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The return of MRSA in a post pandemic world

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Abstract
Since the beginning of the Coronavirus pandemic (COVID-19 virus), society has, and continues to, excessively clean and disinfect surfaces and objects that come into contact with our hands. The COVID-19 virus has been declared a public health emergency by a myriad of health organizations world-wide. While the symptoms of COVID-19 vary, the intensive use of disinfectants in society, associated with COVID-19 pandemic, may give rise to a new pandemic in the form of Methicillin-resistant *Staphylococcus aureus* (MRSA). The reaction of the public's response to COVID-19 pandemic has increased the cleanliness and disinfection of surfaces that may manifest into a new outbreak, because MRSA has the ability to adapt to a changing environment. The effects of consistent use of hand sanitizers could ultimately alter the human microbiome; which, in-turn, creates a change in the diversity of the microbial community, reducing competition and other interactions among the normally diverse microbial communities, leading to possible expansive growth of antimicrobial resistant bacteria, thus making humans more susceptible to not only MRSA, but also other infectious diseases. This article is an overview pertaining to the overuse of hand sanitizers, characteristics of MRSA, its diagnosis, clinical features, and preventive measures to avoid a future MRSA outbreak.

Keywords: Antimicrobial resistance bacteria, COVID-19, hand sanitizer, human microbiome, MRSA, pandemic

Introduction

Most pandemics are generally not a serious public health concern, but they do cause major stress among populations either psychologically, socially, economically, and/or politically [1, 2]. The effects of the COVID-19 pandemic has caused major paradigm shifts that continue to change all aspects of human society. One major shift is how society has become obsessed with the use and misuse of hand sanitizer and disinfecting surfaces, in response to the COVID-19 pandemic, especially since viruses are not capable of reproducing on non-living surfaces [3, 4, 5]. There is a growing concern throughout the scientific community pertaining to the misconceptions and lack of content knowledge pertaining to the concepts of viruses, its replication, and transmission [6, 7]. Furthermore, the number of misconceptions associated with the use and effectiveness of hand sanitizers continues to misinform the general public [8, 9, 10].

The purpose of this review is to summarize published research on the factual aspects of MRSA, discuss the possible future outbreaks associated with the ubiquitous disinfection intensity caused by the COVID-19 pandemic, and discuss how to prevent possible MRSA infections within the general public. More particularly, the focus is to highlight the concepts of MRSA, the advantages and disadvantages of using hand sanitizers, impact of misusing hand sanitizers, and briefly review the basic concepts of virology related to the themes of this paper.

Bacterial resistance is a major threat to the prevention and treatment of bacterial diseases [11]. "Resistance, which enables microbes to escape being killed by antimicrobial (including antibacterial, antiviral, antifungal, etc.) drugs, undermines physicians' ability to treat serious and life-threatening infections" (p. 401) [3] and continues to be a major burden for controlling the rate of infection.

The discovery of antibiotics in the 1940s has led to a significant decline in mortality rates from bacterial infections. The majority of antibiotics that have been introduced into clinical practice have fully manifested their efficacy leading to successfully treating and curing pathogenic bacterial diseases [12]. However, just as there is an abundance of antibacterial drugs, there is also just as many pathogenic bacteria that have developed resistance to these antibiotics [13, 14, 15]; as antimicrobial resistant organisms are one of the greatest threats to human health worldwide [16, 17].

Staphylococcus aureus is often present symbiotically in the human microbiome (HMB), and in a benign form is not pathogenic, specifically occurring in large colonies in our nasal cavity. About 20% of the population are persistent nasal carriers of *S. aureus,* while 30% are intermittent carriers, whereas about 50% are noncarriers [16]. The ubiquity of *S. aureus* significantly makes an individual susceptible to infection by providing a reservoir for the pathogenic emergence of the bacterium. A major challenge associated with *S. aureus* is the remarkable level of acquisition of resistance against multiple antibiotic classes, complicating treatment.

Methicillin-resistant *Staphylococcus aureus* (MRSA) has been, and continues to be, a major public health problem worldwide due to its adaptability and tenacity [18], causing significant illnesses and deaths in hospitals, sports facilities, clinics, and densely populated communities [11, 18, 19]. According to IDSA [3], since the beginning of the millennium, MRSA has killed more Americans every year than emphysema, HIV/AIDS, Parkinson's disease, and homicide combined; and is regarded as a "serious threat" and is of the biggest antimicrobial-resistant pathogens [20]. Figure 1 illustrates several methicillin-resistant *Staphylococcus aureus* (MRSA) organisms.

MRSA, a bacterial skin disease, is known to be resistant to several antibiotics, specifically methicillin, by possessing the *mecA gene*. MRSA is commonly transmitted throughout a community by contact with infected people (skin-to-skin) or by touching contaminated objects (cross-contamination). This includes person-to-person contact with a contaminated wound, nosocomial infection, or by sharing personal items, such as towels, clothing, or razors, that have touched infected skin [21].

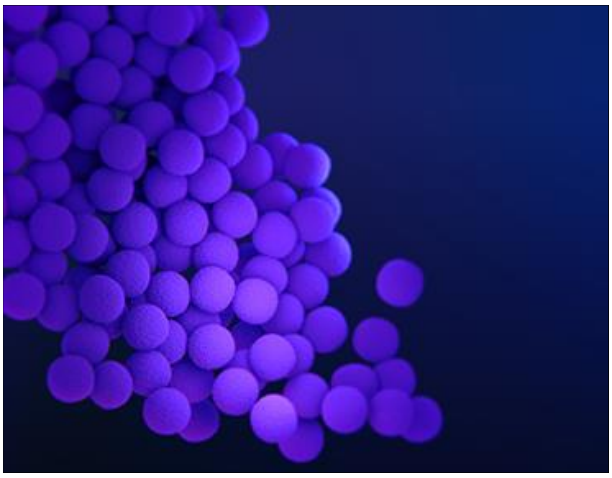

Fig 1: Several methicillin-resistant *Staphylococcus aureus* (MRSA) organisms. Content source: Centers for Disease Control and Prevention, National Center for Emerging and Zoonotic Infectious Diseases (NCEZID), Division of Health Care Quality Promotion (DHQP).

MRSA has not been a topic of discussion in the medical or scientific community ever since the emergence of COVID-19 pandemic. Yet, the ubiquity of hand sanitizers and disinfectants that have been introduced into the global market, the constant disinfecting of surfaces, and the unintentional alteration of the HMB from continuous hand washing and sanitizing may increase our susceptibility to MRSA, leading to re-emergence during or after the COVID-19 pandemic.

Origins of MRSA

In 1959, methicillin was introduced to treat infections caused by penicillin-resistant *S. aureus.* The bacterium *S. aureus* is part of the normal flora of the mucous membranes in the nose. In a methicillin resistant form, it is also an opportunistic pathogen that has the ability to colonize on the skin and mucous membranes of humans [16, 22]. MRSA was first discovered as early as the 1960s in a clinical setting in the U.K. and Denmark by extrapolating blood isolates. Within the same time period, the incidence, prevalence, and mortality rate among hospitalized patients increased due to MRSA infections world-wide [11, 16, 18]. "Approximately 5% of patients in U.S. hospitals carry MRSA in their nose or on their skin" [21]. Additionally, MRSA was isolated from other European countries, and onwards from the other parts of the world, including such nations as Australia [23] Brazil [24], and the United States [25].

Prior to the turn of the century, more than half of *S. aureus* infections in the United States intensive care units were caused by MRSA, causing hospitals to establish surveillance programs for tracking MRSA infections. More recently, the number of deaths from antibiotic-resistant infections in hospitals has decreased from 28% from 2012 to 2017, however, in a 2019 *Antibiotics Resistant Threats Report*, MRSA continues to cause more than 85% of the total bacterial deaths [21].

The origins of MRSA are still not fully understood [11, 16]. Yet, understanding the genomic principles and epidemiological occurrences of MRSA is crucial to establishing public health awareness, especially during the COVID-19 pandemic, to control a possible future MRSA outbreak. *S. aureus* is a very adaptable organism, thriving in a myriad of environments, thus increasing its opportunity, to evolve and develop new strains, which, in-turn, causes new types of disease.

Types of MRSA

MRSA infections are categorized into (1) hospital-associated (HA-MRSA) infections, which most frequently occurs among inpatients and is commonly multidrug resistant [11], (2) community-associated (CA-MRSA) infections, which occurs in in healthy individuals and is usually limited to β-lactam resistance [16, 19], and (3) livestock-associated MRSA (LA-MRSA) [26]. The major differences among the three categories are the clinical and molecular features, the antibiotic susceptibility, and drug-treatment [11, 16]. Some have argued that, because of the ubiquitous prevalence of MRSA in hospitals, it can be almost exclusively regarded as hospital-associated pathogen [16, 19].

MRSA genomes

Whole-genome sequencing is a modern technique for identifying the characteristics, classification, and diversity of any organism. A number of MRSA genomes have evolved since the introduction of methicillin [14, 27]. Using whole-genome sequencing several *S. aureus* and methicillin-resistant strain genomes are now available for scientific research and use, to track and better understand the spread of MRSA. Using whole-genome sequencing to identify MRSA strains that are likely to cause severe disease and/or possess drug-resistance will help decrease the rate of infection.

Epidemiological effects of MRSA

The Center for Disease Control and Prevention [20] "estimates that MRSA is responsible for more than 70,000 severe infections and 9,000 deaths per year" across the United States and is a major health problem world-wide.

Chen and Huang [26] reported the prevalence of MRSA in the majority of hospitals and medical facilities (nosocomial infections) in East Asian countries (Taiwan, Korea, Japan, Hong Kong, and China). Korea accounted for approximately 77.6% of MRSA linked to nosocomial infections during the years 2004–2006; and China, accounted for approximately 45.8% in 2011. In Southeast Asia, "a study showed MRSA rates of 38.1% for the Philippines, 57% for Thailand and 74.1% for Vietnam in 2004–2006" p.608 [26]. The Russian outbreak of MRSA related to healthcare-associated infections in 2012, decreased to 16.63% compared to 32.09% in 2007 [28].

In 2008, nearly 400,000 hospital-acquired infections due to antibiotic-resistant bacteria were estimated to be acquired throughout Europe; MRSA accounted for 44% of infections [29].

Brazil reported the spread of a single HA-MRSA clone in 8 of 9 hospitals, which was the cause of the "Brazilian epidemic clonal complex" [24]. In Argentina, the number of MRSA cases causing nosocomial infections increased from 45 to 58% during 1996 to 2001 [30].

Fortunately, all of these countries have had a decline in MRSA cases by improving conditions in their hospitals and medical facilities, surveillance programs, and taking preventative measures to prevent the spread of MRSA. Figure 2 presents MRSA infection rates worldwide.

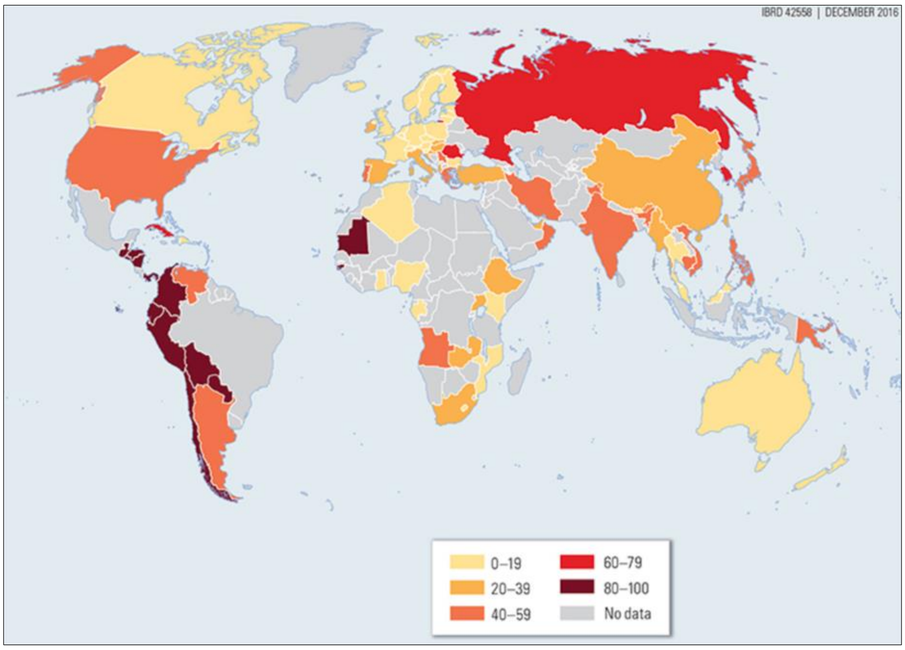

Fig 2: MRSA infection rates worldwide. Content source [31].

Evolution of MRSA

As mentioned above, MRSA emerged within one year after the introduction of methicillin. The adaptive response of MRSA occurs through a number of genomic factors: resistance to methicillin antibiotics is caused by the *mecA* gene, gene transfer, the absence or presence of the mobile element staphylococcal cassette chromosome mec (SCCmec), and through mutation [17, 22]. Furthermore, other factors include disease-enabling environmental settings: antimicrobial consumption, overcrowding, lack of clean water, and poor hygiene [17, 26]. These evolutionary factors do not cause the bacterial organism to be more innately infectious; however, it does make MRSA infections more difficult to treat [11, 22, 32] and thus more dangerous, particularly in hospitalized patients, athletic settings [19] and for individuals with compromised immune systems.

The National Institutes of Health [33] lists MRSA as an emerging infectious disease and an urgent threat to public health; and references the drug vancomycin as a powerful defense against MRSA; stating that the overuse of vancomycin on MRSA patients has led to the evolution of vancomycin-resistant SA (VRSA). The understanding of MRSA and its evolution has benefited from the development of molecular tools and bioinformatics and methicillin resistance determinants [17, 22]. Both of these techniques as well as other modern technology-based tools including polymerase chain reaction (PCR), whole genome sequencing, and bioluminescence, has revealed that MRSA has evolved into phylogenetic ally distinct lineages [30], and can easily cause a new pandemic in response to excessive hand sanitizing, that can coincide with the COVID-19 pandemic. Ideally, these emerging bio-technological techniques will be inexpensive, easy and thus applicable to use at the "point-of-care, and will lead to improved health care outcomes, reduced health care costs, reduced antibiotic resistance, and enhanced novel antibiotic development" (p. 402) [3].

Hand sanitizers

Hand sanitizer is typically an alcohol-based liquid, gel, or foam used as a disinfectant to reduce the number of pathogens on the surface of the hands. The effects of hand hygiene to combat contact-borne and cross contamination is a well-known practice in the food and restaurant industry, schools, athletic facilities (gyms), and hospitals. Hand hygiene is the simplest and most effective measure to reduce the spread of disease and infection [15]. Hand sanitizers and other antimicrobial agents have been, and continue to be used, to prevent infectious diseases from spreading and has successfully reduced illness and death from infectious microbial species.

Hand washing is an important means of preventing the spread of infection if practiced correctly as documented by the CDC [34]. While hand washing may not be accessible to everyone in some daily situations, hand sanitizers are very convenient, easy to use, and useful to disinfect and reduce the number of microbes on the hands, and thus controlling the rate of infection. However, epidemiologic studies have shown beneficial and detrimental effects of the use and misuse of hand sanitizers [10, 15, 35].

The use of hand sanitizers has become ubiquitous throughout the healthcare setting since 2002 [10, 36], and since the impact of the COVID-19 pandemic. Organizations such as NIH, WHO, and CDC have been assisting the general public with the best practices for hand washing and hygiene to protect themselves and society from spreading contaminated diseases [34], more generally, while specifically helping to prevent the spread of COVID-19 pandemic. Concurrently, the majority of the public has increasingly purchased and overly used disinfectant products and hand sanitizers with no regard for using these products responsibly or the consequences of misusing them [8]. This excessive use of disinfectant products and hand sanitizers very likely may lead to the expansive growth of antimicrobial resistant bacteria [8, 12]. There is a growing concern throughout the scientific community that the sudden overuse of cleaning products and hand sanitizers during the COVID-19 [36], pandemic could lead to an increase in the populations of antimicrobial-resistant bacterial species, specifically MRSA, which in-turn, will affect and alter the HMB.

Advantages of using hand sanitizers

The research of Fendler *et al.* [32] concluded that there was a 30.4% decrease in infection rates over a 34-month period in health care facilities where hand sanitizers were used. This research concluded that by using a hand sanitizer once to three times a day significantly reduced the presence of viruses; indicating the use of hand sanitizers completely stopped the transfer of viruses to, and their replication on, hands, surfaces, and fomites.

Disadvantages of using hand sanitizers

Gold *et al.* [37], highlights the myriad of microorganisms that are immune to hand sanitizer and other alcohol-based disinfectants. For instance, alcohols have very poor activity against protozoan (Cryptosporidium), viruses (norovirus), and bacterial spores (*Clostridium difficile*). Many studies have found an association between the consistent uses of hand sanitizers to an increased risk of outbreaks of associated with these microorganisms.

Weaver [38] reported the frequency of hand washing with soap and antiseptics tends to cause chronic contact dermatitis, disrupt the normal flora/microbiome of the skin, which can lead to the colonization, and overgrowth, of MRSA. The research of Jing *et al.* [9] emphasizes the use of hand sanitizers can be damaging to the skin by the denaturation of biological molecules that are naturally produced in the skin; especially depletion of the lipid barrier, which in-turn, alters the HMB, resulting in more frequent colonization by resistant bacterial species. Table 1 lists the advantages and disadvantages of using hand sanitizers. Table 1 lists the advantages and disadvantages of using hand sanitizers.

Table 1: Summary of advantages and disadvantages of using hand sanitizers.

Advantages of hand sanitizers	Disadvantages of hand sanitizers
Quick, easy, and effective to use.	May lead to antibiotic resistance
Stops/reduces the spread of pathogens	Affects human immune system
Promotes health hand hygiene	Alter the human microbiome
Portable	Dryness of the hands
No hand drying by products (hand towels and hand dryer)	Exposure to harmful chemicals
Convenient for large groups (classrooms, offices, etc.)	Does not clean and/or disinfect all pathogens

The human microbiome

The human microbiome is the aggregate of all microbiota that reside *on* or *within* human tissues and biofluids along with the corresponding anatomical sites in which they reside, including the skin, mammary glands, placenta, seminal fluid, uterus, ovarian follicles, lung, saliva, oral mucosa, conjunctiva, biliary tract, and gastrointestinal tract. (e.g., oral cavity, respiratory tract, gastrointestinal tract (gut) and vagina). These microorganisms exist across a diverse ecological spectrum from pathogen through commensal to mutualist [15]. Table 2 shows some common microorganisms (benign and/or pathogenic) that are symbiotically part of the HMB [39]. For example, *Woesearchaeota* is a recently discovered Archaean member of the HMB, and usually is present in natural environments. These single-celled organisms have similar genetic, biochemical, and structural characteristics with both eukaryotic and bacterial organisms and reside in the human colon and oral cavity [39], and also share some characteristics with pathogens that cause disease among humans.

Table 2: Common microorganisms that are part of the HMB.

Bacterial	Fungal	Protozoan	Viruses	Archaea
Clostridium	*Aspergillus*	*Cryptosporidium*	*Enterovirus*	*Methanobacterium*
Corynebacterium jeikeium	*Candida*	*Giardia intestinalis*	*Rotavirus*	*Woesearchaeota*
Corynebacterium aurimucosum	*Debaryomyces*	*Entamoeba histolytica*	*Norovirus*	
Lactobacillus casei	*Malassezia*			
Neisseria sicca	*Penicillium*			
Staphlococcus epidermidis	*Saccharomyces*			

What are viruses?

The term "virus," was first used by Louis Pasteur, from the Latin word meaning "poison." Viruses are infectious particles that cannot reproduce by itself nor are considered to be living; however, viruses require a living host in order to replicate. Viruses are not cells. They are incapable of autonomous reproduction, it have no nucleus, organelles, or cytoplasm, and are smaller than most bacterial and pathogenic microbes. Viruses do have genetic material (nucleic acid) either in the form of DNA or RNA. When viruses do infect susceptible cells, viruses display some characteristics of living organisms. Viral replication requires that a virus particle *virion* (the complete, infective form of a virus outside a host cell, with a core of RNA or DNA and a capsid) infect a cell and program the host cell's genome to synthesize the components required for the assembly of new virus particles that can be released from the infected cell and thus spread the infection.

Viral host range

Viruses are capable of infecting all forms of life (hosts). However, most viruses are limited to only one host and to only one specific cell of that host. For example, the influenza virus does not cause any infection in dogs; and yet it causes severe symptoms and death in humans. In contrast, the rabies virus that we typically associate with infected dogs can attack the central nervous system of many mammals, including humans, but not some other animals.

Viral host specificity

The specific types of cells that a virus can infect is determined by a number of *specific* actors including a virus's ability to attach to, penetrate, and infect a host cell. For example, papillomaviruses infect only skin cells of humans. In contrast, the AIDS virus, known for its lethal effects, attacks cells of many systems of the human body, but particularly those of the immune system. Rubella, measles, chickenpox and shingles are all diseases of the skin causing rashes and lesions, yet Human Papillomavirus (HPV) causes warts and cancer. HPV infections last a lifetime even if warts are removed.

Survival of viruses on surfaces

As mentioned above, viruses require a host in order to replicate. Hence, since surfaces are not living, viruses are not capable of replicating on a surface, but some are capable of remaining infective on surfaces for varying amounts of time if they come into contact with a susceptible host surface (for example the mucous membranes of nose, mouth, and eyes). The potential of a virion particles spreading on a contaminated surface depends particularly on variables including, the physical environment, biological, and chemical factors [5, 40]. Previous research has shown that under these variables, certain virion particles can persist for extended periods on non-living surfaces; but the length of time that the virus would be considered to be "infectious" decreases significantly over time. However, evidence from concerning the role of virion particles, their existence on non-living surfaces, and viral transmission from non-living surfaces has conflicting opinions from experts in the field of virology [4, 5, 40].

So why the consistent disinfection and cleaning of surfaces since the COVID-19 pandemic? "Cleaning and disinfection of contaminated surfaces are one of the frequently implemented measures to control transmission of pathogens in indoor environments" (p. 7769) [41]. While this is a valid point to control and prevent the spread of pathogens (bacterial, protists, and fungal), viruses are not capable of replicating on a surface without a cellular host [40, 42, 43]. The dichotomy of whether viruses are "living or not living" is a continued debate among scientists, researchers, and scientific educators. Moreover, following several discoveries, and general advances, in molecular biology (including the outcome of the genomic and post-genomic era) these insights have recently contributed to a revision of the position of viruses in the living world [42].

CDC guidelines

For the general public, the CDC suggests washing the hands with soap and water for specified intensity and duration, as opposed to using hand sanitizers, whenever possible. This is because hand washing can virtually remove all types of pathogens, while the hand sanitizer can effectively kill up to 99.9% of germs (e.g., less effective with *Cryptosporidium*, *Clostridium difficile*, and norovirus). Additionally, the CDC does recommend frequent hand washing and/or sanitizing for individuals in the healthcare settings, due to the potential risk of nosocomial infections [34].

WHO guidelines

For health care workers, the WHO has implemented multimodal strategies for promoting hand hygiene for the purpose of reducing and preventing the transmission of pathogenic microorganisms. This includes educational programs, using automated sinks, and using hand sanitizer for routine hand antisepsis. However, if hands are visibly soiled, wash hands with soap and water. It should also be noted that hand sanitizer and soap should not be used simultaneously.

FDA guidelines

To the general public during the COVID-19 pandemic, the FDA advises the use of hand washing with soap and water for at least 20 seconds, especially after going to the bathroom, before eating, and after coughing, sneezing, or blowing one's nose as opposed to using hand sanitizer. This is more effective to prevent the spread of pathogenic microorganisms. Moreover, there is currently no evidence that hand sanitizers are any more effective at preventing illness than washing with plain soap and water. In fact, some data implies that hand sanitizer could do more harm than good in the long-term.

Implications and recommendations

MRSA, infectious and difficult-to-treat bacterial organisms, that can augment its genome creating new virulent strains to colonize has been proven to be a particularly adaptable pathogen with the recognized ability to develop resistance to a number of antibiotics [27, 30]. It seems plausible that if society continues to excessively create a germ- free environment by continuing to over-use hand sanitizers, then a MRSA outbreak may inevitably be a consequence.

Hand hygiene survey

As part of a Science Education Partnership Award (SEPA) to the American Museum of Natural History, a kiosk survey was used in 2018 to obtain the public's knowledge of microbes to assess gaps in public knowledge of this topic. The survey's main goal was to promote public awareness and improve the understanding of the critical impact of biodiversity on human health with specific attention to the human microbiome [44]. This survey was exceptionally valuable in influencing critical conversations on national science education and science policy associated with human health, microbes, antibiotics, and hand the use of sanitizers [44].

The results of the responses to Item 1 on the survey are presented as Figure 3. Item 1 was used as a subjective question to provide more precise information on some of the hygiene habits of the public.

1. "How many times on a normal day do you use hand sanitizer"?

1. 0
2. 1
3. 2
4. 3
5. 4
6. 5 or more
7. I don't know what hand sanitizer is

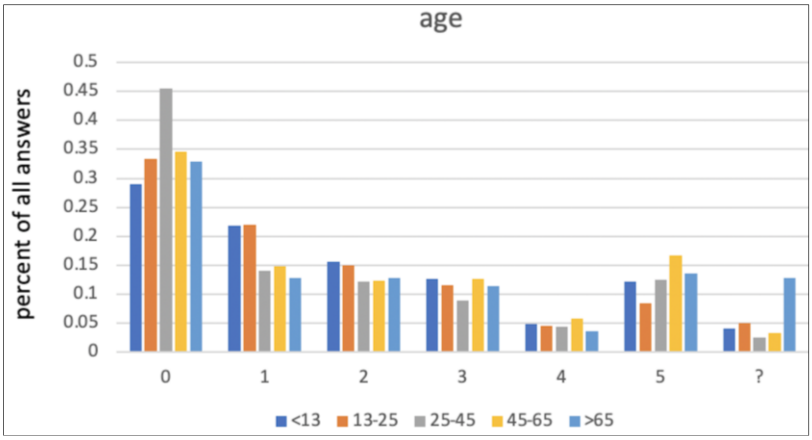

Fig 3: Bar graph of the percentage of individuals by age responding to "How many times on a normal day do you use hand sanitizer"? Item 1.

The results of this survey showed that the participants from ages 25-45 did not use hand sanitizer on a normal daily basis; participants less than 13 years old and from ages 13-25 used hand sanitizer once on a normal daily basis; a similar response from all ages used hand sanitizer two-three times on a normal daily basis; the majority of the participants used hand sanitizer four times on a normal daily basis; ages 45-65 used hand sanitizer five times on a normal daily basis; and ages 65 and older were not aware of what hand sanitizer is.

The bar graph in Figure 4 presents data on the percentage of responses to four items (1 to 4) shown below that were used to obtain information on the public's daily use of hand hygiene and hand sanitizer use.

1. "It is healthier to use hand sanitizer regularly in addition to soap."
2. "Using hand sanitizer a few times a day is a healthy habit."
3. "Hand sanitizer is a convenient alternative to hand washing."
4. "Hand sanitizer should only be used when you have no other option."

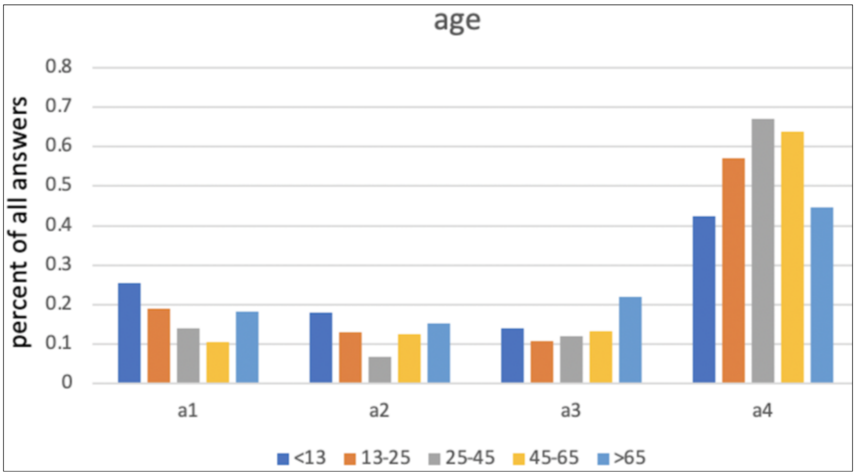

Fig 4: Bar graph of the percentage of individuals by age responding to the public's daily use of hand hygiene and hand sanitizer use, Items 1-4.

Generally, most of the participants had a less favorable response to the belief that it is healthier to use hand sanitizer regularly in addition to soap; whereas the participants under the age of 13 believed using hand sanitizer regularly was healthier than soap. Participants between ages 23-45 did not favor believe that using hand sanitizer a few times a day is a healthy habit; whereas the participants under the age of 13 believed using hand sanitizer a few times a day is a healthy habit. A significant number of participants over the age of 65 responded in favor of hand sanitizer is a convenient alternative to hand washing. A significant number of participants ages 23-65 agreed that hand sanitizer should only be used when you have no other option.

The need for a new curriculum reflecting on COVID-19

Students recognize that certain concepts associated with microbiology, such as sexually transmitted diseases, the process of cleaning and disinfecting surfaces, and harmful bacteria, are fundamentally important to learn in a life science/biology course. If a teacher asks a group of novice learners to list some prior content knowledge pertaining to microorganisms or diseases they can do so easily [45]. Students have an intuitive understanding that washing their hands after they use the bathroom, before they eat, or when touching dirty objects. Hence, as an extension of this advice, they have been taught or programmed to use hand sanitizers consistently when in school and/or work [8].

Students also know intuitively that microorganisms vary in occurrences and in particular regions (epidemiology). If a teacher asks, "how do infectious diseases or microorganisms spread?" the students will most likely answer: through the air or by sexual intercourse. The reality is, most do not know, because they are generally not taught during their lower or middle school years that infectious diseases are transmitted by several modes, which are usually grouped into three categories (1) contact transmission, (2) transmission by vectors, and (3) transmission by vehicles. Table 3 presents an overview of these transmission modes.

Table 3: Overview of categories by which diseases can be transmitted.

Contact transmission	Vehicle transmission	Vector transmission
Direct contact: animal bite, sexual intercourse	*Waterborne*: sharing a glass, swimming, sewage	*Mechanical* (on an insect bodies): ticks, flies, fleas, lice, and mosquitoes.
Indirect contact: through nonliving objects/fomites: stepping on a rusty nail, cross contamination	*Airborne*: breathing, sneezing, coughing	*Biological*: life cycle of the microorganisms continues inside of the host
Droplets: sneezing coughing	*Foodborne*: undercooked food, refrigerated poorly	

Many students and the general public are bombarded with misconceptions pertaining to disease prevention and treatment. In these cases, many students and the general public believe what they view on television and internet to be valid [46]. For example, COVID-19 as well as other viruses have the ability to live and thrive on nonliving surfaces.

To some extent, there is a small number of science classes that teach and focus on concepts associated microbiology. Designing and developing a curriculum and/or lesson ultimately depends on the teacher; especially when a teacher is not familiar with, in this case, microbiology, or the curriculum's content [47]. Implementing additional microbiology topics to an existing course, or teaching it as a separate course, could help to correct some of these common misconceptions [47]. For example, there was a time when middle and secondary school students believed that one could acquire the AIDS virus from a toilet seat [48]; and another common misconception of the 21st century that still exists regarding viruses as some kind of living organism (animal or bacterial cell) [7]. In further support of this finding, Simon *et al.* [7] analyzed middle, secondary, and undergraduate school students prior content knowledge pertaining to viruses (structure, function, replication, medical treatment) and viral misconceptions. Items related to specific knowledge about viruses were generally low. However, content knowledge pertaining to prevention against specific viral diseases by vaccination was high. Still, many students had misconceptions regarding viruses being cellular and how viruses were acquired.

If we succeed in educating students about what viruses are, how they are transmitted, and how to prevent infection, then we as educators can begin to move them toward real understanding of microbial and viral concepts.

Conclusions

In wake of the COVID-19 pandemic, the importance of proper hand hygiene, the use of disinfectants, social distancing, and standing six feet apart from each other all have been brought to the spotlight. The attempts to protect ourselves from COVID-19 by excessively overusing hand sanitizers and disinfectants may have future detrimental effects on our microbiome and consequent invasion of the skin by opportunistic potentially infective microbes such as MRSA that exploit the lack of competition by the normally more abundant benign microbes of our HMB. MRSA will continue to remain an important area of research and development, and through science education awareness. Teaching students' microbiology and viral concepts (viral structure, replication, diseases, and transmission, and epidemiology) at all academic levels, and methods to prevent infection, may thus have direct effects on students' health [7]. Lastly, scientific knowledge must progress to advance and establish science-based recommendations for using hand sanitizers and disinfectants.

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Competing interests

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Authors' contributions

Sole author.

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