holding a phone receiver, and removing laundry from the washing machine. Transfer efficiencies as shown in Table 3, were 27% to 65% for the non porous surfaces (phone receiver and tap) whilst transfer efficiencies from porous surfaces (cloths and laundry) were <0.01%. In most cases, *M. luteus* was transferred most efficiently, followed by phage PRD-1 and *S. rubidea*. These workers also measured transfer from fingertips to the lips. When the volunteers' fingertips were inoculated with 10^6 of the pooled organisms and held to the lip area, transfer rates were 33-41%.

Table 3 – Transfer from contaminated surfaces to hands (Rusin et al 2002)[68]

Organism/surface	Mean log10 cfu or pfu		
	Level in/on surface	Level recovered from ventral surface of hand	Transfer efficiency (%)
Micrococcus luteus			
Dishcloth	10.44	6.90	0.04
Faucet (tap)	6.13	5.59	40.03
Phone receiver	6.60	6.19	41.81
Laundry (100% cotton)	9.73	6.17	0.13
Laundry 50:50 cotton/polyester	9.39	5.99	0.06
PRD-1			
Dishcloth	9.85	5.95	0.03
Faucet (tap)	5.83	4.70	33.47
Phone receiver	4.92	4.68	65.80
Laundry (100% cotton)	8.73	3.63	0.005
Laundry 50:50 cotton/polyester	8.34	2.71	0.0005
Serratia rubidea			
Dishcloth	10.34	5.42	0.0045
Faucet (tap)	6.08	5.22	27.59
Phone receiver	6.31	5.75	38.47
Laundry (100% cotton)	9.79	4.40	0.003
Laundry 50:50 cotton/polyester	9.01	3.64	0.0009

- Butler *et al.* (2010)[69] prepared suspensions of clinical isolates of MRSA, vancomycin-resistant *Enterococcus faecium* (VRE), and *Acinetobacter baumannii* at a 0.5 McFarland turbidity standard, and serially diluted to a concentration of 1:100 000. Swatches of clean, 100% cotton, laboratory coat were inoculated with 0.2ml of suspension. Sanitised pig-skin samples were then rubbed across the inoculated swatches. Results showed that MRSA and VRE and PRA could be transferred from cloth to pig skin 1, 5 and 30 min after inoculation at concentrations of 0.5 McFarland and at a 1:100 dilution. *Acinetobacter* could also be transferred at a dilution of 1:1000. The limitation of the study is that the clinically relevant inoculum size for transmission was not determined.

3.4.2 Investigations on transfer of viral species from clothing etc

Investigations on transfer of viral species are as follows:

- Sidwell *et al.* (1966)[70] exposed wool (blanket and gabardine), cotton (sheeting), terry cloth and knit jersey to vaccinia and poliovirus by direct contact, aerosol and virus containing dust. Fabrics were stored for 16 h at 25°C at 35 and 78% RH, at which time virus titres were about 10-10^4 for poliovirus and 10^3-10^6 for vaccinia virus (defined as per ml of recovery liquid). They were then randomly tumbled with sterile swatches of the same fabric for 30 mins. High virus titres were recovered from the sterile fabrics as little as 1-10 mins after contact. Maximum transfer of both viruses was achieved with wool blanket material. Poliovirus (but not vaccinia virus) placed on fabric by aerosol transfer was transferred at a greater rate than when it was placed on the fabrics by direct contact. Transfer rates were higher for poliovirus (10% but up to 50% in some cases) whilst transfer rates for vaccinia virus were around 1-10%.
- Hall et al. (1980)[61] investigated spread of respiratory syncytial virus (RSV) through contact with environmental surfaces contaminated by RSV-infected nasal secretions. RSV in freshly obtained infant secretions was recovered from countertops for up to 6 h, from cloth gowns and paper tissue for 30-45 min, and from skin for up to 20 min. It was found that infectious virus could be transferred in significant numbers (the data was not expressed in a manner to allow assessment of numbers) to hands following contact with gowns and paper tissues contaminated with fresh nasal secretions. The numbers of viral units transferred from these surfaces to hands declined rapidly as the viability of virus on the cloth and tissues declined, but virus could be detected on hands, following contact with cloth for up to 5 mins for cloth and with paper tissues for up to 10 min.
- Bean *et al.*[63] studied the survival and transfer of influenza virus from tissues inoculated with about 10^5 $TCID_{50}$ of influenza A and influenza B virus. Although viability declined rapidly, viruses survived for 8-12 h on tissues. Measurable quantities of virus were transferred from tissues to hands at 15 mins (10 $TCID_{50}$/0.1ml), transfer at 2 and 8h was not detectable.
- Studies by Gerba and co-workers[68] on the transfer of bacteriophage PRD-1 from cloths and other surfaces to hands are described in Table 3 above

3.4.3 Investigations on transfer of fungal species from clothing etc

Investigations on transfer of fungal species are as follows:

- Hammer *et al.* (2010)[71] studied transfer of dermatophytes fungi, (tinea pedis, onychomycosis (nail infections) and *Trichophyton rubrum*) via clothing. About 10% of the infectious material was transferred from contaminated textiles to sterile textiles during storage in a clothes basket indicating a high infection risk during storage.

The spread of fungal infections such as ringworm and athletes foot via clothing is generally well accepted. CDC, in their fact sheet on ringworm state “Spread usually occurs through direct contact with an infected person or animal. Clothing, bedding and towels can also become contaminated and spread the infection”.[72] Despite this, little data could be identified on the spread of fungal infections via clothing and linens.

3.5 TRANSMISSION OF GONORRHOEA IN CHILDREN

Neisseria gonorrhoeae is a Gram negative bacterium which infects mucous membranes, e.g. inside the mouth, conjunctivae of the eyes (gonococcal conjunctivitis), the urethra, the vagina and cervix (gonococcal vulvovaginitis) and the anal canal. There are many other species of Neisseria (*N. lactimica*, *N. cinera*, *and N. meningitides*) and non-gonococcal *Neisseria* species are part of the normal flora in the mouths and throats of adults and children.

When *Neisseria gonorrhoea* was first identified in the 1880s, it was believed to be strictly a sexually transmitted disease. However, throughout the world it became recognised that once the infection was introduced into a children’s hospital or other institution, it rapidly spreads among pre-pubertal girls, suggesting that non-sexual transmission can also occur. In a 2007 review, Goodyear-Smith et al[73] evaluated over 40 epidemics involving about 2000 children in Europe and the US and concluded that gonococcal infection can be transmitted to young children by infected mothers or other caregivers with contaminated hands, and to older children through communal baths, contaminated bedding, sharing of infected towels or underclothes, or non-sexual contact with infected family members or friends (child-to-child transmission), which most likely occurs under conditions of over-crowding and poor hygiene.

Evidence of non-sexual transmission through person-to person contact or via surfaces such as hands, towels, bedding and clothing, comes from epidemics of conjunctivitis and accidental inoculations. Evidence from the conjunctival epidemics is important because it demonstrates that infection can be transmitted in a manner that is not mucous membrane to mucous membrane. Goodyear *et al*. also reviewed evidence from *in vitro* studies on survival of gonorrhoea on fomites. These show that, although sensitive to heat and drying, if suspensions or infected pus are kept damp, gonorrhoea may remain viable in pus on cloth for several days:

- Cohn *et al.* recovered gonococci from pus on linen kept moist with sterile saline after 5 h and in one case after 22 h, although could not be recovered by culture after 2 h if the cloth was kept dry.[74]
- Elmros *et al.* showed that gonococcal pus placed on glass slides and on towel kept at room temperature survived for up to 24 h on the towel and 17 h on the slide.[75]
- Alausa *et al.* carried out a series of *in vitro* experiments culturing *gonococcus* from contaminated pieces of cloth which showed that, under warm and humid conditions, the cloth would remain damp and the organism could be recovered after 2–3 h.[76]
- Benson and Steer.[77] describes a series of experiments evaluating various items contaminated either artificially or by letting infected children play with them. *Gonococcus* was isolated from wet linen after 24 h, dry linen after 1/2 h, rubber, water and wood after 2 h and metal after 10 min. No isolates were obtained in soapy water at 10 min, which suggests that washing with soap is likely to prevent spread of the infection.
- Srivastava[78] placed drops of gonococcal pus on a range of materials including hard substances (glass, plastic, cellophane, wood, cardboard and paper) and soft substances

(cotton swab, cotton gauze, linen handkerchief, cotton towel, tissue paper and lubricated condom). *Gonococci* were recovered from most of the materials after 24-48 h, and from a few materials (cotton swab, white cardboard and wooden spatula) up to 72 h or more.

Goodyear-Smith also reviewed a number of cases of gonococcal infection where the investigators concluded that infection in young children was probably transmitted by infected mothers or other caregivers with contaminated hands, and other cases where infection in older children through contaminated bedding, sharing of infected towels or underclothes.[73]

3.6 TRANSFER OF CONTAMINATION DURING LAUNDERING

Laundry processes bring about a reduction in the microbial load on clothing and household linens. The effectiveness of various laundry processes is discussed in the 2008 IFH review of the effectiveness of hygiene procedures.[3] The data indicate that, where the laundering process is insufficient to eliminate pathogenic contamination, transmission of pathogens to other items in the load can occur. These risks have been assessed in a number of studies:

- In 1966, a cross-contamination risk by household laundry was demonstrated following an investigation of an outbreak of *S. aureus* skin infections among families in Boston (Kundsin 1966)[79]. A significantly higher prevalence of infection was found in families who used a community laundry compared with families who used their own washing machine. Community washing machines were found to be operating at a temperature of 50-65°C, which was considered inadequate for disinfection of laundry.
- In a 2009 study (reported in detail in the IFH 2010 report,[80] Exner and co-workers studied the hygiene effectiveness of machine laundry processes on cotton samples artificially contaminated with *S. aureus*. Although premium detergent (with bleach) cycles at 40°, 60° and 80°C produced an 8 log reduction in contamination, cycles at 30°C with liquid and gel detergents (without bleach and without prewash) produced only a 1-2 log reduction, and there was also cross contamination between contaminated and sterile laundry samples that were included in the cycle.
- Gerba and co-workers carried out studies to determine to what extent bacteria (*S.aureus, E. coli, S. typhimurium, Mycobacterium fortuitum*)[81] and viruses (rotavirus, hepatitis A and adenovirus)[82] inoculated onto cotton cloth swatches survived a detergent wash cycle at 20-23°C, and the extent to which contamination was transferred to sterile swatches included in the cycle along with 1.2 kg of sterile “ballast” material consisting of cotton T-shirts and underwear. Viruses were inoculated such that initial levels recovered from the swatch were of the order of 5-6.5 logs per 58 sq cm. Laundering produced a 1 log reduction for adenovirus and a 2 log reduction for rotavirus and HAV, but for all 3 strains 2.7 to 3.4 log numbers could also recovered from the sterile swatches after laundering. Bacteria strains were inoculated such that initial levels recovered from the swatch were of the order of 8.0-8.7 logs per 58 sq cm. Laundering produced a 2-3 log reduction, but for all 3 strains, 4-5.75 log numbers could also recovered from the sterile swatches after laundering. The authors reported that, during the course of the work, *Salmonella* was isolated from the laundered undergarments of a child.

Insights into the ability of microbes present in washing machine water, to attach to fabrics during laundering comes from studies by Hsieh et al and O’Toole et al:

- Hsieh et al 1986[83] studied adherent behaviour of the Gram-positive *S. aureus* and *Staphylococcus epidermidis* and the Gram-negative *E. coli* on cotton, polyester and their blends through contact in aqueous suspensions containing 105-108 cfu/ml followed by rinsing. *S. epidermidis* was found to adhere to fabrics much more than *S. aureus.*

Adherence of both *S. epidermidis* and *S. aureus* to fabrics increased as the content of polyester fibres in the fabrics increased. Attachment of *E. coli* to all fabrics was low and was not affected by fibre content. Total numbers of adherent bacteria on cotton and polyester fabrics were related to the concentrations of the bacterial suspensions. The extents of adherence, however, were independent of the bacterial concentration in the suspension. In general adherence increased with contact time

- O'Toole et al[84] investigated transfer efficiency of enteric strains (bacteriophages MS-2 and PRD-1, *E. coli*, and *Cryptosporidium parvum* oocysts) from washing machine water during a wash cycle, to hands and fabric swatches (100% cotton towelling, polycotton knit and 100% cotton knit). Numbers of organisms seeded into the tub before the laundry cycle ranged from 10^4 (for *E. coli,)* to 10^8 cfu or pfu. Transfer efficiency from seeded water to fabric swatches ranged from 0.001% to 0.090%. Transfer rates were greatest for cotton towelling. Transfer rates from washing machine water to poly-cotton knit and to cotton knit fabrics were similar but less than for cotton towelling. Transfer efficiency for all fabrics was highest for *E. coli* or *C. parvum* followed by MS-2 and then PRD-1, the lowest. Transfer from contaminated fabric swatches (contamination levels 10 to 10^4 cfu or pfu /100sq cm) to the surface area (15 cm^2) of hands (fingertips) was also studied. The transfer rate for bacteriophage MS-2 from contaminated fabric to hands was 0.19% but neither *E. coli* nor bacteriophage PRD-1 could not be detected on hands following handling of contaminated swatches.

Data on the efficacy of laundering processes comes mainly from studies of machine laundry cycles. In most households of the lower middle class and poorer sections of the community in developing countries, washing machines are not generally used. In many cases, clothing and linens are washed and cleaned with detergents using water of dubious microbial quality. Even in urban houses of higher economic status, housemaids are assigned the task of washing household garments manually using detergents and water. Commercial laundries also often assign the task of bulk washing and cleaning to washermen who wash them in grossly polluted pond water.

Washing processes and habits differ considerably even in countries where machine laundering is the norm and may affect the efficacy of the process in eliminating pathogenic contamination. In Japan, water from the family bathtub, following use by the whole family, is piped into the washing machine, where it sits overnight before the machine is operated the next day. In the USA, washing machines commonly take their water from the household hot water tank rather than heating the water using a built-in heating element in the machine itself. As a result, it is difficult to achieve the highest temperatures reached in European washing machines.

4. INFECTION OUTBREAKS VIA CONTAMINATED CLOTHING AND HOUSEHOLD LINENS

A number of studies are reported in which transfer via clothing and household linens was identified as the possible cause of an infection outbreak. These include outbreaks associated with both bacterial and also viral (GI and RT viruses) strains.

4.1 INFECTION OUTBREAKS ASSOCIATED WITH BACTERIAL STRAINS

Outbreaks associated with bacterial strains are as follows:

- Payne (1959)85 described an epidemic affecting 128 patients, of staphylococcal cystitis on a gynaecological hospital ward. The source of the infection was traced to blankets

and dust. Blankets and dust were sampled and S. aureus of the epidemic type was isolated from 2/4 blankets, 4/5 samples of ward dust, and from dust in the sterilizing room. Laundering of the blankets and adequate dust control on the ward contributed to successful control of the outbreak.

- After a hospital outbreak of *S. typhimurium*, organisms were isolated from ward dust and from sputum of patients (Datta and Pridie 1960).[86] Several laundry workers and domestic staff became infected when their only contact was with contaminated bed linen.
- Gonzaga *et al.* (1964)[87] reported experiments in which, under well-controlled conditions, newborn infants were exposed to blankets, shirts, and diapers contaminated by known *S. aureus* carriers. Colonization of the newborns occurred, but only if the fomites were heavily contaminated. Storage of the contaminated articles had no effect on the transmission rate, but laundering effectively broke the transmission chain.
- In a 1966 investigation of an outbreak of *S. aureus* skin infections among families in Boston,[79] a significantly higher prevalence of infection was found in families who used a community laundry compared with families who used their own washing machine.
- In a hospital *S. typhimurium* outbreak in the USA, secondary spread was reported in staff whose contact with infected patients involved handling only sheets and specimen bottles (Steere *et al.* 1975).[88]
- Barrie *et al.* (1992) reported 2 hospital patients who developed *Bacillus cereus* meningitis following neurosurgery. During the subsequent investigation into the source of the infection, linen was found to be heavily contaminated with *B. cereus*, but no other prolific source of the organism was found.[89]
- Standaert *et al.* (1994)[90] examined transmission of infection to laundry staff during an outbreak of salmonellosis in a 250-bed nursing home in a rural Tennessee county. Stool cultures from 32 residents and 8 employees were positive for *Salmonella hadar*. Infection among the residents was food-borne, but infection among employees likely represented secondary transmission, as none of the employees ate food prepared in the kitchen and their onset of symptoms occurred 7 to 10 days after that of ill residents. Three laundry personnel who had no contact with residents were infected. Most ill residents (81%) were incontinent, which led to an increase in the degree of faecal soiling and the amount of soiled linen received by the laundry. Laundry personnel regularly ate in the laundry room and consistently did not wear protective clothing and gloves while handling soiled laundry.
- Brunton (1995)[91] describe a persistent outbreak of streptococcal infection associated with a maternity unit in a UK hospital, which reappeared in the winter for 3 consecutive months. Investigations showed the babies were being infected shortly after birth. Environmental sampling failed to yield any positive results, but it was found that the vests given to newborn infants were laundered at the local hospital laundry rather than under the normal laundry contract. Sampling showed extensive contamination of the hot air dryers with the *Streptococcus pyogenes* strain involved in the outbreak. Following this, all babies' vests were autoclaved and the outbreak ceased.
- Weernink *et al.* (1995)[92] investigated increased numbers of isolations of *Acinetobacter* in a community hospital in The Netherlands. A total of 47 *Acinetobacter* isolates were identified during 1989 compared with an average of 15 isolates per year during 1984-1988 and most cases seemed to be associated with severe infection. The organisms were spread throughout the hospital but a common source was suspected. Investigations provided evidence for feather pillows being the source of the outbreak. Feather pillows were found to harbour high numbers of *Acinetobacter*. In addition a number of isolates from patients and from pillows were indistinguishable using biotyping,

antibiogram typing and cell envelope protein typing. Replacement with synthetic pillows and correction of the laundry procedure resulted in a significant reduction of *Acinetobacter* isolations.

- In 2005, Nguyen et al.93 investigated an outbreak of community-associated MRSA skin and soft tissue infection in a college football team. Eleven case-players were identified. Among 99 (93% of team) players with cultured specimens, 8 (8%) had positive MRSA nasal cultures. A case-control study found that sharing bars of soap and having pre-existing cuts or abrasions were associated with infection. A carrier-control study found that having a locker near a teammate with an SSTI, sharing towels, and living on campus were associated with nasal carriage. Successful outbreak control measures included daily hexachlorophene showers and hygiene education.
- In 2005, 5 bloodstream infections occurred in 5 patients in a Japanese hospital related to catheter use. *B. cereus* contamination was observed with reused (dried and steamed) towels (>10^6 cfu/towel) and washing machines in hospital linen rooms.[94] A proportion of the *B. cereus* strains were the same, or similar, to strains from patients. All the strains of *B. cereus* were distinct from typical food-poisoning strains. The authors concluded that specific *B. cereus* strains are circulating within a hospital, and that towels are an important source of contamination, especially in summer.
- In 2006, Turabelidze et al[95] reported a case:control study, involving 55 cases of MRSA in a US prison examining risk factors for 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, 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, a composite “hygiene score” was created which was the sum of scores of 3 hygiene practices, including frequency of hand washing per day, frequency of showering per week, and sharing personal items with other inmates. A significantly higher proportion of cases than controls had lower hygiene scores ($\leq$6) (46.7% vs 20.0%).
- In 2010 Elias *et al* reported an intervention to manage an outbreak of MRSA skin infections in a US county jail.[96] The investigation identified 64 total cases and 19 MRSA cases between January and December, 2007. The intervention involved installation of antibacterial soap dispensers previously not present in dormitories, and twice-daily showering. Sharing of personal hygiene items such as razors, deodorants, soaps, or towels was discouraged. Showers were cleaned twice weekly rather than weekly with antiseptic solution and, after meals, tables were cleaned with bleach instead of soap and water. Inmates and correctional staff received regular personal hygiene education and inmates with skin infections were consistently cohorted. The laundry process was also corrected. It was found that the thermostat of the laundry machines was defective, resulting in inadequately low temperatures. In addition, machines were overloaded and insufficient laundry soap was being used due to dispenser malfunction. The intervention effectively reduced the number of cases of CA-MRSA, with the last MRSA being isolated in October 2007. The author stated “Even though we cannot separate the effect of individual interventions based on our data, it should be noted that the laundry was the first area where changes were implemented. This resulted in a prompt decline of skin infections even before other measures could be implemented (data not shown). This suggests that the laundry process may have been a major factor in the breakdown of infection control in the facility. In contrast, we found no problems with wound care practices, a shortcoming previously associated with MRSA transmission among

inmates". The authors also made a further interesting observation. They stated "The results suggest that several closely related but differing strains were circulating during the outbreak suggesting that MRSA strains endemic in the community were being introduced into the facility at different times during the outbreak, and the breakdown of infection-control measures facilitated the transmission among inmates leading to multiclonal expansion of CA-MRSA. This suggests that the key event is not so much the introduction of MRSA into a facility, which would be difficult to prevent in an endemic situation. Rather, the focus needs to be on surveillance and prevention of transmission, limiting expansion of circulating strains".

4.2 INFECTION OUTBREAKS ASSOCIATED WITH VIRAL STRAINS

Infection outbreaks associated with viral strains are as follows:

- St. Sauver *et al.* (1998)[97] studied hygienic practices and the prevalence of respiratory illness in children attending daycare homes. Never or rarely washing hands by both children and carers was associated with a higher frequency of respiratory illness in both family and group daycare homes. Using shared cloth towels rather than individual paper towels and washing of sleeping mats less than once a week was also associated with a higher frequency of upper respiratory infection.
- High levels of morbidity caused by adenovirus among US military recruits have returned since the loss of adenovirus vaccines in 1999, but the transmission dynamics of adenovirus have never been well understood. In this study by Russell *et al.*[98] enrollment and end-of-study samples were obtained and active surveillance for febrile respiratory illnesses (FRIs) was performed for 341 recruits and support personnel. Environmental samples were collected simultaneously. Seventy-nine percent (213/271) of new recruits were seronegative for adenovirus serotype. FRI caused was observed in 25% (67/271) of enrolled recruits. The percentage of recruits seropositive for adenovirus increased from 34% at enrollment to 97% by the end of the study. Adenovirus was most commonly detected in the environment on pillows, lockers, and rifles.
- Martinson *et al.* (1998)[99] report a study conducted in rural Ghana to measure hepatitis B virus (HBV) seroprevalence in a probability sample of 1385 people of all ages, and evaluate risk factors for the horizontal transmission of HBV in a subsample of 547 children aged 1-16 years who were not hepatitis B surface antigen (HBsAg) carriers. Most residents in the sample area live in compounds which typically contain 2-4 households each. The overall prevalence of HBV seropositives was 74.7% and the prevalence of HBsAg was 20.9%. These data suggest a continuous nonuniform acquisition of HBV infection with advancing age mainly through horizontal transmission in childhood, with the household, rather than the domestic compound, being the main place for transmission. Sharing of bath towels, sharing of chewing gum or partially eaten candies, sharing of dental cleaning materials, and biting of fingernails together with scratching the backs of carriers were identified as behaviours most strongly associated with HBV prevalence.
- Kim *et al.* (1993)[100] collected data on 137 household contacts of 51 chronic carriers of HBsAg and 111 household contacts of 38 controls who were negative for serologic markers of hepatitis B virus (HBV) from March 1990 to August 1991. Using this data, possible routes of intrafamilial transmission of hepatitis B virus among household contacts of chronic carriers of hepatitis B surface antigen (HBsAg) were evaluated and analyzed. The HBsAg prevalence among the household contacts of carriers was 14.1% compared to 0.0% (95% CI 0.0-7.0) among those of controls. The offspring of carriers showed significantly higher risk of HBV infection (relative risk; 6.6). Sharing of towels and handkerchiefs, and drinking vessels was associated with an increased risk of HBV infection via intrafamilial transmission in Korea (relative risk 11.5 for towel and handkerchief, 12.1 for drinking vessels).

4.3 INFECTION OUTBREAKS ASSOCIATED WITH FUNGAL STRAINS

Outbreaks associated with fungal strains are as follows:

- In a nosocomial outbreak reported by Shah et al, 13 staff and 11 patients in an acute and chronic health care facility were infected with the zoophilic dermatophyte, *Microsporum canis*. The dermatophyte was apparently introduced into the facility by a

single infected patient; the authors concluded that a likely mode of disease transmission was handling of contaminated laundry.[101] Evidence of the fungus was found in stored linen.

Overall, the study which is perhaps the most relevant, is the observational study published in 2001, in which Larson and Duarte[102] examined the relationship between home hygiene practices and prevalence of infection amongst household members in 398 households in New York. Infections investigated were non-specific and 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. Hygiene practices studied were mostly non-targeted 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. However, 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.

Although this report is intended to evaluate microbial infection risk associated with clothing, the importance of these items in the chain of infection transmission is also indicated by an investigation of an outbreak of scabies in a Brazilian hospital which was traced to inadequate laundering of bed linen from an infected patient.[103]

5. USE OF QUANTITATIVE MICROBIAL RISK ASSESSMENT (QMRA) TO EVALUATE THE IMPACT OF LAUNDERING IN PREVENTING INFECTION TRANSMISSION

Gibson *et al.*[8] have 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 *Shigella* from hand-to-mouth following hand contact with laundered clothing. To perform the risk assessment, data on the density of pathogens on clothing, the reduction produced by laundering, transference from laundered clothing to hand-to-mouth, and infectivity of ingested pathogens were obtained from the literature, and, after screening for data quality, used to develop probability distributions.

Based on an estimate that a person with symptomatic *Shigella* infection sheds from 10^5 to 10^9 cfu per gram of faeces (for asymptomatic infection, the average number is typically between 10^2 and 10^6 cfu/g), and taking the worst case situation (a person shedding 10^9 cfu per gram of faeces) Gibson et al calculated that:

- Of 100 to 500 grams of faeces excreted per day approximately 0.1 g of faecal material remains on the undergarment (equivalent to 10^4 cfu per laundry item)
- Based on a laundry load of 3178g and a 54.5g piece of underwear (surface area of 1503 cm^3), once in the laundry, the bacteria are diluted and spread throughout all the clothing. Given normal laundering, producing 88.9% reduction, the number of cfu/sq cm clothing after laundering would be up to 1.2×10^2
- Based on previous studies by Gibson and co-workers which estimate an average of 50% transfer from fabric to hands by handling of washed laundry, the contamination level on the hands can be calculated as up to 6.3×10^1 cfu
- Assuming 10% transfer from hand to mouth by touching the hands to the lips, the probability of infection based on a dose response model is 3.1×10^{-5}

From this, estimates of the risk of acquiring shigellosis through contact with clothing after

laundering were calculated as high as 10 per million population to much lower levels associated with lower excretion rates of the bacteria in the faeces. Approximately a 90 and 99% reduction in the probability of disease through laundering and use of a sanitising detergent respectively were suggested by the models. It should be kept in mind that this point risk estimate does not take into account multiple exposures. For example, the person could be excreting for several weeks, by which time several loads of laundry would be washed; exposure through 5 loads of contaminated laundry would increase the individual risk about fivefold (population risk from 10 to 45/million). The authors concluded that, in order to increase the confidence in this estimate, better data are needed on incidence of disease in the population, excretion rates over the course of an infection, amount of faeces spread in the home, distribution of bacteria, survival, and the transfer of the bacteria from surfaces to the hands and to the mouth.

6. DISCUSSION

Data presented in this review indicates the potential risk for transmission of bacterial, viral and fungal infections via clothing and household linens. The data comes from 2 sources. Firstly, from microbiological studies showing how pathogens are transferred to clothing etc from a variety of sources during normal daily life, and the extent to which these agents can survive and spread from contaminated fabrics to hands and surfaces, such that we can become exposed to potentially infectious doses. Secondly, it comes from observational studies of documented cases or outbreaks of infection which were carried out to elucidate likely sources or mode of transmission.

The extent of the risk associated with clothing and household linens can be assessed by evaluating the microbiological data relating to each stage of the transmission cycle as laid out in Figure 1:

- As stated in section 3.1, pathogens which are likely to be found on (and transmitted via) clothing and household linens come from a range of sources. The most likely sources are microbes from our own skin and faecal flora, but also respiratory viruses present in infected mucous, or infected secretions from the eyes. Enteric pathogens on clothing may also come from contaminated food, looking after animals, or taking care of an infected family member. Transfer can occur by direct contact between e.g. clothing and food contaminated surfaces, but is equally likely to arise by transfer from these sources to clothing via hands. Additionally, if the laundry process fails to eliminate contamination from soiled clothing etc, the pathogens can spread to other items in the laundry load, and thereby infect other family members. It is unlikely that viral or bacterial contamination on clothing (apart from desiccation-resistant strains such as *S. aureus* and *C. difficile*) comes from contact with furniture (chairs, seating on public transport etc) since pathogenic bacteria and viruses are only occasionally found on these surfaces. However in a 2010 study, Boone and Gerba[104] reported isolation of human parainfluenza virus from 27, 30 and 47% respectively of table tops, chair arms and desks in office buildings in 5 US cities. Since desiccation-resistant bacteria such as *S. aureus* and fungal spores are frequently found in household dust, recirculation of this dust via the air and surfaces may also contaminate clothing and linens.
- The various field studies reported in section 3 indicate the species that are most commonly isolated from clothing etc. Although the major isolates are normal skin species such as *staphylococci*, *micrococci*, *corynebacteria* etc, pathogenic bacteria, viruses and fungi are sometimes isolated. The studies show that pathogens are most likely to be found on clothing etc in situations where there is an infected or contaminated

source. In particular, a whole range of studies show that, where a patient is infected with MRSA, these organisms are quite frequently isolated from clothing and bed linens of both the patients and healthcare personnel. Although, these are mainly studies carried out in healthcare settings, they are equally relevant to home settings where *S. aureus* (including MRSA (both hospital and community strains) from an infected person may be transmitted via clothing or linens to another family member who may be colonised or infected. Other reported studies where pathogens isolated from clothing etc involved patients infected with *Burkholderia cepacia, P. aeruginosa* and human papillomavirus. Surprisingly perhaps, no field studies could be identified which looked for contamination on clothing, in situations where people were preparing contaminated foods. It is known that raw foods such as poultry, as purchased from retail premises are quite frequently contaminated with species such as *Salmonella* and *Campylobacter*; a 2010 European Food Standards Agency report based on data from EU countries in 2008[105] indicates that *Campylobacter* is found on an average of 30.1% of raw poultry meat samples. *Salmonella* was reported for chicken, turkey meat and pig meat, at mean isolation rates of 5.1%, 5.6% and 0.7%, respectively. Similarly, although studies (as reviewed in the IFH 2011 report[7] isolation of cold and flu viruses from hand contact surfaces in rooms where there are infected people, unfortunately none of these included sampling of clothing.

- As well as studies carried out in relation to known infected or contaminated sources, sections 3.2.2 to 3.2.4 contain data from clothing etc sampled at random (i.e. in the absence of an identified source). These data give an indication of the potential risks during "normal" daily activities. Although the frequency of isolation was less, nevertheless, pathogenic bacteria, viruses and fungi were sometimes found, indicating the ability of these organisms to survive on essentially dry surfaces of fabrics for quite long periods following transfer from an infected source. The studies show that the most frequently isolated spp. are desiccation-resistant strains such as *S. aureus,* but Gram-negative species such as *E. coli* and *P. aeruginosa* were also sometimes found. No studies on the presence of viruses or fungi on clothing sampled at random could be identified.
- Although the data in section 3.1 shows the potential for shedding or spreading of pathogens in faeces, vomit, skin scales etc onto clothing and household linens, in high numbers, the infection risk depends very much on their ability to survive on fabrics. A range of laboratory studies are reviewed in section 3.3 assessing survival of microbes on fabrics. These show that the numbers of viable units declines at a more or less rapid rate on dry clothing etc, depending on the species and other factors such as RH. Indications are, however, that Gram positive spp. such as *S. aureus, C. difficile* and fungal spp. can survive long periods (several days to months) on fabrics. Although Gram negative species such as *E. coli* and *P. aeruginosa* are generally much more sensitive to the lethal effects of drying, survival times of the order of up to 4 or more hours are recorded. In contrast with other Gram negative species, *Salmonella* spp. can survive for relatively very long periods (up to 24 weeks).[55] Relatively less data is available on viruses but these suggest that survival on fabrics is significantly less than bacteria, and that survival on fabrics is significantly less than on non porous contact surfaces; survival times for viruses on fabrics were mostly around 30 mins-12 h up to a maximum of 48 h (although the data of Sidwell *et al.*[53,54] reported longer survival times). Survival times for fungal species were much higher ranging from 1 day to several weeks.
- Importantly, the infection risk from contaminated fabrics depends not only on length of time, but also the numbers of pathogens which survive. The various field studies discussed in section 3.2 gives some indication of the numbers of survivors on fabrics, but more data are needed, particularly on the survival of pathogens on fabrics. The data

suggest that the total bioburden on clothing etc after wearing or use, are typically of the order of 10^2 to 10^6 cfu/sq cm, but it must be borne in mind that these are mostly non pathogenic microbes from the body flora and environment. In particular, the data suggest that substantial numbers of S. aureus (including MRSA) survive on the clothing of medical staff attending infected patients; Perry[20] found that levels of contamination recovered from the uniforms using a slit sampler ranged from 1-100 colonies, but, for MRSA, some counts of >500 cfu were obtained. Some limited data on bioburdens of pathogenic species on clothing and linens from household settings comes from 2 studies carried out in Japan. Ojima 2002[46] found that, where *E. coli, P. aeruginosa* and *S. aureus* (and also coliforms) were found in kitchen hand and counter towels, and bathroom and toilet handtowels, counts were mostly between 1 and 9 cfu/10 sq cm, but counts of 10-1000 were sometimes recorded. In the other study,[47] coliform bacteria (mean levels 10^2-10^4/sq cm) were found in 21/27 samples and *E. coli* ($1.5x10^1$ in underwear up to 10^5 in dishrags) was found in 3/27 samples.

- As shown in Figure 1, the infection risk associated with clothing and household also depends on the extent to which pathogenic bacterial, viral and fungal species are transferred onwards by contact with hands and other surfaces, such that we become exposed. The data reviewed in sections 3.4-3.6 indicate significant transfer of pathogenic agents from fabrics by contact with hands and with other fabrics. Data indicates transfer rates from moist fabrics of around 1-10% for the species tested, but in some cases transfer was as little as 0.1% or less, or as high as 50%. It must be borne in mind however that transfer rates vary significantly between different microbial strains and depends on factors such as temperature, relative humidity, type of fabric and inoculum size, increasing with increasing inoculums. One of the key factors which affects transfer is whether the contaminated fabric is moist or dry; a number of laboratory models[11,12,67] indicate that the number of organisms transferred is significantly less (up to 10 fold decrease) if donor fabric or hands are dry. This correlates with data showing that transfer of pathogens from hands is higher from wet compared with dry hands.
- The data in section 3.6 indicate that, where the laundering process is insufficient to eliminate contamination, transfer of pathogens to other items in the load can occur. This includes studies showing transmission of bacterial strains such as *S. aureus, E. coli, S. typhimurium and Mycobacterium fortuitum*[81] and viral strains such as rotavirus, hepatitis A and adenovirus.[82]
- Considering the final stage in the chain or infection transmission (see Figure 1), as stated previously, the infection risk associated with transfer via clothing and linens depends on the number of pathogens to which we are exposed, either orally, via the respiratory tract, or via the mucous membranes of the nose, eye etc. Infection depends on exposure to sufficient organisms to overcome the body's' natural defences which means that the infection risk increases as the dose to which we are exposed increases. Data summarised in the 2011 IFH review[7] shows that the infectious dose varies significantly according to species and the health status of the recipient. Although the oral infectious dose of *Salmonella* may be as high as 10^6 organisms, it may be much lower, according, for example to whether it is consumed in foods or directly from hand to mouth. Up to 10^6 cells *S. aureus* may be required for infection of intact skin, but the dose may be much lower for damaged skin or wounds. For enteric viruses such as norovirus, or respiratory viruses such as rhinovirus or influenza virus, the oral or respiratory infections dose may be as little as 1-10 virus particles.

Although no intervention studies, which specifically studied the impact of laundry hygiene on infectious disease rates could be identified, valuable data on the causal link between

clothing etc. and infectious disease risk comes from a number of observational studies which suggest that these risks need to be carefully assessed and properly managed. In all, 19 published studies were identified which are reviewed in section 4. In all of these studies, transmission via clothing and linens was identified as a likely cause, or was identified as a significant risk factor. These involved viral, bacterial and fungal infections, and included gastrointestinal and respiratory tract, together with skin and wound infections. Of particular interest is the 2010 intervention study reported by Elias et al[96] which strongly indicates that effective laundering processes are key to preventing the spread of MRSA (and all S.aureus strains) in settings such as households where people are living in close contact.

Some quantitative assessment of the infection risks associated with clothing and household linens comes from studies involving the use of QMRA. The data generated by Gerba and co-workers, as outlined in section 5, suggest that the risk of acquiring shigellosis through contact with clothing after laundering, given 0.1g of faecal contamination present in the load, were calculated as high as 10 per million population to much lower levels associated with lower excretion rates of the bacteria in the faeces. The authors concluded that "whereas the number of cases potentially acquired through handling contaminated laundry are estimated through this example as rare events, this estimate was for a single pathogen and a one-time exposure and likely underestimates the risk". Although risk modelling is a useful approach, it has significant limitations because of the multifactorial nature of infection transmission and paucity of data to specify model parameters. What it does illustrate however is how a relatively small reduction in contamination on a surface or fabric, which may be deemed insignificant in terms of an individual family, can translate into a significant decrease in the risk of infection within a national population. For example, Gibson et al[8] estimated a 90% reduction in the probability of transmission of shigella from contaminated clothing through "normal" laundering (estimated to produce 88.9% reduction in contamination on laundered items), compared with a 99% reduction by use of a sanitising detergent (estimated to produce 99.9% reduction in contamination on laundered items).

Although the weight of evidence presented in this report indicates that clothing and household linens are a risk factor for transmission of infection in home and everyday life settings, without data from intervention studies, it is difficult to assess the extent of the risk i.e the potential health benefits which could be achieved by ensuring that laundry processes are adequate to achieve decontamination of clothing. To an extent, however, this can be achieved, in a semi-quantitative manner, by evaluating the data on clothing etc. relative to that associated with the hands and other contact transfer surfaces.

The "total" data on the causal link between hygiene and infectious disease rates in home and everyday life settings is set out in the 2011 IFH report on the chain of infection transmission in home and everyday life settings.[7] These data demonstrate a strong causal link between hygiene *per se* and infectious disease transmission in home and everyday life settings which is well established through a range of intervention studies assessing single interventions such as hand hygiene and household water treatment, or combinations of environmental hygiene measures with or without hand hygiene. Although these data consistently show that combinations of environmental measures have a significant impact on disease rates, they give no data on the impact of specific interventions such as laundry or surface hygiene either singly, or relative to each other, or relative to hand hygiene.

In order to address this issue and produce an effective code of hygiene practice for the home, IFH has developed the targeted approach to home hygiene. This approach is described in the IFH 2011 "chain of infection" report[7] and section 2 of this review. Targeted

hygiene is based on the principle that reducing the infection risk is not achieved by trying to eliminate infectious agents from our environment but by focussing on breaking the chain of infection transmission by intervening at “critical points” in the chain such as the hands, hand contact surfaces and so on. In order to identify “critical points”, the microbiological and other data was used to assess both the likelihood that pathogens may be present, and the extent to which they are likely to be transferred around the environment such that we are exposed to them. This, in turn, allows us to rank sites and surfaces (Figure 3) according to the level of risk. As outlined in section 2, the data indicate that, overall, the hands are probably the single most important transmission route since they come into direct contact with the mouth, nose and conjunctiva of the eyes. Although, in some cases, the hands alone may be “sufficient cause” for infection transmission, in other cases transmission involves a number of component causes. The data suggest that the most important control points are surfaces which come into contact with our hands and body surfaces, and with food and water. These include hand and food contact surfaces, cleaning cloths and other cleaning utensils, clothing and household linens, together with other surfaces which come into contact with the body such as baths and hand basins.

As far as clothing and household linens are concerned, comparison of the relevant microbiological data with data for other environmental surfaces suggests that, although household fabrics 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. This is because survival of pathogens on the porous surfaces of fabrics is significantly less than that on non-porous surfaces. The comparative studies of Rusin et al,[68] as described in section 3.4.1 show that transfer rates for bacteria and viruses from fabrics to hands are also much lower than those from non porous surfaces. In behavioural terms also, infection transmission risks for clothing etc. are probably less frequent. Whereas there are constant opportunities for transfer from one person to another through mutual touching of e.g. door or tap handles, in reality, we do not deliberately touch other people’s clothing. Also, whereas the relatively 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.

Although this gives us an assessment of the “daily life” risks associated with clothing relative to other contact surfaces, it is important to recognise that the infection risks associated with these items are not constant, and can increase significantly under certain conditions. The data contained in this report shows that the risk of transmission via clothing and household linens is likely to increase in situations where a family member has diarrhoea or vomiting, or a skin or wound infection. It also increases in circumstances where a member of the family has reduced immunity to infection. In particular the weight of evidence strongly indicates that clothing and household linens are a significant risk factor for spread of *S. aureus* (including MRSA and PVL-producing strains of MRSA), and that the hygienic effectiveness of laundry processes may be an important factor in defining the rate of spread of these strains in the community. Over the period since 2002 CA-MRSA strains have become a major problem in the USA. As stated previously, in the USA, washing machines commonly take their water from the household hot water tank, making it difficult to achieve the highest temperatures reached in European washing machines. It is possible that this may have been a contributory factor. In Europe and elsewhere, CA-MRSA infections are still relatively uncommon and there is still an opportunity to avoid the problem escalating to a similar scale.

Whereas the major concerns, currently, are about antibiotic resistant strains, a 2008 UK

study[106] indicates a major general increase in community-onset staphylococcal disease in the past 15 years. These workers found that hospital admission rates for staphylococcal septicaemia, pneumonia, impetigo etc. increased >5-fold. Admission rates increased 3-fold for abscesses and cellulitis and 1.5-fold for bone and joint infections. They postulate that this trend may result from altered virulence or transmissibility of *S. aureus* (in general or of particular strains). Importantly they concluded that, not only widespread use of antibiotics, but also changes in host immunity, changes in transmission dynamics (e.g. increasing use of preschool child care) and changes in hygiene behaviour may be important factors. IFH believes that there is an urgent need to further investigate the impact of laundry hygiene on the spread of *S. aureus* strains in the community. Importantly this needs to include not only the impact on MRSA clinical infections, but also on rates of spread of MRSA colonization in apparently "healthy" households and communities.

This review also shows that, to an extent, the infection risks associated with clothing and linens also vary according to the nature and state of the fabrics, most particularly the dryness and nature of the fabric. The data consistently show that transfer of pathogens from contaminated fabrics to hands and elsewhere is significantly (up to 10-fold) higher if fabrics are wet. Hsieh et al[83] concluded that the hydrophobicity of a fabric is also a determining factor, although they caution that generalization on bacterial adherence to fabrics by the hydrophobicity characteristics of the bacteria or the substrate alone would be misleading. Hsieh showed that adherence to fabrics was higher for the Gram positive organism *S. aureus* than for the Gram negative *E. coli,* possibly due to its higher bacterial cell wall hydrophobicity. Adherence of staphylococci also increased with the amount of polyester fibre in fabrics (probably due to the fact that polyester is a hydrophobic polymer), but *E. coli* did not seem to be affected. O'Toole *et al*[84] concluded that microbial size is an important determinant in the fabric attachment-detachment process during the machine washing cycle, with larger microorganisms (e.g cryptosporidium oocysts) showing greater transference to, and retention on, fabric swatches than smaller ones (e.g.viruses). They also noted that transfer efficiencies were greater for cotton towelling, and postulated that this may reflect its greater absorbency relative to other fabric types. The coarse rather than smooth surface of towelling may also offer greater potential for enmeshing microorganisms within the fabric matrix.

7. CONCLUSIONS

The data presented in this report indicates that clothing and household linens play a significant role in the spread of infectious diseases in the home and everyday life settings during normal daily activities. The data suggest that the greatest risks occur immediately after contact with, or shedding from an infected source. Although the risks decrease as numbers of viable units steadily declines, indications are that pathogens can persist on the surfaces of fabrics for several hours for viruses or Gram negative bacteria, up to days or weeks for desiccation-resistant strains such as *S. aureus, C. difficile* or fungal spores. Most particularly, the data indicates that transmission via clothing and household linen plays an important part in the spread of *S. aureus* (including MRSA) infections.

Unfortunately, the data is not sufficient to make any quantitative assessment of the risks in terms of the impact of promoting effective laundry practices on disease rates. Although it seems likely that the risk is significant, the "daily life risks" are probably somewhat less than those associated with hands, hand contact and food contact surfaces and cleaning cloths which are seen as the key routes of infection transmission. Importantly, the data show that in

some situations i.e. where someone in the home is infected, or there is someone with reduced immunity to infection, the infection risks can substantially increase. In particular the data suggests that clothing and household linens are important risk factors for spread of *S. aureus* (both antibiotic sensitive and resistant strains). Risks are also likely to be increased in developing country situations where clothing etc. is washed manually, at ambient temperatures, in water which may be grossly polluted. The majority of data presented in this report comes from developed country situations and there is a need to carry out further studies to determine the extent to which the risks associated with clothing etc. may increase in low income communities.

The extent to which outer clothing might, in the same way (as with any hand contact surface) act as a vehicle for transmission from one person to another during daily life is impossible to assess from the available data. Although there is a possibility that this could occur, further studies involving laboratory and fields models are needed to assess whether there is evidence of real risk.

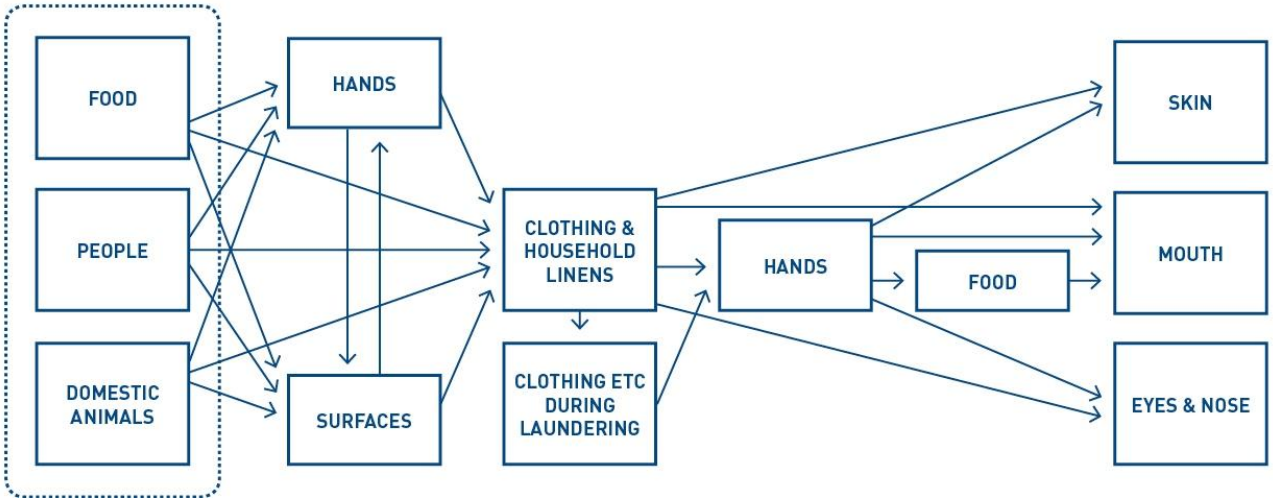
As outlined in the introduction, in the past few years, infectious disease has moved back up the health agenda, prompting governments and health agencies to invest in hygiene promotion as a means of reducing the infectious disease burden. A number of examples illustrate why and where effective hygiene practices associated with clothing and household linens are particularly important:

- The proportion of people living in the home and general community who have reduced immunity to infection is increasing. Although the risks of exposure to pathogens are the same as for everyone, these people are more likely to develop infections as a result of microbial exposure, if hygiene procedures such as laundering of clothing and household linens are not implemented or are inadequate.
- New MRSA strains are now circulating in the community. These community strains (CA-MRSA) differ from hospital strains in that they are just as likely to affect young active people as the elderly or infirm. Although CA-MRSA strains are now a major problem in the USA, they are still relatively uncommon in Europe and elsewhere, and there is thus still an opportunity to avoid the problem escalating to a similar same scale. The findings of this report suggest that transmission of *S. aureus* (including MRSA) via clothing etc is a particular risk and that effectiveness or otherwise of laundry hygiene processes could be an important factor in defining the rate of spread of these strains.
- Technological and policy changes are being introduced to reduce costs and/or environmental effects without regard to the potential impact on disease risks. There are indications that low temperature laundry process may be insufficient to eliminate pathogens from fabrics and that such processes may increase the risks of spread of infection via clothing and household linens.
- In the UK, US and elsewhere, healthcare workers frequently launder their uniforms at home. This report shows the extent to which their clothing can become contaminated by contact with infected patients indicating the importance of effective laundry hygiene at home. A UK questionnaire study of nurses working in 3 hospitals[107] indicated that 31% of nurses did not use the hospital laundry whilst a US survey of nursing staff indicated that 26% home-laundered their scrubs.[108]

Apart from infectious disease, a parallel agenda of global importance is sustainability. Protecting health by preventing infection is in itself a more sustainable approach than treatment. Equally however, hygiene measures must themselves be sustainable. The issue of hygiene in relation to sustainability is assessed in a 2010 IFH report.[80]

From the data presented in this report, it is concluded that, although laundry processes should be able to deliver clean fabrics with minimum, use of water, power and chemicals, it is equally important to ensure that laundered clothing does not represent an infection risk. After wear or use, clothing and household linens, most particularly that which comes into contact with the body surfaces, should be laundered in a manner which not only renders them aesthetically clean, but also hygienically clean i.e. free from pathogens. To achieve this, there is a need to ensure that laundry products are clearly labelled so that consumers can understand whether, and under what laundering conditions, their laundry products can be expected to produce fabrics which are “hygienically” as well as visibly clean. It is also important for regulatory authorities to recognise that the “hygienic cleaning (i.e. biocidal/germ removal action) of laundering is achieved by a combination of heat, rinsing, detergent and chemical oxidative action. This is a very different situation from the biocidal mode of action of disinfectants including antibacterial products) on hands and environmental surfaces.

Figure 1 - Routes of transmission of infection involving clothing and household linens



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