

REVIEW ARTICLE

Do reusables pose greater infectious risks than disposables for consumer goods? A systematic literature review

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Highlights

- Very few studies specifically assess the safety or infectious risks of reusable and single-use food serviceware.
- In general, pathogens will survive on most fomites, especially those with higher porosity and in higher humidity settings.
- The literature does not point to reusable containers as major pathogen transmission sources; thus bans on reusable items may be inappropriate.
- As the adoption of reusable serviceware increases, protocols and guidelines for the general public should be established to help maintain health and safety.

Abstract

Increased concern over climate change and the emergence of the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) virus resulted in a clash of political directives around reusable and disposable food serviceware. Decreasing single-use items will likely reduce consumption and environmental emissions; however, improper cleaning of reusable items could result in greater risks of disease transmission. We sought to assess the risks of reusable and disposable food serviceware and document disinfection protocols by conducting a systematic literature review of articles that assessed materials or products that could be fomites to specific food-borne pathogens. After initial screening, the study team extracted data from 122 articles. The most common pathogens studied were *E. coli* (25% of included studies), general bacteria (24%), and Norovirus (16%). Thirteen studies (8%) focused on SARS-CoV-2. A majority of studies analyzed plastics (27%), stainless steel (22%), or porous surfaces such as paper and cardboard (12%). Forty seven of the studies (35%) were conducted in a food service setting, and 40 studies (30%) tested disinfection techniques. Despite a large body of related literature, there is very little evidence suggesting that either reusable or disposable food serviceware is safer for minimizing infectious risks. Pathogens can survive on various fomites, though greater surface porosity and higher humidity levels increase viability of most pathogens. There appear to be no major differences in pathogen viability on various fomites. There is a paucity of research that can specifically aid in developing policy or guidelines for appropriate use of reusable food serviceware. Though given recent studies on SARS-CoV-2, banning reusable bags and food serviceware is an inappropriate response to this particular pathogen, which is rarely spread through surface contact. Further research is needed that explicitly studies pathogen viability, transmission risks, and appropriate disinfection techniques for disposable and reusable food serviceware in order to devise effective sustainability policies.

Keywords: *single-use plastic; reusable; food service; pathogens; fomites; infection; sustainability*

Received: 3 September 2023; Revised: 8 October 2023; Accepted: 8 October 2023; Published: 7 October 2024

In recent years, there has been increasing concern over the growth of single-use and disposable consumer plastics consumption and the resulting environmental and health issues.^{1,2} First developed in the 1800s, plastic production has exploded from 2 million metric tons in 1950 to 348 million metric tons in 2017, and is expected to double in production rate by 2040.³ Driven by convenience, cost, and perceived safety, consumer products and their packaging are often made of single-use and disposable plastics. Of the 335 million metric tons of global plastics produced in 2016, 5% was used to make carrier bags, 6% for plastic bottles, 4% for household goods, and 2% for food services disposables.³ Most plastics are manufactured from fossil fuel-based feedstocks, leading to a variety of environmental pollution as a result of oil and gas extraction.⁴ Though generally considered stable, plastics are known to leach hormone-mimicking chemicals called phthalates which can disrupt biological systems and cause cancers in humans and other animals.⁵ Plastic end-of-life has much to be desired, with one study estimating that of the ~6.3 billion metric tons of plastics ever made only about 9% has been recycled.² Geyer et al. estimate 12% has been incinerated, releasing hazardous air pollutants such as dioxins,⁶ and 79% has accumulated in landfills or the natural environment.² Single-use plastics are some of the most commonly found litter during beach clean ups and are estimated to make up 60–95% of global marine plastic pollution.⁷ With a flourish of media attention, The Ellen MacArthur Foundation released a report estimating that by 2050, there will be more plastic in the ocean than fish, by weight.¹

In response to these alarming statistics, many retail stores began to encourage customers to bring reusable bags or reusable containers for coffee and leftover food. In addition, many federal, state, and local governments targeted single-use plastics in the food service sector, creating regulations that disincentivized or banned items such as plastic grocery bags, plastic straws, and polystyrene takeout containers.

Many of these policies were quickly reversed in early 2020, however, as the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) (coronavirus disease 2019 [COVID-19]) pandemic emerged. Many grocery stores prohibited reusable shopping bags and restaurants and coffee shops banned reusable takeout containers, for fear of spreading the virus causing COVID-19.

The Plastics Industry Association submitted a letter to the US Department of Health and Human Services, citing three studies that highlighted the potential of reusable bags to carry and transmit pathogens; however, none of the studies referenced investigated coronaviruses, such as SARS-CoV-2.⁸ One study looked at a single outbreak of norovirus, a very contagious gastrointestinal (GI) virus, but was unable to differentiate between the handling of

the food and the handling of the bag containing the food.⁹ The other two studies explore potential for contamination inside reusable bags, and not transmission risks to staff and other customers using the bags. Both recommend regular washing of bags and other hygienic protocols be encouraged with the general public.

The harms of single-use plastics on public health and the natural environments on which humans depend should be addressed, and they need to be balanced with the potential risks of spreading pathogens in the consumer goods and food service sector. Therefore, this study systematically reviews existing scientific literature focused on the viability of SARS-CoV-2, as well as common pathogens causing foodborne illness, on common food-contact surfaces (fomites). Study fomites include carryout bags, reusable and single-use foodware, and the different materials used in these products. We examine the literature to determine transmission risk and effective decontamination strategies for specific pathogens, as well as to identify opportunities for further research to inform safe and environmentally sustainable alternatives to single use consumer plastics in the food sector. It is our hope that by better understanding the risks of various pathogens on multiple types of surfaces in the food service sector, we might design a system that is both safe AND environmentally sustainable.

Methods

Following the PRISMA guidelines for systematic reviews, in October 2021, a trained medical librarian (TR) performed searches for studies without language or date restrictions in the Medline, Inspec, and Embase databases. (Medline search strategy available in Appendix.) The citations of relevant Systematic Reviews and included studies were screened for additional studies. Abstract and full text screenings were completed in Covidence systematic review software by at least two members of the research team (HB, MS, ML, YG), using the inclusion and exclusion criteria shown in Table 1. Conflicts were resolved through consensus. Data were extracted from each included paper by two members of the research team (MS, MT, RA, YG) with any discrepancies addressed by a third reviewer. Studies were excluded if they focused exclusively on hospital acquired infections such as *Staphylococcus aureus* or *Pseudomonas aeruginosa*, and water-borne pathogens (as from wastewater treatment). After an initial screening process, the team decided to expand exclusion criteria to remove papers focused on antimicrobial properties of silver and copper, studies that may have fomites (specifically plastics) mentioned above but focused on a medical setting, and studies where the fomite was solely hands or cell phones. Additionally, non-English studies were excluded during full text review.

Table 1. Study inclusion and exclusion criteria

| Category | Inclusion criteria | Exclusion criteria |
|--------------------|--|--|
| General | <ul style="list-style-type: none"> • Studies on the survival rate, load and transmission or transfer efficiency of stated pathogens on one or more of the surfaces/materials of interest. • Studies that look at the decontamination efficacy of stated on surfaces/materials of interest • Human/public health impacts and/or food safety impacts of bacterial/viral contamination of surfaces investigated • Studies that provide evidence and recommendations to reduce fomite transmission from stated pathogens • Peer-reviewed <ul style="list-style-type: none"> ▪ Include non-peer reviewed and preliminary findings for SARS-CoV-2 articles ONLY | <ul style="list-style-type: none"> • Not in English • Not Original Research • Methods Development Only • Animal Model Only • Not Fomite of Interest • Incorrect Pathogen • Hospital Study (EXCEPT fabrics and stainless steel when the pathogen is of interest) |
| Fomites, products | <ul style="list-style-type: none"> • bags (plastic single-use, plastic reusable, cloth reusable) • single-use and reusable takeout food ware (ex. plates, bowls, cups, trays, glasses, straws, stirrers, condiment cups, and utensils) | <ul style="list-style-type: none"> • Studies that do not include surfaces/materials of interest • Hands or hand-to-phone transmission |
| Fomites, materials | <ul style="list-style-type: none"> • List of plastic resins of interest: <ul style="list-style-type: none"> ▪ Polyethylene terephthalate (or PET) ▪ High-density polyethylene (HDPE) ▪ Low-density polyethylene (LDPE) ▪ Polypropylene (PP) ▪ Polystyrene (PS) ▪ Bio-based or mixed plastic resins (ex. PLA, PHA) • List of 'natural' materials of interest <ul style="list-style-type: none"> ▪ Wax-coated paper or cardboard ▪ Uncoated paper ▪ Bamboo ▪ Treated paper ▪ Molded fiber ▪ Cloth (cotton, hemp, etc.) • Other materials of interest <ul style="list-style-type: none"> ▪ Steel (incl. stainless) ▪ Glass ▪ Porcelain ▪ Silicone | <ul style="list-style-type: none"> • Studies that do not include surfaces/materials of interest • Studies exclusively on copper or silver materials |
| Pathogens | <ul style="list-style-type: none"> • SARS CoV-2 • SARS CoV • MERS • Top foodborne outbreak illness pathogens, e.g.: <ul style="list-style-type: none"> ▪ Escherichia Coli ▪ Campylobacter spp. ▪ Salmonella spp. ▪ Norovirus, and rotavirus (human enteric viruses) ▪ Clostridium perfringens/ C. difficile ▪ Listeria | <ul style="list-style-type: none"> • Airborne pathogens • Water-borne pathogens (from wastewater treatment) • Healthcare-associated infections <ul style="list-style-type: none"> ▪ Staphylococcus ▪ methicillin-resistant Staphylococcus aureus (MRSA) ▪ Pseudomonas aeruginosa (Ps. Aeruginosa) ▪ Candida • Pathogens not typically spread via fomites <ul style="list-style-type: none"> ▪ Herpes ▪ H1N1/ influenza A ▪ Cholera • Pathogens not explicitly listed |

Results

Demographics of included studies

After duplicates were removed, the initial search yielded 1,138 results for title/abstract screening (Fig. 1). A total of 435 studies were excluded at the full text screening stage, leaving 122 articles that met all inclusion criteria.

Forty seven studies (35%) were conducted in a food service setting, 30 (22%) in a hospital setting, 20 (14%) in a general commercial or household setting, and 34 (25%) in unspecified settings or contexts (several studies considered multiple settings). The most common pathogens found in the complete dataset were *E. coli* (25% of included studies), general bacteria (24%), and Norovirus (16%). Thirteen studies (8%) focused on SARS-CoV-2.

A majority of studies analyzed plastics (76 studies, 27%), stainless steel (61, 22%), or porous surfaces such as paper and cardboard (33, 12%). A majority of plastics studied were unspecified (21, 30% of this subset), polypropylene (14, 20%), non-specified polyethylene (12, 17%), or polystyrene (8, 12%). Most common ‘natural’ materials

included cloth such as cotton or hemp (22, 41% of this subset) and wood (18, 33%).

Most studies were lab-based (101, 75% of total), followed by in-situ tests (30, 22%), and models (5, 4%). Most studies assessed the presence of pathogens (96, 72%), while 12 (9%) assessed transmissibility, and 16 (12%) assessed both presence and transmissibility. Forty studies (30%) tested disinfection techniques (see Appendix for related figures and tables).

Though we had no date exclusion criteria, the earliest study included was published in 1978. It appears that these studies are increasing over time, with a plurality, perhaps unsurprisingly, in 2020 (Fig. 2). These studies were published in 60 unique journals, with seven articles each in *The Journal of Hospital Infection*, *PLoS One*, and the *International Journal of Food Microbiology*.

A majority of the studies reported support from federal grants (53, 38%), with 20 (14%) reporting industry sponsors and 40 (29%) not listing any funding support. Most studies were conducted in the United States or by researchers from the US (49, 40%), the United Kingdom (13, 11%),

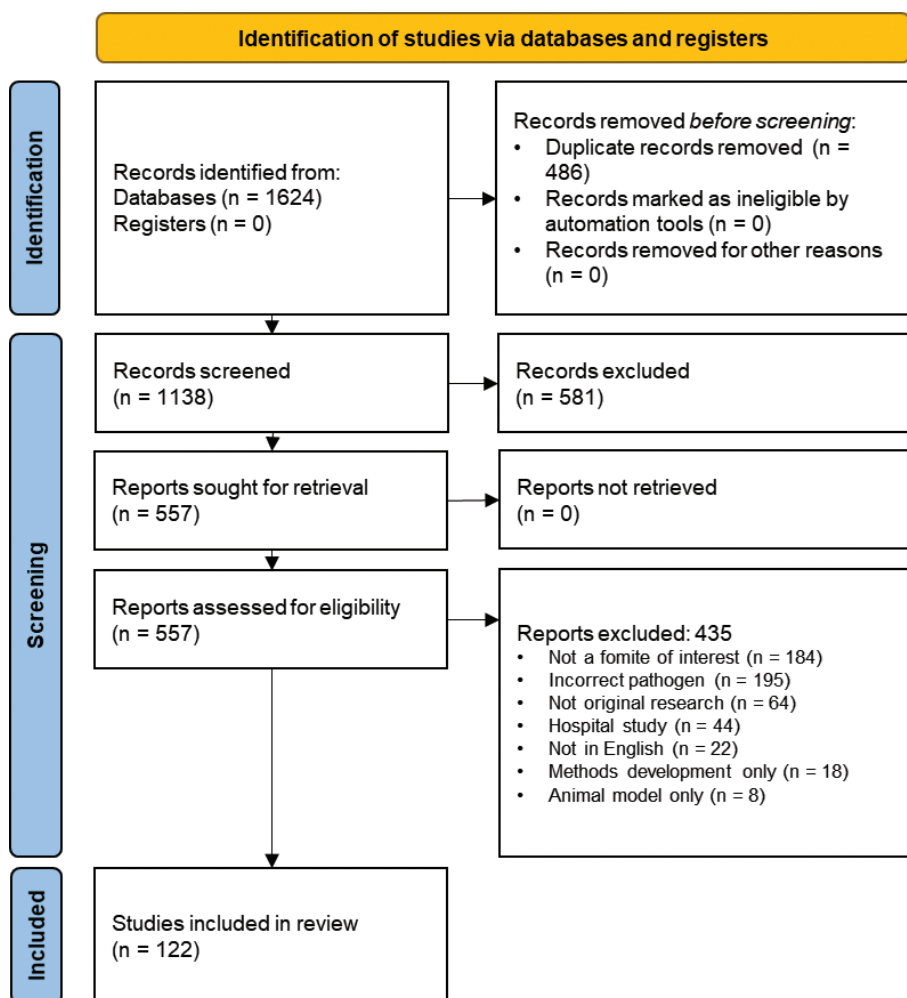


Fig. 1. PRISMA flow diagram for systematic review of pathogens on food service related fomites.¹⁰

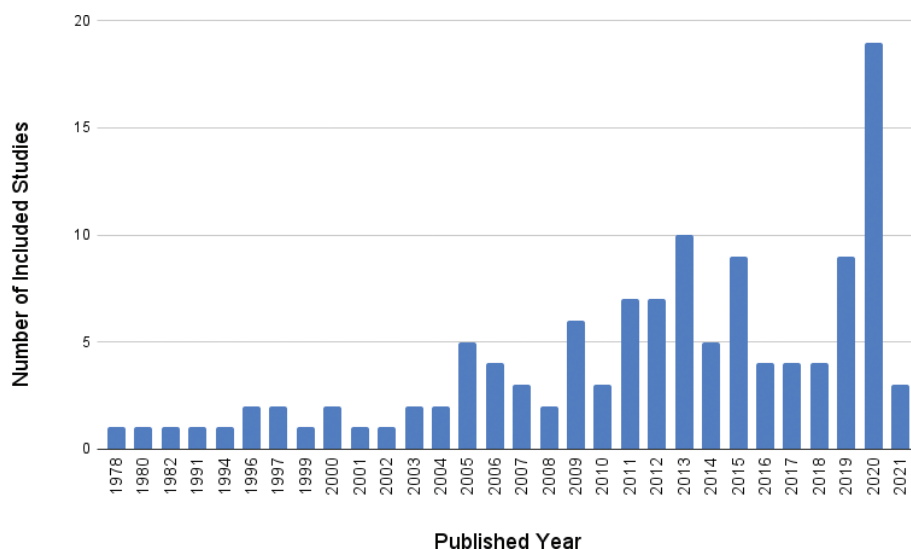


Fig. 2. Number of included studies by year of publication.

or Canada (7, 6%). The remaining 53 studies (43%) were conducted in 29 unique countries.

Pathogen viability and transmissibility from various fomites

Given the variation in viability and transmissibility by pathogen, the following section summarizes study results by pathogen. Any studies conducted on more than one pathogen will be summarized in the appropriate sections. A summary of transmissibility studies is shown in Table 1.

Escherichia coli

Escherichia coli (*E. coli*) are Gram negative bacteria commonly found in the environment and in the lower gastrointestinal tract. They represent a large and diverse group of bacteria. While most strains are harmless in the gastrointestinal tract, some strains can cause diarrheal illness or more severe systemic disease. Of the papers selected for inclusion, *E. coli* was studied in 48 (40%) of the included papers. A total of 41 papers were conducted in a lab setting and seven papers were in-situ. A total of 15 of the 48 papers analyzed a disinfection method. The fomites discussed in these studies include plastics (34), natural/porous material (21), metal (19), stainless steel (15), glass (9), and porcelain/ceramic (8). Of the 48 papers that were selected as *E. coli* studies, only five of them involved food-related fomites.

Fomite features that can influence microbial adhesion include surface energy and topography. All surfaces have a charge that can create interactions with other surfaces. Usually, the smaller the structures, the more the interactions that can form between the fomite and the structure (such as bacteria).¹¹ One study investigated adhesive characters of bacteria, swab features, and fomite surface properties in terms of contamination and bacterial colony counts. The fomites studied in this experiment were

untreated planed wood, plastic computer tower, acrylic painted wall, glass, aluminum, wrestling mat squares, and ethylene-vinyl acetate footwear.¹¹ The greatest retrieval of bacteria was from the acrylic surface and the least retrieval was from the wood. This is because a rough surface/topography decreases adhesion of the bacteria to the surface compared to a smooth surface/topography.¹¹ Therefore, retrieval was highest for the acrylic fomite.

Attachment to the surface can also vary based on the bacterial species itself. One study investigated the transfer efficiency of *Acinetobacter baumannii* from contaminated nitrile gloves to polypropylene plastic. It was found that *A. baumannii* could transfer from the gloves 3 min after inoculation of bacteria to the plastic, even after the glove surface was dried completely.¹² *A. baumannii* is able to attach and form biofilm structures on plastic and glass surfaces but *E. coli* is not able to form these attachments as easily. The glove material also influenced transfer efficiency as when conducting an experiment using latex gloves instead of nitrile, transfer efficiency was higher for latex (1.6% vs. 0.2%).¹² Oxygen treatment on surfaces can create a hydrophilic surface that reduces bacterial adhesion by 68.7% as found in another study. This oxygen treatment along with fluorine reactive ion etching treatment on the surface allowed for a 99.6% reduction of *E. coli* cell adhesion compared to the control polypropylene plastic surface.¹³

One study investigated the transfer efficiency of bacteria from porous and nonporous surfaces under different relative humidity conditions. The porous surfaces tested were cotton, polyester, and paper currency (one dollar bills), and the nonporous surfaces tested were acrylic, glass, ceramic tile, laminate, stainless steel, and granite.¹⁴ It was found that transfer efficiencies were greater under high relative humidity conditions compared to low relative humidity conditions. It was also

found that fomite type did influence transfer as porous surfaces are able to better trap organisms, and provide a much greater surface area for adherence. Specifically, transfer efficiency was up to 57% for porous surfaces and less than 6.8% for nonporous surfaces under low humidity conditions and up to 79.5% for porous surfaces and less than 13.4% for nonporous surfaces under high humidity conditions.¹⁴

Some surfaces may have antimicrobial activity and can be effective against certain bacteria. In one study, copper was found to demonstrate antimicrobial activity against all bacteria studied in the experiment, including *E. coli*, *Enterobacter spp.*, *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, and *Acinetobacter baumannii*.¹⁵ *E. coli* was found to be inactivated within only a few minutes of being exposed to the copper surfaces. It was found that a higher copper content of alloys (Cu99% vs. Cu63%) and a dry inoculation technique as opposed to wet, increased contact killing, decreasing viability and subsequent transfer.¹⁵ Another study similarly found that copper has strong antimicrobial properties. However, it has poor corrosion resistance and is unsuitable as a surface material. Nickel or silver that contain copper do have improved durability and can greatly reduce bacterial survival. In one study, after 120 min of exposure at 20 degrees Celsius and 360 min at 4 degrees Celsius, *E. coli* could not be detected on a copper nickel surface.¹⁶

Campylobacter Spp.

Campylobacter are Gram negative bacteria that are the most common bacterial cause of diarrheal illness in the United States. *Campylobacter* can be acquired from eating undercooked meat, unpasteurized milk, or by eating contaminated fruits or vegetables. Of the papers selected for inclusion, three (2%) studied *Campylobacter*. Two of these papers were conducted in a lab setting and one in-situ. Two of the three papers analyzed a disinfection method. The fomites discussed in these studies include plastics like polypropylene (1), natural/porous material like paper or cardboard (1), cloth (1), metal (1), glass (1) and porcelain/ceramic (1).

Campylobacter was found to be most prevalent on plastic and wood, according to a study investigating the killing of *Campylobacter* on contaminated wooden cutting boards by glycerol monocaprates.¹⁷ Past research shows that wood has an antibacterial effect. This may be due to moisture being naturally drawn into the board and therefore bacteria tend to be less viable on wood compared to other materials. The glycerol monocaprates sanitizer tested in this study had difficulty entering the pores of the wood, which allowed more bacteria to survive.¹⁷ Because plastic is a nonporous surface, the bacteria were more viable on this material, as liquid cannot pass through the plastic as is possible with wood.

Another study investigated the cross-infection of potential food pathogens in the domestic kitchen during chicken preparation.¹⁸ The study tested 325 sampling sites after 25 chickens were prepared, 11 of which were contaminated with *Campylobacter*. For the homes where there was *Campylobacter* contamination, the maximum contamination was found on draining boards (four homes), followed by counter tops and hands (three homes), and oven handles (two homes).¹⁸ In another study, it was hypothesized that *Salmonella* and *Campylobacter* may be able to survive a typical washing-up process and persist on dish surfaces. The factors affecting the survival of *Campylobacter* and several other bacterial strains during a washing-up process were investigated. It was found that *Campylobacter* survived least well compared to *E. coli*, which survived the best.¹⁹ The *Campylobacter* cells were most sensitive to towel drying and did not recover on these dried dishes after a washing-up process.¹⁹ However, some sterile dishes washed subsequent to contaminated dishes did contain *Campylobacter*, indicating that transfer of bacteria through washing-up water can occur.¹⁹

Clostridium perfringens and Clostridioides difficile

Clostridium perfringens bacteria are a common cause of food poisoning. *C. difficile* bacteria can cause a diarrheal illness, especially in healthcare settings or in people who have recently taken antibiotics. Both of these bacteria form spores that allow them to survive in the environment, and both can produce toxins in the gastrointestinal tract and cause diarrhea. Ten of the included papers (8%) studied *C. difficile* or *C. perfringens*. Of these, seven were lab-based, and four were in-situ. Eight papers assessed disinfection techniques. The fomites discussed in these papers included stainless steel (6), plastic (4), fabric (2), and glass (1). It was found that *C. difficile* was viable on all of these surfaces.

In one disinfection study where the efficacy of a pulsed xenon disinfection device was being investigated, it was found that at baseline, the glass slides were contaminated with 5 log₁₀ CFU of bacteria.²⁰ One study measured the effect of Perasafe (a high-level disinfectant that generates peracetic acid in-situ when dissolved in water) and sodium dichloroisocyanurate (NaDCC) against spores of *C. difficile* on stainless steel and polyvinyl chloride.²¹ It was found that Perasafe was significantly more active than NaDCC against *C. difficile* spores dried on stainless steel surfaces and was less effective against *C. difficile* spores fixed on polyvinyl chloride floor covering material. This may suggest that *C. difficile* spores are more viable on the polyvinyl chloride surface compared to stainless steel.²¹ Another study investigated the prevalence of *Clostridium difficile* on retail surfaces and shoppers' plastic bags. A total of 800 samples were taken from 17 supermarkets in Saudi Arabia. It was found that *C. difficile*' prevalence on

sampled surfaces was overall 0.75% and that the highest prevalence was found on retail baskets and trolleys, followed by plastic bags last.²² Though only 3 isolates/400 were obtained from plastic bags, it was concluded that *C. difficile* is present in surfaces in retail supermarkets and can contaminate shoppers' plastic bags.²²

Listeria

Listeria are Gram positive bacteria that are widespread in the environment. Unlike most other foodborne pathogens, *Listeria* can grow at standard refrigerator temperatures, which makes it more of an infection risk in refrigerated ready-to-eat foods. *Listeria* can cause febrile gastroenteritis in people with normal immune systems, but it can cause invasive infection in older and immune compromised people, and in pregnant women can cause miscarriage or sepsis in the neonate. Three of the included papers (2%) focused on *Listeria*. Of these, one paper was lab-based and two were in-situ. None of the papers mentioned disinfection methods. The fomites discussed in these studies include plastic (2), fabric (2), natural/porous material (1), metal (1), silicone (1), cutting boards (1), and kitchen utensils (1).

Listeria was most prevalent on wet surfaces, like dish clothes and places of stagnant water. One study investigated the prevalence of *Salmonella*, *Staphylococcus aureus*, *Bacillus cereus*, *Clostridium perfringens*, *Listeria monocytogenes*, and fecal coliforms like *E. coli* in 15 food and hand contact surfaces in 250 randomly chosen domestic kitchens in Wageningen, Netherlands.²³ *Listeria monocytogenes* was found in 10% of the houses investigated and were mainly isolated from wet surfaces like dish cloths and places of stagnant water.²³ Likewise, another study found *Listeria* on cleaning tools, mainly those that could retain moisture. This study evaluated the association of multiple types of bacteria with cleaning tools (floor mops), cleaning cloths, and handling devices (disposable plastic gloves) used to fill baguette and assorted salad preparation in four retail delicatessens in Johannesburg, South Africa.²⁴ Floor mops consistently yielded the highest APCs (aerobic plate count), CCs (coliform counts), ECs (*Escherichia coli* counts), while gloves had the lowest corresponding counts. *Listeria* was detected in five cleaning tool samples.²⁴ Bacterial attachment occurs more readily to surfaces in moist environments. Because the floor mops and cleaning cloths remained moist, the environment for bacterial attachment and growth on the mops and cleaning cloth fibers was provided.²⁴

Salmonella Spp.

Salmonella are Gram negative bacteria with several subspecies that cause human disease. *Salmonella* often live in the intestinal tracts of animals and can be transmitted to humans through consumption of food contaminated with

animal feces. Very old, very young, and immunocompromised individuals are at higher risk for complications from *Salmonella* infection. Of the papers selected for inclusion, a total of eight studies (7%) studied *Salmonella*. Of these eight papers, five were conducted in a lab-setting, and three studies were conducted in-situ. Five of the eight papers were food service setting papers. Two studies analyzed various disinfection techniques. The fomites discussed in these studies include porous material like paper, fabric or cloth (5), plastic (4), glass (3), metal (2), stainless steel (2), porcelain/ceramic (2), and wood (1).

According to the CDC, many foodborne outbreaks occur in restaurants and can be due to contaminated food and poor personal hygiene. In a study exploring the persistence of *Salmonella* on the surface of restaurant menus, *Salmonella* was found to survive on laminated menus for up to 72 h and not paper menu coupons.²⁵ In follow-up studies exploring the transmissibility of *Salmonella* from contaminated menus to fingertips and from the fingertips to clean menus, it was found that microorganisms could be transferred from damp menus to fingertips for up to 24 h.²⁵ There is also a higher transfer of bacteria from wet surfaces. This was also found in another study that studied mops and cloths as potential reservoirs for bacterial contamination. It was found that bacterial attachment to surfaces occurs more readily in moist environments, and the floor mops and cleaning cloths used in the study were kept moist.²⁴ *Salmonella* was detected on three of the cleaning cloths and two mop samples, and these cleaning tools may transfer microorganisms to food contact surfaces and contaminate food in restaurants.²⁴

Studying the resistance of various bacterial species in dry conditions is important as well. *Salmonella* can survive air-drying for at least 24 h.¹⁹ In one study, it was found overall that Gram-negative bacteria lose their viability in the air faster than Gram-positive bacteria.¹⁰ When adding protein such as bovine serum albumin, however, bacterial survival increased even when the bacteria was dried.¹⁰ This effect was seen in *Salmonella*. One study exploring cross-contamination of food-borne pathogens in *Salmonella*-infected chicken preparation, found 100% contamination on places in the kitchen such as the counter-top and dishcloth.¹⁸ When comparing various fomites, one study found that stainless steel may be the best surface to prevent bacterial contamination on cutting boards in comparison to plastic and wooden cutting boards.²⁶ This could be because the harder metallic surface of stainless steel makes it difficult for bacteria to attach.

In conclusion, there are many factors that can cause foodborne infection, such as: preparation of food too far in advance, improper cooling, and inadequate heating.²³ However, cross-contamination via various fomites is highly likely, and, as such, it is important that proper hygiene is always followed to reduce risk of transmission.

General bacterial pathogens (Gram negative or positive)

A total of 42 (34%) of the included papers focused on general bacterial pathogens. Of these, 31 were lab-based, 14 were in-situ, and 1 was a modeling study. A total of 14 papers were disinfection studies, of which 10 were lab-based, seven were in-situ, and one was modeled. The fomites that were discussed in a plurality of studies include: plastic (31), fabric (16), metal (12), stainless steel (11), cloth (11), wood (8), glass (7), and aluminum (3).

Bacterial viability is not only due to the fomite it is present on, but also due to the bacterium strain, temperature, and humidity. In all 43 papers, different strains of general bacteria were present and able to survive on the fomites investigated in the studies. The presence and viability of different pathogens on dry surfaces was investigated in multiple papers and it was found that bacteria can survive on dry surfaces regardless of the material. In one study, the survival of *Acinetobacter baumannii* on dry surfaces was investigated. The survival curve of the bacteria was found to be significantly associated with the specific strain of bacteria rather than material.²⁷ Ten strains of bacteria were studied on ceramic, polyvinyl chloride, rubber, and stainless steel in dry conditions. It was found that the recoverable proportion of the strains on the different materials did differ greatly, with 12% on ceramic to 96% on rubber, with an average of 46% of inoculated microorganisms recovered.²⁷ When looking at the influence of materials on the recoverable portion and reduction by drying, no influence was found in association with survival curves.²⁷ There was a significant association between survival curve and bacterial strain, instead.

In another study, the effect of thermal control of dry fomites on regulating the survival of human pathogenic bacteria was investigated and it was found that the colony forming units of the bacteria decreased only if the temperature increased.²⁸ Vinyl chloride, stainless steel, and aluminum were the fomites in this study, and there was no difference in bacterial counts between these three materials. Bacteria tended to favor a lower temperature regardless of the fomite, even in dry conditions. However, temperature may not always affect the viability of bacteria, as it was found in one study that *Yersinia enterocolitica* populations did not change across varying temperatures and soil conditions. The serum in the soil had a protective effect on *L. monocytogenes* but did not cause the same growth and survival for all bacteria. In this study, it was shown that survival was more dependent on pathogen type.²⁹ In another study, cleaning tools were studied as it was hypothesized that they may play a role in the contamination of foods without proper hygiene, and it was found that the most bacteria were found on floor mops compared to disposable plastic gloves.²⁴ It was thought that this was the case because bacteria need moisture to grow and the floor mops and cleaning cloths had been

diluted in a sanitizer when they were not being used for cleaning.²⁴

As for specific fomites, studies found bacteria were viable on plastic, stainless steel, glass, and wood, though the most bacterial contamination was often found on plastic fomites. Bacteria can survive for several weeks on plastic after drying.³⁰ In one disinfection study focused on the safety of hardwood cutting boards in food preparation it was found that between maple, beech, and plastic cutting boards, the plastic boards were the most contaminated with bacteria with a mean count of 41 CFU/cm² compared to 7.5 CFU/cm² for maple and 23.5 CFU/cm² for beech.³¹ In a similar study of cutting boards, bacteria survived best on plastic and glass and were not viable on wood.³² When looking at wood, it was found that oak exhibited an antibacterial effect and that after cultivation, bacteria could not be found on the wood after 48 h. When studying stainless steel that was composed of 74% iron, 18% chromium, and 8% nickel, it was found that at room temperature and refrigeration temperature, bacteria survived for more than 28 days in a desiccated state. The inhibitory effects of 21 copper-containing alloys was also tested on cultures of *E. coli* and it was found that copper can have an antibacterial effect due to its corrosive nature. As copper content, or temperature or relative humidity increased, it was found that the bacteria survived less.¹⁶

Norovirus

Norovirus is a highly infectious virus that causes acute gastroenteritis with vomiting and diarrhea after ingestion. It is spread by eating contaminated food, by touching contaminated surfaces and then touching the mouth, and can be spread from person to person. Thirty one (25%) of the papers studied Norovirus. Of these 31 papers, 20 were lab-based, five were in-situ, one paper was modeling, two papers were a combination of lab-based and modeling, one paper was a combination of lab-based and in-situ, and two papers were a combination of in-situ and modeling. Furthermore, 11 of the papers were disinfection studies. The fomites discussed in these studies include: stainless steel (30), plastic or plastic resin (17), porcelain/ceramic (8), fabric (7), natural or porous material (5), glass (5), metal (3), nitrile/rubber (3), latex (2), and vinyl (2).

The studies mostly point towards the same conclusion: that norovirus is viable on most fomites for long periods of time. One study found that norovirus consistently survived longer on wood, when observing the inactivation rates of norovirus over varying temperature and humidity levels on rubber tree wood and stainless steel.³³ Specifically, it was found that norovirus consistently survived longer on wood compared to stainless steel at a lower temperature. One study found that the presence of food residues on fomites may elongate viability of

norovirus on fomites. This study evaluated the survivability of norovirus (murine norovirus-1) on desiccated food residue-attached stainless steel coupons.³⁴ Food residue included lettuce, cabbage, and ground pork. The study found that a 6.2 log MPN/ml of MNV-1 was completely lost at day 30 in residue-free coupons, whereas only a 1.4 log MPN/ml reduction was observed in coupons with residues.³⁴

Several studies point to the fact that norovirus outbreaks may be more of a result of improper cleaning protocols and improper hygiene practices. One study found that the initial cleaning of dorm rooms tied to a norovirus outbreak, by cleaning staff uninformed on proper cleaning protocols for norovirus, actually increased the amount of norovirus-positive rooms from 40 to 73%.³⁵ In another study, often cited by those advocating for single-use consumer plastics,⁸ a norovirus outbreak was found to be associated with coming into contact with a contaminated reusable grocery bag. This study investigated a reported norovirus outbreak that affected nine members of a soccer team. The outbreak was associated with contact with a reusable grocery bag and/or consuming its packaged food contents. The bag and its contents were previously stored in a bathroom used by a person with norovirus-like symptoms.

Even though it was found that contaminated surfaces do play a role in transmission and as virus donors, this is to a lesser extent compared to contaminated hands themselves as vehicles of virus transmission. One simulation model evaluated the contribution of fomite-mediated exposures to infection and illness risks in outbreaks, accounting for hand-to-porous surfaces, hand-to-nonporous surfaces, hand-to-mouth, -eyes, -nose, and hand washing events.³⁶ Infection risks ranged from 70.22 to 72.20% and illness risks ranged from 21.29 to 70.36%, with the number of hand-to-mouth contacts and the number of hand washing events having the strongest relationships with model-predicted doses. This model suggested that fomites accounted for 25–82% of illnesses in an outbreak.³⁶ Overall, this study concluded that fomite-mediated exposures accounted for a large portion of the attack rates in outbreaks that involve various transmission modes,³⁶ but proper gloving and hand-washing compliance are the most effective in controlling contamination of food products from norovirus.³⁷ Norovirus can be readily transferred from the hands to other surfaces such as food, being the most efficient route.³⁷

SARS-CoV-2

SARS-CoV-2 is a respiratory virus that causes COVID-19, with symptoms ranging from mild upper respiratory tract infections to acute respiratory disease syndrome and death. SARS-CoV-2 can be transmitted through respiratory droplets and aerosols, and to a lesser extent through fomites. Of the 13 SARS-CoV-2 related papers, 11

measured prevalence of virus on fomites, one measured transmissibility, and one measured both. Nine studies were conducted in a lab setting, three in-situ, and one both lab and in-situ. The most prevalent fomites include plastic (9 studies, either unspecified (3) or PP (3)), stainless steel (5), glass (4), and cloth or fabric (3).

All four in-situ studies found the presence of SARS-CoV-2 RNA (ribonucleic acid) on a wide range of fomites,^{38–40} including wooden chopsticks. One study concluded that prevalence of SARS-CoV-2 RNA on various fomites correlated with the patient's viral load, whether the patient was symptomatic or asymptomatic.⁴¹ Of the four in-situ studies, only one measured viability, finding that none of the collected samples had infectious titers of SARS-CoV-2 when added to tissue culture assays.⁴⁰

The 10 lab-based studies assessed adhesion, decay rate, and disinfection techniques for SARS-CoV-2 on various fomites. One study found that SARS-CoV-2-inoculated plastic surfaces retained the ability to infect cells for up to 84 h at both room temperature and 28 C.⁴² Two studies found that increasing temperatures and humidity drastically reduced the survivability of the virus to as little as 24 h at 40°C.^{43,44} Droplet volume and surface type (stainless steel, plastic, nitrile glove) were not found to significantly impact decay rate.⁴⁴ However, one study found that SARS-CoV-2 took up to 20 days more to degrade on experimentally-inoculated plastic personal protective equipment (PPE) when compared to 100% cotton fabric.⁴⁵ Similarly, according to a study focused on intermolecular interactions between SARS-CoV-2 and surfaces using atomic force microscopy under simulated respiratory droplet environment, polystyrene (plastics) showed strongest adhesion, followed by stainless steel, gold, and glass.⁴⁶

General viral pathogens

Fourteen (11%) of the included studies assessed general viral/respiratory pathogens. Of these, 12 were lab-based and two were in-situ; three papers were disinfection studies. The fomites that were discussed in a majority of these studies include plastic or plastic resin including polypropylene, polyvinyl chloride, polyester and polystyrene (9), metal (8), stainless steel (8), fabric (3), porcelain/ceramic (3), glass (2), silicone (1), cloth (1), and aluminum (1).

One study tested the effect of both high and low humidity on the transfer of pathogens from a fomite (surface) to finger from various common surface types. Nine fomites were investigated in this study and they comprised six nonporous and three porous surfaces. It was found that, overall, viral pathogens had higher transfer efficiencies in high relative humidity for all surface types, compared to low relative humidity.¹⁴ It was also found that a nonporous surface (acrylic, glass, ceramic tile, laminate, stainless steel, and granite) had a much higher transfer efficiency under high and low relative humidity for all

types of surfaces. The transfer efficiency under high relative humidity for a nonporous surface was up to 57% compared to less than 0.6% for a porous surface. Under low relative humidity, the transfer efficiency for a nonporous surface was up to 79.5% compared to less than 13.4% for a porous surface.¹⁴ Four different organisms were studied in this paper including *E. coli*, Poliovirus (serotypes 1 and 2), *B. thuringiensis*, and Emesvirus zinderi or Bacteriophage (MS2) coliphage. Fomite type affects transfer efficiency rates for all of these organisms except PV-2. It is suggested that the reason porous surfaces have much lower transfer efficiency rates is because they can trap organisms and have a higher surface area. This was found to be the case in another study where bacteriophage Phi 6 was being studied, and it was shown to survive longer on nonporous surfaces compared to porous surfaces.⁴⁷ Another study studied the inactivation rates of murine norovirus (MNV), MS2 and hepatitis A virus (HAV) on wood and stainless steel under various temperatures and humidity conditions. It was found that the viruses survived longer on wood at low temperatures and were not as viable on stainless steel. This was thought to be the case because stainless steel is hydrophilic and carries a negative surface charge, creating stress for microbe survival.³³ Though the survival of the viruses depended on more factors than just surface type, such as virus type and temperature, overall the results of the study indicated that the viruses were able to survive for more than 1 month.³³

Another study investigated the survival of HAV on six fomites including ceramic, rubber, glass, wood, stainless steel and plastic.⁴⁸ Survival was measured up to 28 days, and it was found that the virus survived the longest on the wood, followed by rubber, plastic, ceramic, glass and for the least amount of time on stainless steel. On the other hand, another study showed that several influenza viruses survived the longest on stainless steel. In this study, three surfaces were studied which were stainless steel, microfiber cloth, and cotton. The virus strains survived on the steel for 174.9 h, 34.3 h on the microfiber cloth, and 17.7 h on the cotton.⁴⁹ In terms of transmissibility, it was found that quantities of influenza A could be transferred from stainless steel to an individual's hands for a period of 1 day after the steel is contaminated. However, the virus can only survive on the hands for up to 5 min, so this was concluded to be a limited amount of time for pathogen transmission into the mucous membranes to cause respiratory illness.^{49,50} Another study investigated the virucidal action of disinfectants assayed against hepatitis A and human rotavirus which were dried onto polystyrene. Polystyrene was used as a fomite so that the behavior of enteric viruses on nonporous surfaces could be studied, and it was shown that these viruses were viable on the polystyrene.⁵¹ Another study also investigated hepatitis A

and human rotavirus as well as adenovirus and poliovirus, and virus survival on various surfaces. The surfaces included paper, cotton, aluminum, china, glazed tile, latex and polystyrene. It was concluded in this study that the four viruses were able to survive on all of the surfaces for prolonged periods of time. It was found that HAV and human rhinoviruses (HRV) were more resistant to inactivation than Adenovirus (ADV) and PV when dried onto the various surfaces. Specifically with HAV, inactivation rates were found to be higher on porous surfaces compared to nonporous surfaces.⁵² In one study, RSV was specifically looked at and it was found that RSV could be recovered from countertops and gloves for the longest periods (average of 7 and 5 h respectively). Survival rate diminished greatly as on cloth, the virus was recovered for an average of 2 h and on the skin and paper tissue, survival was diminished to an average of 30 min.⁵³

Fomite disinfection techniques

Thirty nine studies assessed the effectiveness of disinfection techniques on various pathogens and fomites.

Energetic treatment

Five studies assessed the effectiveness of disinfection techniques that use ultraviolet radiation and photocatalytic inactivation to disinfect a variety of fomites or surfaces. Energetic treatments are not chemical processes, but rather effective physical processes to render microorganisms such as bacteria, viruses, yeasts, and fungi harmless within seconds.

Photocatalytic inactivation

One study found that modified titanium films were found to be most efficient in bacteria inactivation at the starting concentration of 105–106 CFU/ml. Photoinactivation was not observed under visible light irradiation of titanium oxide coatings. After 8 h of irradiation in the presence of catalytic titanium oxide, the concentration of *E. coli* decreased by a factor of 103. It was demonstrated that catechol-photosensitized titanium oxide films can be used as potential antimicrobial coatings.⁵⁴

Ultraviolet radiation

Pulsed xenon ultraviolet disinfection was found to be effective in reducing the recovery of MRSA and *C. difficile* within a 10-min exposure time.³¹ As the distance increased between the device and the pathogens, the device did not work as efficiently. Compared to ultraviolet C radiation, UV-C achieved significantly greater log-10CFU reductions than the PX-UV device. Ultraviolet radiation applied for 120 s using the UVSC equipment was effective in disinfecting slides inoculated with four microorganisms involved in healthcare-associated infections such as *P. aeruginosa*, *E. coli*, *S. aureus*, and *C.*

albicans. The effect was even greater against spore-forming *B. subtilis*, obtaining an effect similar to that of 70% ethanol and 2% chlorhexidine.

However, UV-C devices do contain mercury which can be toxic to people in the hospital; therefore the pulsed xenon ultraviolet device has advantages. Furthermore, UV-C cannot be used when people are present in the room. This is interesting to note because UV-A can be used at moderate doses with people present in the room, and can still cause reductions in bacterial count.⁵⁵ At an irradiance of 3 W/m² there was a progressive reduction in recovery of the vegetative microorganisms over 24 h in comparison to untreated controls. After 8 h of exposure to UV-A, MRSA and MS-2 were reduced by >1 log₁₀ CFU or PFU, whereas *Candida auris* was reduced by 0.7 log₁₀ CFU. Phi X174 was reduced by only 0.6 log₁₀ PFU over 24 h.

It was also found in a study that the effectiveness of UV light is very dependent on the specific surface/fomite that is being disinfected. When using the disinfection technique on Formica laminate and stainless steel, it was found that inactivation on Formica laminate was much lower than on steel. It was also found that inactivation of bacteria and viruses on hard surfaces differed from inactivating microorganisms in liquids. To properly disinfect microorganisms regardless of the fomite, UV light doses would have to be adjusted.⁵⁶

Dishwasher/heat

Heat is a very common and effective way to sanitize and disinfect objects and various fomites from various pathogens, particularly in residential settings. Heat is effective as when the temperature is high enough, this causes the enzymes in microorganisms to denature which leaves them unable to infect other organisms. One study assessed the effect of heat on pathogens. The creation of heat through a boiling technique was found to be the most effective in inactivating microorganisms and able to cut back the overall counts by 9.9–4.7 log CFU/sponge (50%), whereas the usage of hypochlorite (a chemical treatment) reduced the overall bacterial counts by 8.8–6.8 log CFU/sponge (31%). Heat was found to be more effective than a medical care blanching agent. One study measured the safety of using several disinfection techniques on cutting boards. The three types of cutting boards tested included maple wood, beech wood, and polyethylene hard plastic. The plastic boards were cleaned using an industrial dishwasher and standard detergent, and the wood boards were hand washed with tap water, washing liquid, and a soft cloth. Before cleaning, it was found that the maple and beech boards had the least bacteria, with a mean count of 7.5 and 23.5 CFU/cm² of aerobic mesophilic microorganisms. The plastic board has the most bacteria with a mean count of 41 CFU/cm² of aerobic

mesophilic microorganisms. After cleaning, 23 out of 30 of the samples had less than 2.5 CFU/cm² of aerobic mesophilic microorganisms. The study concluded that proper cleaning and disinfection of utensils was necessary to minimize cross-contamination effects. The wooden boards were found to entrap bacteria in the cracks of the board, as a result of constantly cleaning the wooden boards in the dishwasher under harsh conditions. Because plastic harbored more bacteria than the wooden boards, it is recommended to follow the cleaning instructions specific to the materials or products in use (i.e. hand cleaning wood products instead of using a dishwasher).³¹

Chemical treatment

Chemical disinfectants are used to inactivate pathogens on inert surfaces. The most common chemical disinfectants include alcohol, hypochlorite, and hydrogen peroxide. Ethanol and isopropanol are the main alcohols used as disinfecting agents to target a wide range of bacteria, viruses, and fungi. Hydrogen peroxide is a peroxide-based disinfectant that denatures proteins by oxidizing disulfide bonds and denaturing them. These various chemical disinfectants are widely available and used in the household as they have low toxicity, are inexpensive, and are able to inactivate a wide range of pathogens. A total of 47 studies assessed chemical treatment techniques.

Hydrogen peroxide

Hydrogen peroxide is a commercially available, stable and effective disinfectant that has been used to clean various surfaces for decades. One study used 30% hydrogen peroxide vapor and found that after exposure to vapor, all materials tested including vinyl flooring, ceramic tile, and plastic showed a 4 log₁₀ reduction in viral titre within 20 min.⁵⁷ When cleaning glass, plastic or ceramic tile surfaces, an exposure time of 15 min was required.⁵⁷ Hydrogen peroxide vapor, however, was found to be least effective against feline calicivirus (FCV) on stainless steel.⁵⁷

Overall, it was found that hydrogen peroxide vapor was suitable for disinfection of various surfaces contaminated with norovirus and influenza viruses including H1N1.⁵⁸ One study tested hydrogen peroxide vapor and found that even at a low vapor concentration of 10 ppm, a 2-log₁₀ reduction was observed after only 2.5 min of exposure.⁵⁸ After 2.5 min, exposure to 10-ppm HP vapor resulted in 99% inactivation.⁵⁸ For air saturated with triethylene glycol (TEG) vapor, the disinfection rate was about 16 times faster.⁵⁸

Sodium bicarbonate, sodium chlorite, sodium hypochlorite Sodium hypochlorite, sodium bicarbonate, and sodium chlorite are very common chemical disinfectants. Sodium hypochlorite was found to be very effective across multiple studies and was shown to reduce

microbial population significantly compared to no disinfectant on various types of fomites, including plastic, stainless steel, and others. Sodium hypochlorite was found to be effective in reducing FCV and MNV by using 5 ml of the disinfectant for a contact time of 5 min. Through the use of sodium hypochlorite (5,000 ppm), FCV and MNV were both inactivated below the limit of detection on fabric, cloth, plastic, and glass.⁵⁹ Sodium chlorite was also found to be effective in virus disinfection which induced a 3 log titre reduction of HAV and HRV in most scenarios.⁵¹ However, chlorine dioxide was found to be more effective than sodium chlorite. When studying the lethality of sodium chlorite and chlorine dioxide against *E. coli* O157:H7 on stainless steel, glass, plastic and wooden surfaces, chlorine dioxide was able to kill *E. coli* with greater efficacy with the exception of wooden surfaces. In one study, sodium bicarbonate was mixed with other disinfectants and the efficacy of these techniques was tested. The various disinfectants tested included sodium bicarbonate + glutaraldehyde, sodium bicarbonate + activated dialdehyde, and sodium bicarbonate + hydrogen peroxide at various concentrations. It was found that increasing the concentration rendered the sodium bicarbonate to be more effective. Thus, 5% sodium bicarbonate was a rapid virucidal agent killing greater than 99.22% FCV in 1 min while a 2% concentration took 10 min to kill 99.60% of FCV. Sodium bicarbonate alone at 5% concentration or a combination of sodium bicarbonate with glutaraldehyde or activated dialdehyde inactivated 99.99% of the virus load from food contact surfaces in a short contact time.

Alcohol. Compared to dry cleaning with cellulose tissues and microfabric clothes the efficacy of alcoholic lenses was much higher when compared to the alcohol-free formulation. It was found that wet cleaning was much more effective than mechanical cleaning with dry wipes.⁶⁰ One study specifically studied the contamination and disinfection of soft surfaces in health care settings.⁶⁰ Soft surface sanitizer that contained ethanol was successful in lowering the heterotrophic plate count (HPC) bacterial burden on soft surfaces and also in urgent care facilities and physician's offices. It was found that the soft surface sanitizer showed an overall 99.99% reduction of seeded microbes in laboratory-controlled studies. A 95–98% reduction of HPC bacteria was achieved with the most effective disinfection on waiting room chairs.⁶⁰ Another study tested the efficacy of various disinfecting agents on healthcare workers' pagers.⁶¹ One of the disinfecting agents used was 70% vol/vol isopropyl alcohol wipes. The 0.5% chlorhexidine–70% isopropyl alcohol wipes were found to be effective in eliminating all bacterial growth. The next most effective was isopropyl alcohol. Ammonium compounds were also effective but not

as effective as the isopropyl alcohol. It was found that after disinfection, no pathogens were found on any of the pagers.⁶¹

Other disinfection techniques

Non-ionized or ionized X without or with β -pinene

The results of this study indicate the relative antimicrobial effects of diffuse ionized gaseous species and volatile bactericidal compounds in the vapor phase. The combination of an ionizing source, such as a corona discharge or a candle flame, with a bactericidal volatile has a greater effect on surface-borne bacteria than either treatment alone.⁶²

Oxidative chlorine

Average available chlorine contents of the halogen-activated SS-HACM-Cl coupons, used for antimicrobial efficacy analysis, were measured as $9.6 \times 1,016 \pm 1.9 \times 1,016$ atoms/cm².⁶³ The SS-HACM-Cl stainless steel coupons provided a complete inactivation of about 6 logs (the limit of detection for the antimicrobial assay) against *S. aureus* and *E. coli* O157:H7 bacteria within 15 min of contact time in all three replicate assays. These results showed superior inactivation time and efficacy against both Gram-positive and Gram-negative bacteria when compared to previous antimicrobial modified stainless steel surfaces.

Ozone

Ozone disinfection is an extremely strong method for eliminating harmful pathogens. An ozone generator can be used to create reactive ozone from oxygen already in the atmosphere. That reactive ozone can be used to damage bacteria and viruses, which can stop them from causing infections. The findings of one study demonstrate that ozone at 25 ppm and RH 90% is bactericidal to strains of bacteria that commonly cause nosocomial infection, and the bactericidal effect was accomplished with a short exposure (20 min).⁶⁴ The ozone generator can provide a valuable decontamination tool for the removal of bacteria in many communal settings, including hospitals and other health care institutions.

Soap

Soap is the most common and convenient method in the home to eliminate germs on the hands and washable surfaces. Soap is composed of molecules with hydrophilic heads and tails and is effective at destroying the surface membranes of some bacteria and viruses, including the coronavirus. When washing the hands, microorganisms surround the surface of the hand and the hydrophobic tails wedge themselves into certain microbes and viruses. This destabilizes the bacteria and viruses.

In one study, soap and chlorhexidine (CHG) were equally effective at preventing initial contamination of the basins compared with tap water.⁶⁵ The qac-positive MRSA strain was recovered in slightly higher numbers in CHG-A and CHG-B compared with the other bacterial species (median, 0.5 CFUs/cm² for MRSA vs. 0 CFUs/cm² for other bacterial species; $P = 0.057$).⁶⁵ The negative control basins (tap water without bacterial inoculum) yielded extremely low values in both the immediate effect and the residual effect tests, and data are not reported.⁶⁵ CHGA and CHG-B had a marked residual effect on bacterial contamination compared with soap or tap water ($P < 0.0001$).⁶⁵ There was no significant difference in residual activity between CHG-A and CHG-B. When results from basins containing CHG-A and CHG-B were combined, there was no difference in median bacterial counts for the four tested species of bacteria ($P = 0.23$).⁶⁵

Another study tested the effectiveness of killing *Campylobacter* on contaminated plastic and wooden cutting boards using glycerol monocaprinate/monocaprin and washing-up liquids (WUL).⁶⁶ WULs are thick soapy liquids. It was found that viable *Campylobacter* counts were reduced below the detectable level on plastic board surfaces after treatment with monocaprin (MC) emulsions with or without WULs. It was also found that mixtures of MC-WUL were highly bactericidal on surfaces contaminated with *E. coli* and that these mixtures were stable at low temperatures. In future studies, mixtures of MC and body soaps or bathroom cleaners should be studied to further determine their microbicidal activities.⁶⁶

TEG saturated air

TEG vapor can be used to kill odor-causing bacteria for the purpose of air sanitation. It has been found that under optimal conditions, which is about 15–40% relative humidity and 40–100% of glycol vapor, TEG vapor can cause rapid bactericidal action.⁵⁸ It can possibly be used in conjunction with surface contamination simultaneously even when a room is occupied with people. Vapor concentrations of 10 ppm HP or 2 ppm TEG can provide effective surface disinfection. At these low concentrations, the potential for damage to even the avionics of an airplane would be expected to be minimal. At a TEG vapor concentration of 2 ppm, there are essentially no health risks to people. Vapor concentrations of 10 ppm HP or 2 ppm TEG can provide effective surface disinfection.

Discussion

Though we set out to determine the microbial and infectious risks of food serviceware including reusable shopping bags, cups, and food containers, the literature leads us to no strong conclusions. There appear to be no major differences in pathogen viability on various fomites. There is a paucity of research that can specifically aid in

developing policy or guidelines for appropriate use of reusable food serviceware. Though given the recent studies on SARS-CoV-2, banning reusable bags and food serviceware is an inappropriate response to this particular pathogen, which is typically spread through droplets and aerosols, and rarely through surface contact.⁸ The only other obvious takeaway from existing literature is that any material – reusable or disposable – present in the room of someone infected with norovirus should be properly cleaned and sanitized before use to avoid transmission.

Of the disinfection techniques studied, the most likely to be available for everyday use in the home would be soap and sodium bicarbonate (baking soda). Soap, likely combined with hot water, is sufficient at reducing pathogen load on a majority of studied fomites, suggesting that commercial dishwashing that meets health codes should be sufficiently safe for public health. The literature seems to identify ultraviolet light as the most efficient sterilization technique, and, outside of drying items in the sun, this is not a readily available approach for households, especially for disinfecting reusable food serviceware. A majority of disinfection techniques in the included literature are not accessible to or feasible for the general public. Most of this literature focused on the efficacy of certain disinfection methods common in the hospital space. Surprisingly, none of the included literature assessed the impact of laundering on cloth products, though perhaps our inclusion and exclusion criteria omitted these types of studies.

Sustainability and single-use plastics

Plastics have great utility, but most are currently overused and undervalued, especially within the food service and retail industries. Though sometimes considered a by-product of the oil industry, the plastics industry drives approximately 6% of annual global oil production. In 2019, the production and incineration of new plastics results in over 850 million metric tons of GHGs.^{1,4} In addition, plastics pose significant environmental risks as macro and micro pollutants and as sources of endocrine disrupting chemicals, risks that are not currently accounted for in life cycle assessments and other environmental impact methodologies.²

Circularity or ‘circular economy’ is a popular framework, promoted by the Ellen MacArthur Foundation and others, which would see the recovery and reuse of plastic resources (and other resources) through reuse, recycling, and proper composting of bio-based plastics, among other tactics.⁴ Unfortunately, plastics recycling is currently an unreliable market that can exacerbate social inequities, globally, while further polluting ecosystems. Bio-based plastics and their potential composting can also be problematic, as most products must be industrially composted, which may not be a treatment pathway available to most consumers. Single use plastic bans should not be

considered an ‘end-all’ for sustainability in the food service sector, but they have been found to catalyze waste awareness and environmental action amongst the general public. Policies banning single-use plastics can be an important tool to curb environmental pollution, especially when combined with proper information and infrastructure for maintaining safety with reusable replacements.

Limitations of our study

The scope of this study made for a challenging systematic review. By including multiple fomites and many pathogen types, we found that measurement techniques and other study methods varied substantially. Though we have tried to summarize major findings, future systematic reviews may focus on a single fomite or a single pathogen for better comparisons between studies. Due to the breadth of potential studies, we may have missed some studies in our selected search terms. In addition, some of the inclusion criteria ended up being somewhat subjective, as we hoped to capture both common reusable and disposable food service products AND the materials that make those products. This led to a challenge in whether or not we should include studies focused on hospital gowns, for example. These gowns are typically composed of a polypropylene fabric, which is a material that could also be used in reusable shopping bags. However, the hospital setting is a very different use case when compared to an individual’s home, a grocery store, or a restaurant. For this reason, we decided to exclude studies that focused on hospital-acquired infections, as these were unlikely to be encountered in our use case setting. The study team also did our best to collect literature on SARS-CoV-2, but as the literature is quickly evolving, there may be more recent studies which we were unable to include.

Conclusion

Despite a large body of related literature, there is very little evidence suggesting that either reusable or disposable food serviceware is safer for minimizing infectious risks. Very few studies focused specifically on the question of safety of reusable versus disposable food serviceware. Various pathogens can survive on various fomites, though greater porosity of the surface and higher humidity levels seem to increase viability of most pathogens. Proper cleaning protocols – including hand hygiene – appear to be the major factor in minimizing infectious risks from any pathogen.

As society at large struggles to reduce the environmental impact of human systems, we must identify safe opportunities to reduce plastic pollution. Eliminating single-use plastics and replacing them with reusable substitutes is a viable opportunity; however, existing literature does not help inform the cleaning and disinfection protocols that should be recommended for everyday people. Further research is needed which explicitly studies pathogen

viability, transmission risks, and appropriate disinfection techniques for disposable and reusable food serviceware in the consumer goods space in order to devise effective sustainability policies.

Conflict of interest and funding

This research was funded by Break Free From Plastic. Authors report no other potential conflicts.

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Appendices

Ovid MEDLINE Search Conducted October 10, 2021

1. (Bamboo or Plastic or Cloth or cotton or hemp or Composite materials or glass or polyethylene or Molded fiber or Polypropylene or Polystyrene or Styrofoam or foodware or utensils or steel or metal or cardboard or ((coated or treated or wax) adj2 paper)).ti,ab.
2. (Coronaviruses or Deltacoronavirus or Betacoronavirus or 2019-nCoV or covid or *Staphylococcus* or Norovirus or *E. coli* or *Escherichia coli* or *Campylobacter* or *Salmonella* or *Clostridium* or *Listeria*).mp. [mp=title, abstract, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword, floating subheading word, candidate term word]
3. 1 and 2
4. transfer efficiency.ti,ab.
5. exp Cross Infection/
6. fomites.mp. or exp Fomites/
7. (Microbial adj2 viab*).ti,ab.
8. 4 or 5 or 6 or 7
9. 3 and 8
10. exp *Viruses/
11. 1 and 8 and 10
12. exp *Fomites/
13. 9 or 11 or 12
14. fomite*.mp. or exp Fomites/
15. 8 or 14
16. 1 and 2 and 15
17. 13 or 16

Summary of Included Studies

Table 1. Studies by pathogen

| Pathogens | Count of included papers | Disinfection study | Lab-based (ex:Anything using surrogates, taking material and applying pathogen to it) | In-Situ (Case study or live setting) | Modeling | Lab-based + Disinfection | In-Situ + Disinfection | Modeling + Disinfection |
|--|--------------------------|--------------------|---|--------------------------------------|----------|--------------------------|------------------------|-------------------------|
| SARS-CoV-2 (Covid 19) | 13 | 2 | 10 | 4 | 0 | 1 | 1 | 0 |
| <i>Campylobacter</i> spp. | 3 | 2 | 2 | 1 | 0 | 2 | 0 | 0 |
| <i>Listeria</i> | 3 | 0 | 1 | 2 | 0 | 0 | 0 | 0 |
| GENERAL viral/respiratory (i.e. flu, etc.) | 14 | 3 | 12 | 2 | 1 | 2 | 1 | 0 |
| <i>Salmonella</i> spp. | 15 | 3 | 12 | 5 | 0 | 3 | 1 | 0 |
| <i>Clostridium perfringens</i> / <i>C. diff</i> | 10 | 8 | 7 | 4 | 2 | 6 | 3 | 2 |
| Norovirus | 31 | 11 | 23 | 7 | 3 | 9 | 2 | 1 |
| GENERAL bacteria (i.e. gram negative or gram positive); should not include bacteria that form spores (<i>Bacillus</i>) | 42 | 14 | 31 | 14 | 1 | 10 | 7 | 1 |
| <i>E. coli</i> | 48 | 15 | 41 | 12 | 2 | 14 | 4 | 0 |
| TOTAL | 179 | 58 | 139 | 51 | 9 | 47 | 19 | 4 |

Count of Included Papers, Lab-based (ex: Anything using surrogates, taking material and applying pathogen to it), In-Situ (Case Study or Live setting), Modeling and Disinfection study

