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Developing an Evidence-Based Approach to Domestic Hygiene Which Protects Against Infection Whilst Also Addressing Sustainability Issues

Changes in recent years mean that preventing infection through hygiene in home and everyday life has become increasingly important. In developing and promoting home and everyday life hygiene, a number of issues which represent a barrier to change need to be addressed and balanced against the need for effective hygiene. These include environmental and toxicity issues, and concerns about antibiotic resistance and whether we have become "too clean". Education of the public is key, but this can only be achieved if hygiene practice is based on a simple, plausible approach to hygiene, which health professionals and the public can relate to. This in turn needs to be underpinned by an evidence base which demonstrates to health professionals and other hygiene stakeholders who communicate with the public that the procedures and products which they advise are capable of reducing infection risks to an acceptable level, with sustainable use of resource necessary to deliver hygiene such as water, heat, microbiocides etc. The purpose of this paper is to outline a multimodal targeted approach to home and everyday life hygiene based on risk management. This includes a framework for developing effective and sustainable hygiene practices, including hand hygiene, surface hygiene and laundering practices.

Key words: Hygiene, home, domestic, risk management, targeted hygiene

Entwicklung eines faktengestützten Ansatzes für die Haushaltshygiene, der vor Infektionen schützt und gleichzeitig Nachhaltigkeitsaspekte berücksichtigt. Veränderungen in den letzten Jahren haben dazu geführt, dass die Prävention von Infektionen durch Hygiene im Haus und Alltag immer wichtiger wird. Bei der Entwicklung und Förderung von Heim- und Alltagshygiene müssen eine Reihe von Problemen, die ein Hindernis für Veränderungen darstellen, angegangen und gegen die Notwendigkeit einer wirksamen Hygiene abgewogen werden. Dazu gehören Umwelt- und Toxizitätsprobleme sowie Bedenken hinsichtlich der Antibiotikaresistenz und ob wir „zu sauber" geworden sind. Die Bildung der Öffentlichkeit ist der Schlüssel, aber dies kann nur erreicht werden, wenn die Hygienepraxis auf einem einfachen, plausiblen Hygienebegriff beruht, auf den sich die Angehörigen der Gesundheitsberufe und die Öffentlichkeit beziehen können. Dies wiederum muss durch eine faktengestützte Basis untermauert werden, die den Gesundheitsfachleuten und anderen Stakeholdern, die im Bereich der Hygiene mit der Öffentlichkeit kommunizieren, zeigt, dass die von ihnen empfohlenen Verfahren und Produkte in der Lage sind, Infektionsrisiken bei nachhaltiger Nutzung von Ressourcen, die für die Hygiene notwendig sind, wie z. B. Wasser, Wärme, Mikrobiozide usw., auf ein akzeptables Maß zu reduzieren. Der Zweck dieses Beitrags ist, einen multimodalen, gezielten Ansatz für die häusliche und alltägliche Hygiene auf der Grundlage des Risikomanagements zu skizzieren. Dies umfasst einen Rahmen für die Entwicklung wirksamer und nachhaltiger Hygienepraktiken, einschließlich Handhygiene, Oberflächenhygiene und Waschverfahren.

Stichwörter: Hygiene, Zuhause, Haushalt, Risikomanagement, gezielte Hygiene

1 Introduction

The profound impact of infectious disease on health and prosperity is recognised by health agencies worldwide. Changes in recent years mean that preventing infection through hygiene in home and everyday life has become increasingly important. A current driver for this is the fundamental part that hygiene plays in tackling antibiotic resistance [1]. Promoting hygiene in community settings addresses antibiotic resistance by reducing the need for antibiotic prescribing in primary care and also by reducing spread of resistant strains such as Methicillin Resistant *Staphylococcus aureus* (MRSA) and multidrug resistant Gram-negative strains across the community and across international borders [2]. Concern about the need for greater investment in hygiene promotion is also prompted by the growing numbers of people, whose immunity to infection may be underdeveloped or impaired in some way, who are at greater risk of infection but are being cared for, or caring for themselves, at home. It is estimated that 1 in 5 or more people living in the community are at increased risk of infection [3]. The largest proportion is the elderly, who have generally reduced immunity to infection. It also includes the very young, patients discharged recently from hospital, and family members with invasive devices such as catheters, and those undertaking drug therapies or who have underlying illness e. g. HIV/AIDS which adversely affect the immune system.

In developing and promoting home and everyday life hygiene, a number of issues which represent a barrier to change need to be addressed, and balanced against the need for effective hygiene. Meeting this challenge can only be achieved if hygiene practice is underpinned by a strong scientific evidence base which demonstrates that procedures and products are capable of reducing infection risks to an acceptable level, with sustainable use of the resources necessary to deliver hygiene, such as water, heat, microbiocides etc.

This aim of this paper is to outline an evidence-based multimodal approach to home and everyday life hygiene based on risk management. This includes a framework for

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developing effective and sustainable hygiene practices, including hand hygiene, surface hygiene and laundering practices. The evidence base which has been used in developing targeted hygiene is set out in a number of data reviews prepared by the International Scientific Forum on Home Hygiene (www.ifh-homehygiene.org) [3–5].

2 Barriers of development and promotion of effective hygiene in home and everyday life – why is a science-based approach important

Whilst assessment of environmental and safety issues associated with hygiene procedures and products, and *c*oncerns about possible links between use of microbiocidal products (disinfectants, antibacterials, sanitizers) and the rise in antibiotic resistance is essential, these issues must be balanced against the need for effective hygiene. Particularly in Northern Europe, whilst concerns about environmental impacts of hygiene products and procedures are strongly voiced, there has been a tendency to downplay the importance of hygiene in home and everyday life. For example, lower temperatures home laundering provides the means to conserve energy, but also produces a reduction in hygiene efficacy [5]. Similarly, although hygiene is achievable using detergent-based cleaning, in some situations there is need for a disinfectant product or hand sanitizer [6–10].

In assessing problems associated with antimicrobial resistance, expert reports commissioned in the last 10 years continue to agree that laboratory-based experiments indicate that certain types of microbiocidal products can cause reduced susceptibility to antibiotics in microbial populations, but conclude there is still no evidence that microbiocide use has contributed to the rise in antibiotic resistance in clinical practice [11–13]. Unfortunately, as shown by a review of media coverage, the former statement may be quoted without reference to the latter, suggesting that the problem has been identified under real life conditions [14]. These expert bodies stress the hygiene importance of microbiocides, but also stress the need to use them prudently.

Whilst we have long known that some microbes cause infection, we are now seeing the extent to which microbe-human interactions are essential for health [15]. It is becoming increasingly clear that diverse exposure to human, animal, and natural environments, particularly in early life, is key to building a healthy microbiota [15, 16]. Failure to sustain a diverse microbiota is associated with an increasing range of diseases including allergic and autoimmune diseases (such as multiple sclerosis, type 1 diabetes and inflammatory bowel disease) which have risen sharply in the last 50 years [15, 16]. Data indicate that the underlying causes of reduced microbial exposure are lifestyle changes such as caesarean section rather than natural childbirth, bottle rather than breast feeding, less sibling interaction, less time outdoors, excessive antibiotic use and altered diet [15, 16]. A 2017 survey of media coverage [18] of the 1989 hygiene hypothesis [17] proposing a link between "too much hygiene and cleanliness" and the rise in allergic diseases shows that, unfortunately, this concept is still being promoted by the media and some experts as the underlying cause, despite lack of supporting evidence [16]. Public responses to the media coverage suggest that this is undermining confidence in hygiene [18]. For example, it includes advice to consumers to avoid fundamental hygiene practices such as handwashing [19, 20].

Another barrier to change is the widespread misunderstanding about hygiene and hygiene issues. Three issues need to be addressed. The first is the lack of understanding of hygiene which is still largely seen as synonymous with cleanliness aimed at eradicating dirt – inappropriately regarded as the main source of harmful microbes. The survey of media coverage from 1989–2017 [18] suggests that people fail to understand that, although cleaning is a means of achieving hygiene, visual cleanliness does not necessarily mean "microbiologically safe". Because communications about different hygiene issues (hand hygiene, food hygiene, respiratory hygiene etc) are being developed independently by different health agencies and stakeholders, without reference to a common strategy, advice is sometimes conflicting causing further confusion. This is compounded by ongoing messaging [18] that "too much hygiene and cleanliness" is causing the rise in allergies. Public-facing advice needs to be based on sound science rather than long held beliefs.

Use of the term "germs" in a sinister way is also counterproductive to changing hygiene behaviour, because it is no longer credible and has led the public to become sceptical about the need for hygiene [18]. In this outdated model, potentially harmful microbes and high risk situations are not properly differentiated from microbes and situations where there may be high levels of microbes that pose little infection risk. Responses to media articles suggest that the public are mistrustful of what they hear from the media and other sources [18]. A typical response is "if there were so many dangerous microbes in our home, how come we are not constantly sick".

People are also rightly concerned about the need to conserve energy and water (e. g. low temperature laundering) and about environmental and human health impacts of hygiene products, particularly microbiocidal products, but are unsure how to balance this against the scare stories they hear about infection risks. Faced with this, there is a tendency to reject established hygiene practices, which could increase the risk of infection, and fuel greater demand for antibiotics [18]. It could be argued that, if targeted use of microbiocidal products contributes to reducing infection risks, they could actually decrease the need for antibiotics, which is a key part of tackling antibiotic resistance.

In order to develop a code of hygiene practice that is both effective and sustainable, and addresses the above issues, it requires a simple plausible approach underpinned by an evidence base which demonstrates that the hygiene practices are capable of reducing infection risks to an acceptable level, with sustainable use of necessary resources (water, heat, microbiocides etc).

3 A risk management approach to hygiene in home and everyday life – targeted hygiene

Since the 1980s, scientists have adopted a risk management approach for developing hygiene in home and everyday life. This scientifically-validated system is a well-supported approach developed by the food and other manufacturing sectors as the means to protect food, pharmaceuticals, etc. from contamination during manufacture. Applied to home and everyday life it has come to be known as targeted hygiene [21–24].

A particular concern is the inconsistent and misleading terminology used by scientists and health professionals, which hinders communication amongst health professionals and with other hygiene stakeholders particularly those who may have limited training and technical understanding of microbiology and infection. Possibly the greatest confusion comes from use of the term "cleaning", which is sometimes used to describe the process of visible soil removal and, at other times, is used generically to describe

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any process intended to make surfaces "microbiologically safe" regardless of whether it involves disinfection and/or mechanical removal of pathogens [25, 26]. i.e. cleaning is used interchangeably with the word hygiene.

For the purpose of this review, "microbiologically safe" is referred to as "hygienically clean" to distinguish it from "visibly clean or soil-free" states. As stated above, for most people "clean" means absence of visible dirt. Since we have no way of "seeing" or easily validating whether a surface is hygienically clean, a surface can only be considered hygienically clean if the cleaning process has been done properly e.g. handwashing has been carried out according to the prescribed technique.

3.1 Targeted hygiene – identifying risk points

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

Figure 1 shows that the chain starts from a source of infection. In the home, the main sources of harmful microbes are not places which are "dirty", but people who are infected or are healthy carriers of potentially pathogenic strains (e.g. *S. aureus, Escherichia coli),* contaminated foods and domestic animals. Pathogenic or potentially pathogenic microbes are continually shed from these sources into the home environment. This provides the basis for a simple plausible approach to hygiene; targeted hygiene involves intervening at key sites and surfaces in the chain of transmission, at appropriate times, to break the chain of infection. Analysis of the evidence base [4] on how microbes survive and spread in the environment and the extent to which we are exposed to them during our daily lives indicates (see Fig. 2) that the critical points for transmitting pathogens are the hands, hand and food contact surfaces and cleaning utensils. Clothing and household linens, and toilets, sink and bath surfaces also contribute to spread of infection, although the risks associated with these surfaces are normally somewhat lower as they rely on surfaces such as the hands to transfer the microbes to a susceptible person.

Assessing the relative importance of hand hygiene and hygiene of surfaces, cloths, baths, hand basins, toilets, and clothing and household linens is particularly difficult because of the interdependence of the routes of transmission. Figure 2 shows a rule of thumb ranking of risks based on the available data [4]. Although hands are probably the single most important transmission route because, in all cases they come into direct contact with the known portals of entry for pathogens (the mouth, nose and conjunctiva of the eyes), and are thus the key last line of defence, in many cases transmission involves a number of component causes (e.g., from contaminated food, to a food contact surface, to hands, to the mouth of a recipient) [27].

The microbiological evidence base [4] has also been used to determine the critical times when pathogens are most likely to spread. These are during food handling, using the toilet, coughing, sneezing, nose blowing, care of domestic animals, handling and disposal of refuse, or where a family member is infected. The targeted approach to hygiene means that hygiene procedures are focused on maximizing protection against spread of infection at these critical times, rather than on sites or surfaces where there is visible dirt (but not necessarily disease risk), or high microbial levels but low infection risk because presence of pathogens is unlikely. Cleanliness achieved by routine non-targeted daily or weekly cleaning may contribute to preventing spread of pathogens, but there is little data to suggest that its contribution is significant relative to hygienic cleaning at critical points at key times [4].

People routinely ask "what are the sites and surfaces in my home which "harbour" germs", believing these to be the main source of infection. In reality, whereas there are some situations where potentially harmful microbes can form a permanent growing reservoir of infection in the home [4], it can only occur where there is sufficient nutrients, water, etc. The fastidious growth requirements of primary pathogenic bacteria and all viruses is such that they do not "grow" outside animal or human tissue, although they can survive briefly, or prolonged periods, depending on the species. *Legionella pneumophila* is an example of a potential pathogen which can grow in the stagnant water in shower heads, but is mainly pathogenic if inhaled by people with reduced immunity to infection e.g. the elderly. Other species sometimes identified from home sampling is *E. coli,* one of a group of species collectively called "coliforms". Coliforms may originate from people's bowel, where it is commonly found, but some strains survive and grow in wet environments. There are many strains of *E. coli,* but only a limited number are harmful, and many of these are only harmful e.g. when transferred from the bowel to the urinary tract. Whereas, media articles tend to quote *E. coli* as an example of a "dangerous" microbe in the home, this is not necessarily the case [18].

As shown in Fig. 1, infection only occurs if a person is exposed to a sufficient dose of potentially harmful microbes, in a way which allows access to the body (mouth, eyes, noses, cuts etc). The dose of pathogens required to cause infection can vary considerably. Even for healthy adults the infectious dose of some pathogens e.g norovirus, may be very

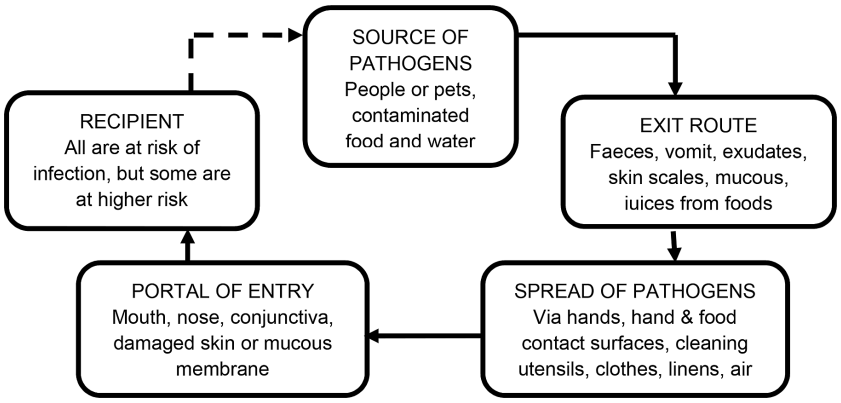

Figure 1 The chain of infection.

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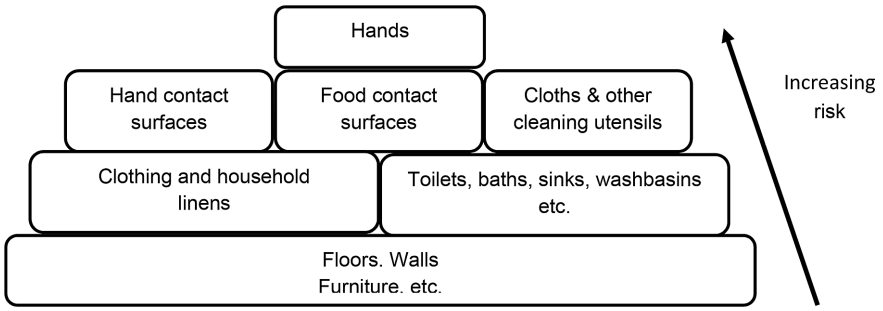

Figure 2 Ranking of sites and surfaces based on risk of transmission of infection.

small (less than 10 particles), whilst for others e. g. *Campylobacter* or *Salmonella* it may be several hundreds or thousands [4]. Although we are all at risk of infection, for those with reduced immunity to infection, the dose of pathogen required to cause infection may be lower, which makes them at greater risk. Thus, although Fig. 2 is a useful ranking of risks associated with different surfaces, risks can increase significantly, e. g. where there is an infected person, or a person colonized by resistant or pathogenic strains, or a person undergoing treatments that undermine infection immunity.

3.2 Targeted hygiene – developing effective hygiene interventions

Of equal importance are the hygiene procedures (products plus process) used to get rid of pathogens from hands and other critical surfaces before they spread further and cause infection. If procedures are not effective, infection transmission is not prevented. Data in support of this is set out in a 2017 review by Bloomfield, Carling and Exner [28] which also shows the limitations of current research approaches to developing effective procedures and assessing their ability to prevent infection transmission. In this paper they outline a framework for addressing this issue.

This research framework is based on the simple, basic principle that hygienic cleaning of hands, surfaces and fabrics can be achieved in the following 3 ways:

- Physical removal of pathogens using soap or detergent-based cleaning, or dry wiping. This is usually referred to as cleaning.
- Using a microbiocidal product (disinfectant, antibacterial or alcohol hand sanitizer), or processes (e. g. heat at 60 °C or above) that inactivate/kill pathogens *in situ*. This is usually called disinfection.
- Combined action e. g. during laundering, physical removal is combined with heat inactivation.

The aim of a hygiene procedure is reduction of microbial contamination to a safe level. All three approaches are valid ways to achieve this, regardless of whether this is the hands, environmental surfaces or fabrics. Health agencies and the household care industry sometimes fail to appreciate this commonality. Whereas there is extensive published data on the efficacy of disinfectants and disinfectant products, this is not so for physical removal processes, [28] or inactivation by heat (or its impact on detergency) which can increase the hygiene efficacy of procedures.

At present many experts still believe that, for domestic situations, risks of infection are relatively low except which a family member is sick. As a result, they advise that hygiene can be consistently achieved using soap or detergent and water or dry wiping. However research data to confirm this is lacking, and a number of more recent in situ studies suggest otherwise [6–10]. These studies show that wiping a surface with detergent, without subsequent rinsing transfers contamination to the cloth and hands, which is then spread to other surfaces, thereby promoting transmission of microbes. In this situation cleaning and also disinfection is needed to break the chain of infection.

Microbiocidal activity is usually expressed as the Log_{10} reduction (LR) in the level of microbial contamination, where Log_{10} 3, 4 or 5 log reduction is equivalent to 99.9, 99.99 and 99.999 % reduction respectively. Whilst laboratory tests measure the microbiocidal performance of disinfectant products, they do not assess, what health professionals, need to know. Firstly they need data from studies simulating in use situations, which show whether, when used correctly (product plus process), the hand, surface or laundry hygiene procedure which they are recommending, (whether it involves cleaning alone, or cleaning plus disinfection) can reduce contamination to a "safe" level and prevent onward transmission. Secondly, they need similar data on new disinfectant products, hand sanitizers, or other new technologies, which benchmark the procedure against detergent-based cleaning or wiping technologies in order to understand their relative efficacy. Without such data, it is difficult to provide professional home carers and the public with evidence–based advice about the hygiene procedures they should use in different situations.

Figure 3 illustrates how this could work. Some of the values used in these figures are hypothetical, because requisite data is not available. For hands, handwashing with soap (HWWS) is used to produce hands which are hygienically clean, provided the technique is correct [29]. Data suggest (see Fig. 3a) that HWWS, carried out correctly, can produce 0.5 up to 3 or more LR in bacterial contamination on hands [21, 30]. If soap and water are unavailable, alcohol hand sanitizers (AHS) can be used, which (apart from some non-enveloped viruses e. g. hepatitis C) produce equivalent or greater than 3 LR on hands [24]. In higher risk situations where initial contamination on hands may be higher or the safety target level lower (e.g. before changing dressings or catheter care, after changing a nappy or handling raw chicken) it may be advisable to recommend HWWS followed by use of AHS. This would, as illustrated in Fig. 3a, be expected to increase the LR by 3 or more [24].

For environmental surfaces (Fig. 3b and c) which are dry wiped or detergent wiped without rinsing, it is reasonable to expect that the LR will be less than that resulting from detergent-based cleaning followed by rinsing under clean running water. It may be considered that a 1–2 LR achieved by wiping alone is sufficient for hygienic cleaning of low risk surfaces such as floors and furniture. On the other hand, for high frequency touch surfaces which cannot be rinsed, such as food preparation surfaces, toilet seats and flush han-

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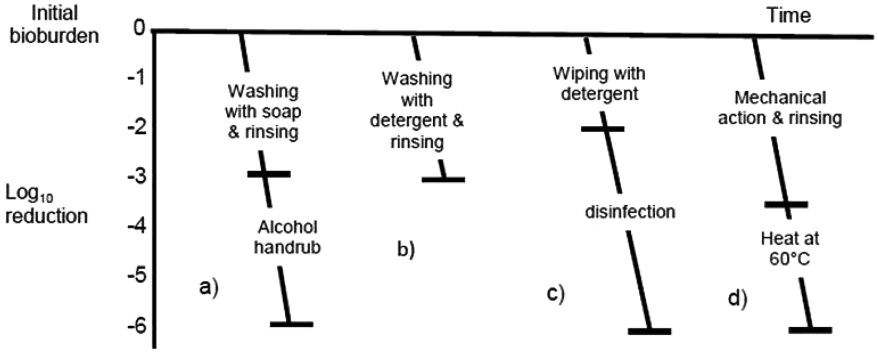

Figure 3 Hypothetical visualisation of total Log_{10} reductions (LR) of contamination which could be achieved by combined application of removal and inactivation procedures involving a) hand washing with soap, with or without use of alcohol handrub b) detergent-based wiping of surfaces followed by rinsing with clean running water c) detergent-based wiping of surfaces followed by disinfection and c) machine laundering of fabrics at 60 °C with a detergent.

dles, door handles, etc., additional use of disinfectant product which gives added LR may be needed to ensure that contamination is reduced to a safety target level equivalent to that produced by detergent cleaning with rinsing is achieved. For higher risk situations (high surface contamination levels after preparing a contaminated chicken or where there are persons with impaired immunity) it may be concluded that combined cleaning and disinfection which produces a higher LR is needed. Relatively little comparative data are available on the hygiene efficacy of removal and killing processes for surfaces and is reviewed by Bloomfield, Carling and Exner [28].

For clothing and household linens etc. (Fig. 3d), hygiene is achieved by combined action of heat inactivation and removal during machine wash and rinse cycles. Data suggests that laundering at 60 °C with a detergent can produce 3–6 or more LR (depending on microbial strain) due to the combined effects of removal by the washing and rinsing process, and the microbiocidal action of heat at 60 °C. Efficacy can be enhanced by using active oxygen bleach-containing detergents, which release active oxygen that supplements microbicidal action by 1 or more Logs, depending on temperature and test strain. [31, 32]. This allows hygiene efficacy equivalent to laundering at 60 °C to be delivered at lower temperatures.

Based on this approach Bloomfield, Carling and Exner propose a "hygiene assurance" framework for researching and developing hygiene procedures (both those involving cleaning and those involving inactivation using disinfectant products or heat) [28]. This 4 stage process as illustrated in Table 1 and, importantly is equally applicable to hands, surfaces and fabrics.

Stages 1 and 2 are used for products (disinfectant products) or processes (e.g. heat) with microbicidal action and is designed to quantify their capacity to inactivate microbes under laboratory conditions simulating use (presence of soil, temperature, types of potentially harmful organisms likely to be present). These methods can also be used to assess, for example, the separate LR contribution made by active oxygen bleach (AOB) in a laundry detergent [9, 31] or by the action of heat [32]. Surfactants in soap and detergents can themselves contribute some microbicidal action [30, 32]. Kim et al. [30] showed if different bacterial strains were inoculated into solutions of plain soap for 20 s, the LR values varied from zero up to as much as 1.5.

The purpose of stage 3 is to assess, by test models which mimic in use conditions, whether the hygiene procedure (product plus process – regardless of whether it involves detergent-based cleaning only or whether it involves using a disinfectant product) reduces contamination on hands, surfaces or fabrics to a safe level, and prevents onward transmission of contamination. This allows the following to be determined:

- It provides quantitative evidence that the procedure reduces transmission of pathogens when used in risk situations, and thereby reduces human exposure.
- It ensures that new products/processes/technologies are at least as effective as existing ones in preventing spread of contamination under use conditions.
- It quantifies the extent to which inclusion of a microbiocide (or other new technologies) enhance microbicidal effectiveness compared with procedures involving cleaning only.
- It enables development of new procedures which combine kill and removal in an additive or synergistic manner to deliver required safety target levels with more sustainable use of energy and chemical products

Although a hygiene assurance level approach could be very useful for comparing hygiene efficacy across a range of situations, it is important that it is not used inappropriately to set performance requirements unless or until more comprehensive data is available on the relationship between LR and infection risk reduction. This is further discussed below.

Stage 1	Quantify microbiocidal efficacy by suspension tests under laboratory test conditions, relevant to intended use	Provides evidence of ability of microbiocidal products or processes (e.g. heat) to inactivate microbes
Stage 2	Quantify microbiocidal efficacy by surface tests under laboratory test conditions relevant to intended use	
Stage 3	Demonstrate hygiene procedure (product + process) delivers appropriate safety target levels on hands, surfaces and fabrics, under conditions of use and prevents onward transmission	Provides quantitative evidence of reduced exposure to pathogens
Stage 4	Evaluate the extent of reduction of infection rates produced by the hygiene procedure (product plus process) through clinical intervention studies, or QMRA in non-healthcare settings	Used to quantify reduction in infection rates

Table 1 Hierarchy for development of hygiene procedures used on contaminated hands environmental surfaces and fabrics

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3.3 Targeted hygiene – estimating the effect of hygiene procedures on rates of infection in home and everyday life

The aim of stage 4 is to provide a quantitative estimate of effectiveness of the hygiene procedure in reducing infection rates. Although there is still a tendency to demand that studies on the impact on infection rates take precedence, it is increasingly accepted that this is not feasible for home and everyday life. In the home, because routes of transmission via hands, surfaces and fabrics are interdependent, it is impossible to determine separate effects of different interventions, whilst large population sizes required to produce a significant result makes the cost prohibitive. A shift of opinion on this issue is reflected in a 2005 report by the UK Health Development Agency which concluded "Although the randomised controlled trial has the highest internal validity and, where feasible, is the research design of choice when evaluating effectiveness, however, many commentators felt the Random Control Trial may be too restrictive for some public health interventions, particularly community-based programmes. In addition, supplementing data from quantitative studies with the results of qualitative research is regarded as key to the successful replication and ultimate effectiveness of interventions" [33].

In the last 20 years Quantitative Microbial Risk Assessment (QMRA) has been increasingly used to estimate the impact of hygiene procedures on infection rates. QMRA involves using published data (initial pathogen level, extent of transfer via hands and surfaces, infectious dose etc.) to model the chain of infection and give a quantitative estimate of infection risk. The LR in contamination produced by the hygiene procedure (determined by stage 3) is then used to estimate the reduction in infection rates.

In a recent study [34] Ryan et al. used QMRA for setting hygiene safety target levels i.e. for estimating the LR on a surface needed to reduce the infection risk to an acceptable level. For each of 7 microorganisms, data were extracted from the literature and infection risk determined for a scenario where a contaminated surface was touched with fingers, and the fingers then touched the mouth, nose or eyes. Using dose-response models, hand to mouth infection risk calculated for a single touch of the contaminated surface suggested that, on average, 2 LR was sufficient to achieve a 10^{-6} safety target level (deemed as the acceptable level of residual risk) for *E. coli* and *Listeria*, whilst norovirus required an LR of 3.44. For *Pseudomonas* spp, *Salmonella* spp, and *S. aureus* it was estimated that no decontamination process was required. It should be noted that these calculations were based on ambient levels of surface contamination, rather than levels which would occur at critical times.

Risk modelling allows a number of issues to be resolved:

- It can be used to determine the added health benefit from new products or technologies by calculating how a quantifiable increase in efficacy (e.g. using a process which produces a 3 rather than 2 LR) can translate into a significant decrease in the rates of infection within community/national/global populations.
- A 2018 study shows how quantitative modelling can be used to assess the relative impact of different interventions. A mathematical model was constructed using data from a norovirus outbreak on a cruise ship [35]. It was estimated that wiping surfaces with chlorine bleach could reduce the outbreak by 10% (range 3–59%) However if 80% passengers who did not wash their hands changed their hygiene habits, the outbreak could be stopped.

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- QMRA can be used to set safety target levels according to what is considered an acceptable residual infection risk for a particular situation. This contrasts with the current situation where a pragmatic approach based on performance criteria which have been accepted for many years, but have no clinical basis. Since exposure to a given residual dose of pathogens (e.g. from surface to hand to mouth) carries the same level of risk, this obviates the need to carry out all testing stages for every new cleaning or cleaning and disinfection procedure. Once the LR required to meet the safety target level is determined by QMRA, it can be used as a performance standard for any hygiene practice to be used in that situation.

At present, many experts reason that disinfectants or hand sanitizers should only be used in healthcare situations in the home, where there is an infected person, or a person with compromised immunity [36]. The hygiene assurance framework allows us to start by deciding on the safety target level appropriate for the situation, and then consider what sort of hygiene procedure is required to achieve this in the most sustainable manner, either by wiping, by detergent cleaning, or whether detergent cleaning plus a disinfectant product is needed.

3.4 Targeted hygiene and sustainability

Whilst targeted hygiene was adopted as a means to develop effective hygiene practice for home and everyday life, it also provides a framework for building sustainability into hygiene and use of hygiene products because it meets the following criteria:

- It maximises protection against infection,
- It minimises environmental impacts and maximises safety margins against hazards,
- It minimises risks of spreading antibiotic resistance,
- It addresses the question "how can we develop lifestyles which sustain exposure to the right sort of microbes, whilst at the same time protecting against those that cause disease?" [16].

In public and domestic situations, there is pressure to deliver hygiene in a manner which is sustainable. Using data from stage 1 and 2 with stage 3 tests enables us to understand how inactivation and removal processes can work synergistically to optimize LR on hands, surfaces and fabrics. It can be used for developing new approaches to hygienic cleaning, including new cleaning and disinfection agents, new technologies, and surface modification to facilitate detachment. Whilst the Food and Drug Administration and the European Union Biocidal Products Regulations ensure that products making a microbicidal claim are effective and safe, it is also important that these regulations do not restrict future development of new technologies and approaches, where low level microbiocidal action (involving heat or chemicals, including those (e.g. detergents) not registered as biocides) are combined with removal processes (e.g. detergency and rinsing) to deliver hygiene with minimum environmental impact [28].

4 Conclusions

This paper reviews an evidence-based approach for developing hygiene for home and everyday life aimed at reducing the burden of hygiene-related diseases, whilst at the same time addressing sustainability and other issues. It is recognised that the proposals set out in the review do not provide a definitive answer to the challenges we face, but is a unified framework on which to build, in order to achieve this goal.

The need for a sound scientific evidence base underpinning hygiene in home and everyday life is threefold:

- It is required to convince health agencies, health professionals and others that the codes of hygiene practices which are promoted for home and everyday life, if followed, can reduce rates of hygiene-related disease in the community.
- It is required to argue the case with opinion formers, health professionals, environmentalists, immunologists, regulatory authorities etc. for a balanced approach in which hygiene is given equal weighting with other hygiene-related issues.
- It provides an approach which is simple and plausible for the public and community health workers to understand, i.e. breaking the chain of infection, and thus has the potential to restore confidence in hygiene and how it differs from cleaning. The extent to which misunderstanding about hygiene has developed in recent years suggests that hygiene behaviour change is unlikely to happen unless we also work to change hygiene perceptions.

The concept of a targeted approach to hygiene, as summarised in this paper, was discussed by a groups of experts in home and everyday life hygiene, at a meeting in London in March 2017. From this, a consensus white paper outlining recommendation for change was produced [37]. The report concludes that "targeted hygiene" needs to be placed at the heart of a multimodal infection prevention strategy, alongside vaccination and other interventions. To achieve consistent messaging, targeted hygiene needs to be incorporated into all community infection prevention policies.

It was agreed that one of the problems hindering progress is the lack of a unified voice lobbying on behalf of the importance of home and everyday hygiene. There is a need for hygiene experts and professionals, and the private sector to develop a unified approach to hygiene and work to lobby other stakeholders such as environmentalists, immunologists, regulatory authorities and the media to ensure a more balanced approach, where the importance of hygiene is given due recognition alongside other **issues.** We must work together to provide the public with a clear, consistent restatement of the importance of hygiene, and work to change perceptions about hygiene and good hygiene practice.

Although the process of identifying critical points in the chain of infections and the times when there is greatest risk of infection transmission is well supported by scientific data, we need a more robust evidence base for developing hygiene products and procedures which deliver effective hygiene under use conditions and is applicable to detergent-based and other hygiene procedures, as well as those involving microbiocides. The scientific framework for delivering effective targeted hygiene needs to be strengthened through collaborative research by academia and the private sector.

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