Hand Hygiene in the 21st Century: Cleanliness in Context

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A brief history of hygiene

Hygiene is an ancient concept with roots in good health, but in modern times hygiene has become more narrowly defined as rigorous cleansing or even sterilization of skin and environmental surfaces. Despite early recognition of the importance of hand hygiene in particular[1,2], regulations in healthcare settings did not emerge until the 1960s, culminating in the World Health Organization's (WHO) publication of the comprehensive *Guidelines on Hand Hygiene* in 2009. The role of hand drying as an aspect of hand hygiene has been largely ignored until recently[3]. Recognition of the role that residual moisture plays in the transfer of microbes between surfaces[4–7] has focused some attention on this issue, but there remains no consensus to inform recommendations from regulatory agencies; the WHO *Guidelines* include just three paragraphs on hand drying[8], and note that, "Further studies are needed to issue recommendations on this aspect."

The common misconception that "all microbes are germs" is apparent in the majority of studies of hand hygiene, reflected in the focus on bulk reduction in microbial number — even those conducted by clinical microbiologists[9–12]. The concepts of hygiene and sterilization are often conflated, which is perhaps unsurprising given the history of hospital sanitation practices[13]. Hand hygiene is regarded as the most important practice to prevent the transmission of disease, although compliance in healthcare settings has been reported as no better than 40%[13,14].

The human-associated microbiome

Most of the existing literature and the prevailing understanding of hygiene is based on cultivation-based studies (Fig. 1), which entail the growth and enumeration of bacteria in the laboratory. These techniques fail to account for the high abundance and ubiquity of non-harmful — and potentially helpful — bacteria on human skin[15,16]. Modern cultivation-*independent* techniques (Fig. 1), including DNA sequencing technology, have facilitated a deeper exploration of microbial diversity and expanded our understanding of the trillions of bacteria, fungi, and viruses living on the healthy human body, collectively known as the **microbiome**, and their role in maintaining health[17]. Hands harbor greater bacterial diversity that is more variable through time than other places on the skin[18]. Studies that focus on hygiene should take this diversity and ecological context (Fig. 2) into account, recognizing that not all microbes are harmful, and that there is a *continuum* between pathogenic and beneficial microbes. For example, the bacterium *Staphylococcus epidermidis* is commonly found on human skin and is generally regarded as commensal[19], although it can occasionally act as a pathogen[20,21] or a protective mutualist[22]. Despite the growing use of these modern sequencing technologies, there have been no cultivation-independent studies investigating the *direct* effect of hand hygiene and/or product use on the hand microbiome[18].

Defining hygiene

The evidence that microbes are essential for maintaining a healthy skin microbiome supports the idea that hygienic practices aimed at the simple removal of microbes may not be the best approach. Rather, hygienic practices should aim to reduce *pathogenic* microorganisms and simultaneously increase and maintain the presence of beneficial microorganisms essential for host protection. It is clear that microbial colonization of the skin is not deleterious, *per se*. Humans are covered in an imperceptible skim of microbial life at all times, with which we interact constantly. We posit that the conception of hygiene as a unilateral reduction or removal of microorganisms has outlived its usefulness and that a definition of hygiene that is quantitative, uses modern molecular biology tools, and is focused on disease reduction is needed. As such, we explicitly define hygiene as '**those actions and practices that reduce the spread or transmission of pathogenic microorganisms, and thus reduce the incidence of disease**'. To examine the effects of thinking about hygiene in this way, we examine one aspect of the hand hygiene literature in some depth: hand drying.

Hand drying and hygienic efficacy

Much of the existing work on hand drying has examined the "hygienic efficacy" of various methods — typically paper towels, warm air dryers, and jet air dryers. What is meant by "hygienic efficacy" is often left unstated, but usually is measured by change in microbial load, dispersal of microbes from the hands, or some proxy thereof.

Most research has shown that *warm air dryers* may increase the number of bacteria on the hands[23–27], with some exceptions showing no change[26,28–32] or a reduction[33–35]. This increase in bacterial counts could be the result of the existing bacteria within the dryer mechanism[23,27], the re-circulation of microbe-enriched air[36,37], the liberation of resident bacteria from deeper layers of the skin through hand rubbing while drying[11,24,35], or some combination of the above. Additionally, warm air dryers are slower at drying the hands[3,11,12,23,24,24–27,36,38,39], which is thought to reduce compliance with drying (i.e., people walk away with wet hands).

Research on *jet air dryers* has focused on the importance of the total dryness of hands, contrasting the speed of jet air drying with that of warm air dryers and emphasizing the risk of cross-contamination with wet hands[11,12,31,39]. These studies typically employ cultivation and counting to measure the number of bacteria transferred and use residual moisture to measure efficiency of drying. The reduced drying times achieved by jet air dryers are noted repeatedly[12,40,41], with drying times that are generally comparable to paper towels[3,12]. Many jet air dryers (e.g., the Dyson Airblade™) are marketed as designed with a high-efficiency particulate air (HEPA) filter built into the airflow system, which reduces the risk of redistribution of airborne microbes to the hands[11]. However, there is concern about the propensity of such rapid air movement to aerosolize microbes from users' hands or the surrounding environment, as evidenced by the number of studies examining the dispersal of microbial suspensions or some proxy thereof by such devices[12,31,39,40,42]. Particular attention has been paid to the distance such rapid air movement is capable of dispersing potentially contaminated droplets from the hands, though methods typically employed unrealistic microbial loads or artificial proxies such as paint[12,39,40,42].

Drying with *paper towels* is the method recommended for healthcare workers by both the Centers for Disease Control and Prevention[43] and the WHO[8], due in large part to bulk bacterial count data indicating that paper towels are effective at removing surface bacteria[3,24,25,27,35,39,44]. Use of paper towels is also associated with only minimal spread of droplets from the hands[12,39,40,42,45,46], though it is possible that waste paper towels may serve as a bacterial reservoir[28,31]. Additionally, there is great variance in the manufacture and storage of paper towels, which may lead to risk of contamination as part of the manufacturing process, particularly of recycled paper towels[46].

Several Life Cycle Analyses (LCA) have compared other aspects of these different drying systems, including cost effectiveness and environmental impacts[47–48]. In general, impacts are driven by usage, rather than manufacturing or maintenance, and paper towels tend to have greater environmental impacts because the energy costs inherent in shipping bulky materials outweighs the energy necessary to run most air dryers. A holistic consideration of environmental impact of hand drying would include efficacy according to the definition of hygiene we have offered, which may be more important in some contexts than others (such as hospitals).

Recontextualizing cleanliness for the 21st century

Hand drying literature can be divided into two opposing divisions: one attempting to demonstrate that air dryers are as hygienically efficacious as paper towels[11,28,33,46], and the other attempting to discredit the newer air dryer technology in favor of paper towels[3,12,23,39,40,42,44]. While both divisions utilize bulk reduction in microbial load as a proxy for hand hygiene[11,39], research from the first division largely focuses on the potential of wet hands to transfer microbes[5] and the ability of air dryers (whether warm or jet) to effectively dry hands[11,12,28,31]: viewed this way drying is hygienically efficacious *if hands are dry* and new microbes are not acquired through the process. Research from the second division focuses on the risk of air dryers to spread microbes in the environment by aerosolizing moisture from the hands[12,39,40,40,42,45]: viewed this way drying is hygienically efficacious if new microbes are not acquired through the process and if *production of aerosols are minimized*. It is difficult to compare the two divisions because many studies include methodological issues (e.g., variation in protocols, lack of appropriate controls or statistical analyses) that make it difficult to compare results.

Despite there being an obvious interplay between the divisions, many of the concerns on either side remain unaddressed. **Utilizing a definition of hygiene that explicitly relies on reduction in disease spread** would address concerns on both sides of the debate: there is currently no evidence linking aerosolization of residual moisture (and associated microbes) with the actual spread of disease. Likewise, despite demonstrations that wet hands allow for increased bacterial transmission, no evidence was found linking wet hands after washing to deleterious health outcomes. The complex ecological context of the hand microbiome (Fig. 2) may modulate effects of both aerosolization and prolonged moistening. Additionally, the majority of hand drying research largely ignores the relative hygienic contribution of the hand *washing* step[11,28,39,40,42]; understanding the relative contribution of washing to hygienic efficacy is necessary to put the hand drying literature in proper context. Future research should take advantage of cultivation-independent techniques, explicitly include the contribution of handwashing (and other controls necessary to accurately interpret results) and work to increase sample size to ensure statistical rigor. Such research should aim to bridge the gap between the existing divisions of research by using health outcomes (such as the spread of disease) as dependent variables, taking into account the microbial community context of the microbiome, and focusing on understanding the relative contribution of bioaerosols and residual moisture to the risk of disease transmission.

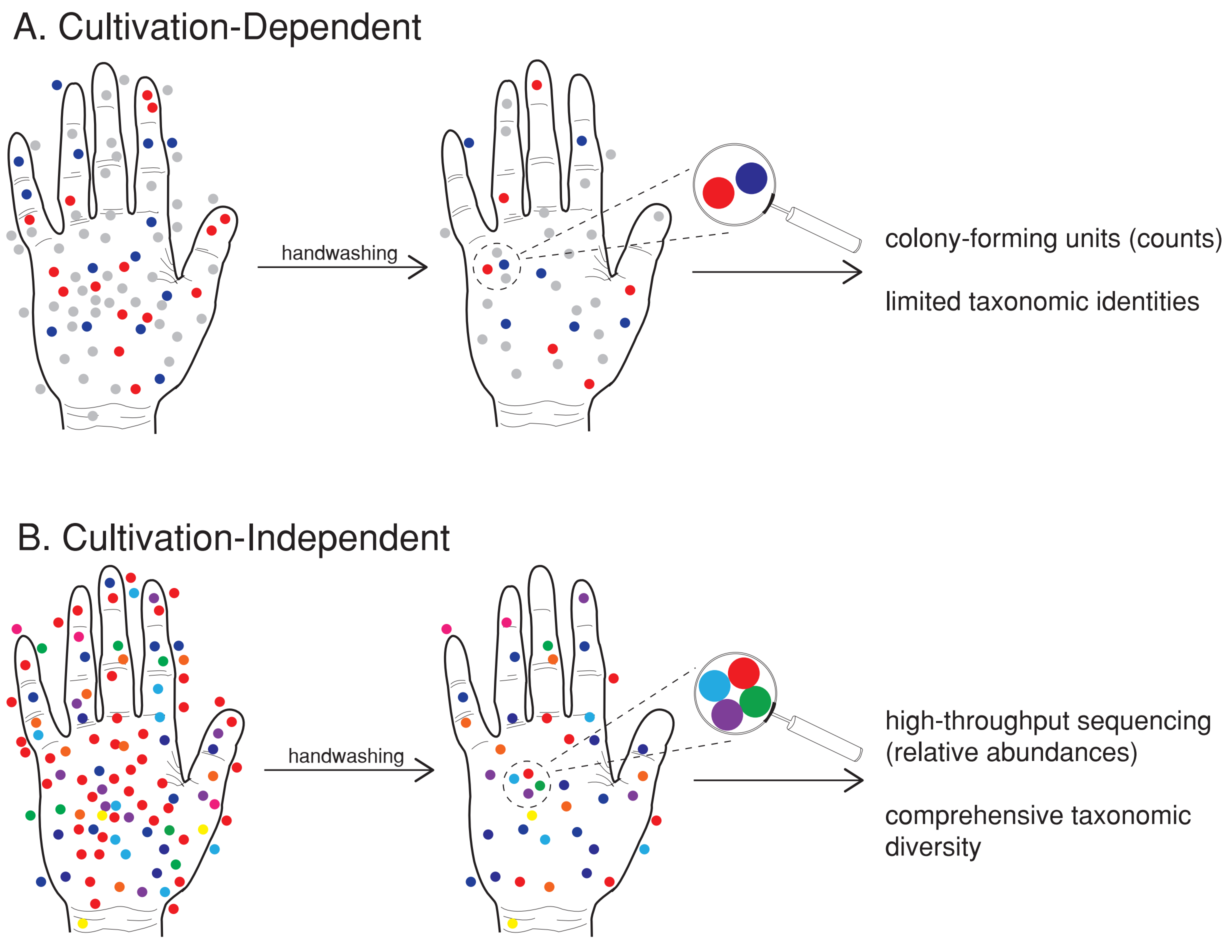

Figure 1: Cultivation-dependent methods (A) are commonly used to study aspects of hand hygiene; many microbes are not detectable using this methodology (represented in grey). Handwashing reduces bulk microbial load, and cultivation yields data showing changes in the numbers of colony-forming units (counts); some studies identify colonies using morphological or molecular methods, yielding limited taxonomic information. **Cultivation-independent methods (B)**, including high-throughput DNA sequencing, are commonly used to study the microbial ecology of the skin. Using these methods, it is possible to quantify alterations in relative abundance of bacterial populations with treatment (such as handwashing), obtain deep, comprehensive taxonomic diversity estimates; depending on technique, it may be possible to also obtain information on functional metabolic pathways (using metagenomics), assessment of proportion of the community that is active (using rRNA / rDNA comparisons, or live/dead cell assays), among other things.

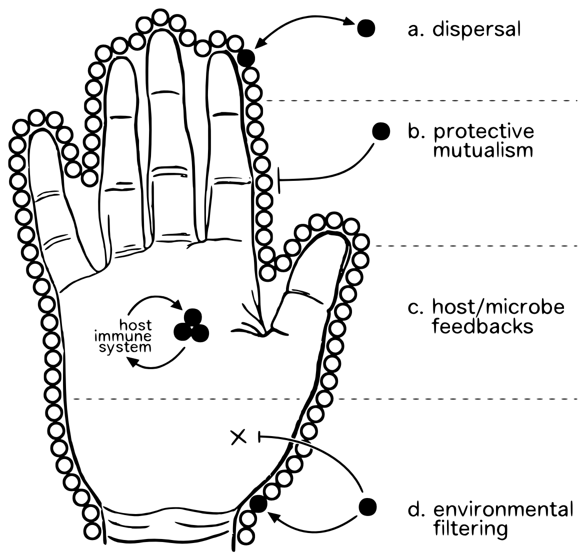

Figure 2: Important ecological factors impacted by hygienic practice. ***Dispersal* (a)** is the movement of organisms across space; high dispersal rates due to human behaviors (e.g., microbial resuspension due to drying hands with an air dryer) have the potential to disperse both beneficial and harmful bacteria alike. In ***protective mutualisms* (b)**, harmful microorganisms are excluded from colonization by the earlier colonization of benign, non-harmful microbes. ***Host/microbe feedbacks* (c)** occur via the microbiota's ability to activate host immune response, and the host immune system's ability to modulate the skin microbiota — such feedbacks between host immune response and the skin microbiota are thought to be important to the maintenance of a healthy microbiota and the exclusion of pathogenic microbes. ***Environmental filtering* (d)** works on the traits of dispersed microorganisms; microbes that can survive in a given set of environmental conditions are filtered from the pool of potential colonists. The importance of ***diversity*** of the microbiota to each of these ecological factors should not be underestimated; interactions between microbes may change their ecological roles, and the overall characteristics of the microbiome may be altered by changes in community membership.

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