RESEARCH ARTICLE

Person to person transfer of microorganisms through food.

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Abstract

A major focus of food safety is on the contamination by microorganisms which occur during multiple stages along the food production and supply chain process. The microorganisms associated with foodborne illness are well-studied but normally do not include human nosocomial pathogens, particularly human respiratory diseases transmitted via mucosal droplets. A generally accepted mode of transmission for respiratory diseases include touching contaminated fomites followed by self-inoculation with fingers and hands by touching the face. Based on the existing modes of disease transfer, there is also the potential to spread these respiratory diseases through food. Several possible examples of direct transfer include sharing foods such as drinks, dipping sauces and popcorn while foods could also be indirectly contaminated by hands and utensils. Thus person to person transfer of disease agents seems likely by direct or indirect contact with food just prior to or during consumption.

1. **Introduction**

Efforts to improve food microbiological safety have traditionally focused on foodborne pathogens that originate from the production environment, processing facilities and food handlers. A farm to table approach has been implemented by government and industry groups to target intervention strategies at points where food contamination can be limited or mitigated with appropriate measures. Microorganisms that have become the focus of food safety include the CDC's top 5 pathogens causing foodborne illness; Norovirus, *Salmonella* spp., *Clostridium perfringens*, *Campylobacter* spp. and *Staphylococcus aureus*, while microbes leading to more serious infections requiring hospitalization include *Clostridium botulinum*, *Listeria* spp., *Escherichia coli* and *Vibrio* spp.[1] A foodborne outbreak is defined as two or more people becoming ill from eating the same contaminated food or drink.[2] The US Food and Drug Administration and Centers for Disease Control have surveillance systems to investigate and control foodborne outbreaks.[2,3] Microorganisms causing foodborne illness listed above are not the same types typically associated with human infectious respiratory diseases such as the rhinovirus (common cold), respiratory syncytial virus, influenza, coronaviruses (SARS, MERS, COVID-19), pneumonia, tuberculosis and Legionnaires Disease. Current knowledge on how these respiratory diseases spread is believed to be primarily through hand contact with contaminated surfaces and airborne transmission.[4] Until the late 1700s, it was believed that infectious diseases were spread by noxious vapors called miasmas. However, even up to the early 1900s during the Panama Canal construction, yellow fever and malaria (literally bad air in Italian) was thought to be a result of breathing miasmas from the sludge rising from the canal base.[4] This belief and resulting treatments actually made the diseases more deadly by keeping hospital wards open and bringing in plants which gave mosquitos access to humans and breeding locations near humans.[5] Dr. Walter Reed, based on the original theory of Cuban scientist Carlos Finley, proved the diseases were blood borne and spread by mosquitos and not the oral route. But for some diseases such as the respiratory diseases listed earlier, the "bad air" theory has a coincidental validity since the disease can be transmitted in air on tiny water droplets derived from the oral cavity of infected individuals. Respiratory viruses are spread through three modes of transmission; direct contact (infected individual contact with uninfected individual), indirect contact (transfer from infected to uninfected person via an inanimate object (fomite), or aerosol transmission.[6]

For respiratory diseases that are spread from the oral route there has been little discussion as to the spread of these infectious microorganisms through food. This review will discuss various activities involving food that can potentially spread microorganisms and respiratory disease agents. Several potential routes of transmission of disease from the oral cavity of an infected individual exist through food: 1. Direct contamination of food from the saliva of the infected source to be consumed by a susceptible person as with sharing drinks, double-dipping or blowing out birthday candles; 2. Direct transmission from the hands of the infected individual to the food of the susceptible person as with sharing popcorn or drinking games such as "beer pong;" and 3. Indirect contamination of a surface such as a menu or utensil by the hands of an infected person that is then touched by an uninfected person who in turn, self-inoculates the food they consume (Figure 1). Of course touching any surface contaminated with a pathogen immediately before touching food will likely transfer the pathogen to the food and individual. This manuscript will discuss these transmission routes for disease using food as a possible vector.

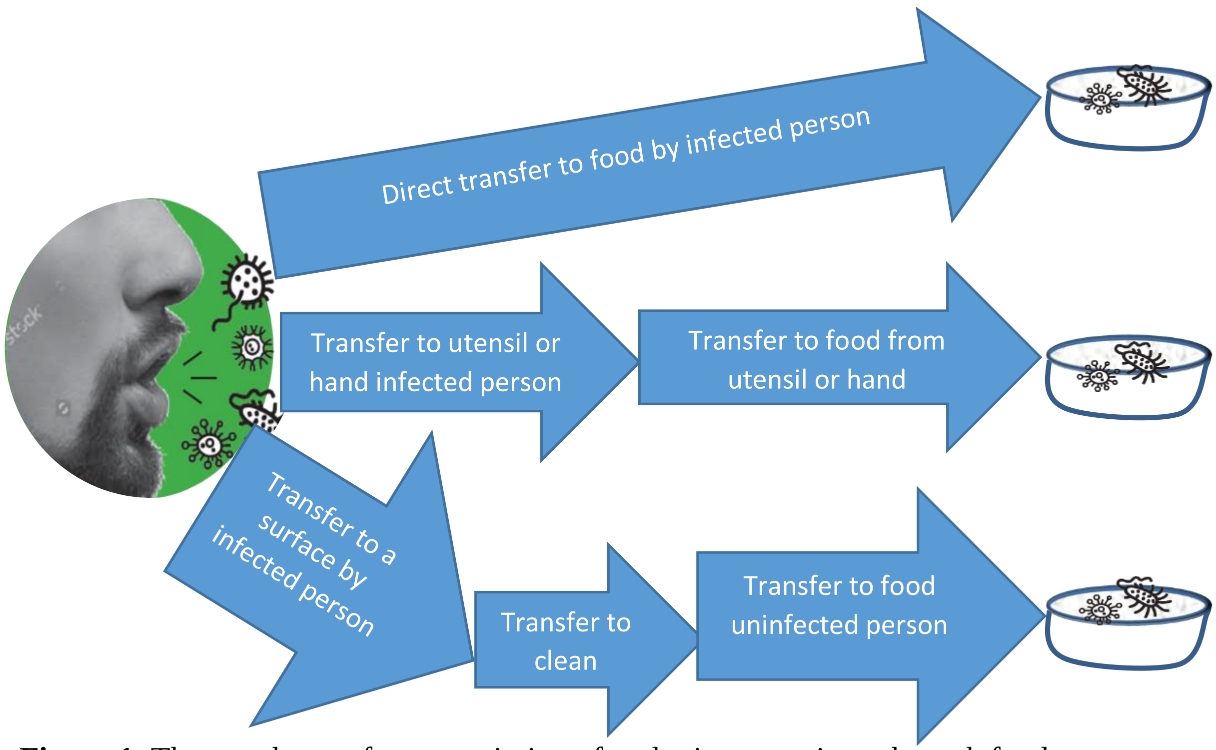

Figure 1. Three pathways for transmission of oral microorganisms through food.

2. Direct Transfer to food from an infected person

2.1 Airborne transfer directly to food

While exposure to microorganisms are unavoidable and most are harmless or even beneficial, bioaerosols can have adverse public health consequences[7,8].In fact, every exhaled breath contains between 693 to 6,293 CFU of bacteria/cubic meter.[3] Studies on oral cavity airborne droplet size were published as early as 1899[9] along with several others before the mid-20th century.[10,11,12,13,14,15] These early studies came to varying conclusions but reported that bioaerosols were released into the environment from humans that are breathing, coughing and sneezing. Duquid (1946)[11] reported that 90% of bacteria-carrying droplets remain airborne for 30 minutes in still air and that some smaller droplets remained airborne for up to 30 hours. More recently, Wan et al. (2014)[16] established that up to over 2,000 moisture particles less than 5 um in diameter were released per breath. Particle size is important since bioaerosols carry both bacteria and viruses in small particle droplets generated by breathing, blowing and coughing.[17] The average size of oral bioaerosol particles generated by coughing and speaking are much larger (13.5 um for coughing and 16.0 um diameter for speaking) than bacterial cells and viral particles.[18] Thus, oral bioaerosols are large enough to carry both viral particles and bacteria. Normal respiratory aerosols can include *Staphylococcus* spp., *Streptococcus* spp., *Corynebacterium* spp., *Haemophilus* spp., and *Neisseria* spp.[19] as well as pathogenic species such as *Streptococcus pneumonia* and *Staphylococcus aureus* that reside in the oral cavity.[14]

In fact, humans emit 37 million bacterial gene copies per hour and therefore are a significant contributor to indoor aerosolized microorganisms.[20]

2.2 Blowing out candles on a birthday cake

So what happens when someone blows out birthday candles? Blowing out candles on a cake is a centuries-old tradition to celebrate the birthdays[21]. The problem with this practice is obvious once we consider that the person blowing out candles releases aerosolized bacteria from the oral cavity directly to the top of the birthday cake. Blowing out candles over cake icing increased the bacteria recovered from the icing 15 times compared to icing that did not have candles blown out.[22] In addition, the variation (range) in bacterial populations recovered from icing was 100 times greater for icing exposed to the blowing out of candles compared to icing not exposed blowing. Respiratory droplets expelled by coughing and sneezing are sources of both normal human flora and pathogens.[23,24,25,26,27] Airborne transmission is a pathway for viral diseases[28,29,30] and Stelzer-Braid et al. (2009)[31] detected viral influenza in the exhaled breath of infected patients. For example, Fabian et al. (2008)[32] reported that 60% of patients with influenza A had detectable levels of the virus in exhaled breaths. In another study, Lindsley et al. (2010)[33] found that 81% of influenza patients had influenza RNA in their breath. In addition to viruses, Fennelly et al (2004)[34] reported that 25% of tuberculosis patients exhaled from 3-633 CFU per cough of *Mycobacterium tuberculosis* in expelled air particles. The spread of respiratory diseases including coronaviruses (including SARS, MERS, COVID-19, H1N1 and avian influenza), pneumonia, Legionnaires disease, tuberculosis and the common cold have been attributed to oral airborne transmission.[35,36] Influenza virus particles were detected in the exhaled breath of infected individuals through coughing, breathing and talking.[24,25,26,37] When respiratory droplets are released, they spread infection directly from person-to-person or by contamination of surfaces then touched by others.[19]

2.3 Direct transfer of microbes from the oral cavity

Direct transfer to food from the oral cavity can also occur when a person dips a chip or cracker into a dipping sauce from which they have already taken a bite or using the popular vernacular "double dipping." Between approximately 150 and 1,000 CFU/ml of dip were transferred from the oral cavity to cheese (pH=6.0), chocolate (pH= 5.3) and salsa (pH=4.0) by double-dipping.[38] Salsa had the highest number of bacteria transferred of the dips tested presumably due to the low viscosity of the dipping solution allowing more contaminated dip to fall back into the dipping bowl. Furthermore, after 2 hours at room temperature, the bacterial counts in the double-dipped salsa had dropped to be nearly the same level as the chocolate and cheese (aka. 100-150 CFU/ml).

2.4 Sharing drinks

Another transmission route from infected to uninfected individuals and probably the most direct is sharing beverages. An average of 100,000 bacteria were transferred to rims and 1,500 to water in cups after sipping with up to 1 million and 15,500, respectively.[39] Sports teams were warned not to share water bottles back in 2009 due to fear of spreading the swine flu after the death of a 13 year-old youth hockey player from the disease.[40] In fact, several studies have reported on the transfer of oral microorganisms during Common Communion as early as 1897.[41,42] Several studies found that bacteria survived on silver chalices[43] and that sharing common Communion cup would transfer oral bacteria between individuals including pathogens.[44,45] Thus the direct inoculation of a food by one person as with blowing out birthday candles, double-dipping and sharing drink containers will transfer microorganisms to food to be eaten by another person, potentially spreading organisms capable of causing illness.

3. Direct transmission from infected person's hand/utensil to food.

3.1 Sharing food

Psychologists tell us that sharing food is a sign of friendship and even intimacy. However, when sharing food there is more than just food being shared. For instance, when eating popcorn from a bowl with hands, bacteria from the hands was transferred to the popcorn remaining in the bowl 79% of the time.[29] Transmission of disease via human hands is a public health concern[46,47,48,49] thus, sharing popcorn will transfer microorganisms from hands to the popcorn left in the bowl and to the handful eaten. Hand contact with food is also a concern with viruses since influenza A remained infectious and was shed from fingers for 30 minutes after inoculation.[50] An even greater microbial transfer rate was reported from sharing food such as soup and rice using spoons, hands or chopsticks.[51] Between 130,000 and 470,000 bacteria were transferred to spoons while eating rice and soup while between 360,000 and 870,000 bacteria were transferred to chopsticks when eating rice. This resulted in 73,000 oral bacteria being transferred to soup and 340,000 transferred to rice when eating with a chopstick and spoon, respectively. When hands were used to eat rice 760,000 bacteria were transferred to the rice.

3.2 Drinking games

Another transmission route for microorganisms between humans is the popular drinking game known as "beer pong." The game which was invented at New England University fraternities in the 1950's involves throwing ping pong balls into a cups of beer to require your opponent to drink the cup of beer. This game has become so popular that there are beer pong leagues worldwide and regional, national and world beer pong championships. Organizers of these contests have reported contestants complaining of what has become known as "pong flu." In 2009, officials at Rensselaer Polytechnic Institute in New York State temporarily banned beer pong games on campus since health officials believed the games caused a high number of bird flu cases on campus. Ping pong balls collected from beer pong games being played during a College Homecoming weekend had an average of 200,000 bacteria per ball and up to 3 million bacteria on some balls.[52] Bacterial species isolated from the balls included potential pathogens such as *Listeria*, *Staphylococcus* and Gram negative *Bacillus* spp. Furthermore, nearly 100% of the bacteria on inoculated ping pong balls placed into beer was transferred to the beer.

3.3 Touching garnishes and ice

Cutting and handling lemons, limes or other garnishes by an infected person before adding to a drink can potentially transfer microbes to a drink subsequently consumed by another person.

An average of 5% and a maximum of 30% of inoculated *E. coli* on hands were transferred to lemons during cutting and handling.[53] Furthermore, when handling ice while making a drink, an average of 19.5 and a maximum of 67% of inoculated *E. coli* was transferred to the drink, while an average of 66% of *E. coli* inoculated onto stainless steel scoops were transferred.[52] Garnishes are often added to carbonated and alcoholic beverages which sometimes gives a false sense of security in the belief that the acid or alcohol content of the drink will kill any dangerous organisms in the libation. Pathogens such as *Shigella sonne*i, *Salmonella* Typhii and *E. coli* frozen in ice then allowed to melt and sit in a drink for 30 minutes were not eliminated in various carbonated and alcoholic beverages. In fact, the following approximate percentages of these pathogens were recovered in each drink after 30 minutes: club soda (~100%), cola (55-74%), scotch and soda (64-94%), pure Scotch (11-16%) and pure Tequila (5-10%).[54] Ethanol concentrations of at least 70% are recommended to inactivate viruses and 10 minutes of exposure was required to reduce a hepatitis virus by 3 log cycles[55] while higher concentrations of 80-90% were needed to reduce the infectivity of SARS coronaviruses by 4-5.5 logs.[56]

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4. **Indirect transmission from surfaces to uninfected hands then food**.

4.1 Microorganism survival on surfaces.

Infectious microorganisms such as bacteria, viruses, fungi and parasites can remain viable on inanimate surfaces such as plastic, metal and paper (Table 1) as well as skin. Generally gram-negative bacteria such as *E. coli*, *Shigella* spp. and *Salmonella* spp. can persist longer on surfaces than gram-positive bacteria such as *Listeria*, *Staphylococcus* and *Streptococcus* spp. however both gram types can persist for months with lower temperatures enhancing persistence. Spore-forming bacteria can survive for many months in the spore state. High humidity increases survivability for most bacteria with *S. aureus* being an exception preferring low humidity.[57] Non-enveloped viruses like the rotavirus, poliovirus remain infective longer than enveloped viruses which include respiratory viruses such as human coronaviruses, influenza and H1N1.[58] Pathogenic fungi such as *Candida albicans* lasted 4 months[59] while parasites such as Cryptosporidium survive only a few hours.[60] Neely and Maley (2000)[61] found that *Staphylococcus aureus* is capable of adhering to plastic and also surviving on plastic for at least 1 day while some *Staphylococcus* spp. were capable of surviving up to 56 days on certain plastic materials such as polyester and from 22 to 90 days on polyethylene. After 24 hours at 37°C there were still 10^6 CFU/g *E. coli* after a starting population of 10^8 CFU/g,[62] while at lower temperatures such as 4°C, there was no decline in bacterial populations after 48 hours and only a 1 log decrease after 6 days. Human coronaviruses remain infectious on inanimate surfaces such as steel and plastic for up to 9 days at room temperature and longer at refrigerated temperatures.[63] Lai, et al. (2005)[64] reported that the SARS coronavirus remained infectious for 7 days in respiratory samples at room temperature, 24 h on paper forms (but could not be recovered after drying) but survived on gowns for 1-2 days. The persistence of viruses shown in Table 1 are general values however viruses can remain active on metal, wood, paper and plastic up to several weeks and months when held at refrigerated and frozen temperatures.[58,63] Self-inoculation of mucous membranes of the nose, eyes or mouth from dry surfaces contaminated with the coronavirus has been theorized,[65] emphasizing the importance of coronavirus persistence on inanimate surfaces. As previously discussed, saliva bioaerosols are released during coughing, sneezing, talking and just breathing. These bioaerosols carry bacterial cells and virus particles from an infected individual that can land on nearby surfaces. When these surfaces are touched the infectious agent can be transferred to hands and then to the body by self-inoculation or by touching food just prior to eating. This could be the case with menus and salad bar utensils.

Table 1. General duration of persistence on surfaces for selected infective microorganisms.

Bacteria	Persistence	references
Clostridium difficile (spore)	5 months	66
E. coli	hours-months	67,68,69,70
Listeria spp	days-months	56,69,71
Salmonella spp	hours-months	69,70
Viruses		
SARS coronavirus	hours-5 days	72,73,74
Human coronavirus	2-9 days	75,76
Influenza virus	1-2 days	77,78
Norovirus	1-7 days	79,80
Fungi		
Candida albicans	days-months	81,82

4.2 Menus and food bars

How do menus and salad bars impact the spread of disease? Is there a risk of contracting a foodborne disease from eating out? Individuals contracting foodborne illnesses traditionally consume more of their food outside the household compared to people not contracting foodborne illnesses.[83] Olsen et al (2000)[84] reported that an important fraction of known foodborne outbreaks are related to restaurants. Public dining establishments such as restaurants, cafeterias, and bars are locations most often cited for foodborne illnesses and food-related diseases.[85] These locations were responsible for 54% of outbreaks in the UK between 1993 and 1998[86] and were associated with 45% of outbreaks in the US.[37] Of the 841 reported outbreaks and 14,481 documented illnesses from the CDC foodborne disease outbreak surveillance system, 64% of the outbreaks and 44% of the illnesses were linked to dine-in restaurants[87] and an additional 14% of outbreaks and 29% of illnesses were linked with catering services. While these outbreaks are not necessarily directly related to menus, menus are touched by nearly everyone that enters a restaurant or delicatessen, including customers and workers. Griffith et al (2000)[88] indicated that hand contact surfaces in restaurants are contaminated and do not meet food industry sanitation standards. Furthermore, restaurants may be harboring Hepatitis A virus and that repetitive hand contact with tainted surfaces may increase the spread of Hepatitis A virus, including customers and restaurant staff.[89] For example, a Hepatitis A outbreak at a single restaurant in Pennsylvania, resulted in 601 patrons getting the virus, 124 hospitalizations and three deaths.[90] Random sampling of restaurants estimated that menus carried between 6,000 and 12,000 total bacteria and 1,200 to 3,200 *Staphylococcus* spp. bacteria[91] while another study found bacteria from soil, *E. coli* and Staph on menus.[92] Furthermore, 10% of bacteria on menus inoculated with *E. coli* were transferred to hands after touching the menus and *E.coli* survived for several days on inoculated laminated menus.[90]

Food bars have a similar problem in that many people handle tongs and ladles on the bar as well as touch surfaces around the bar. The need for proper sanitation of utensils, especially in public eating areas, should be obvious since as mentioned earlier, diseases associated with saliva/mucus include but are not limited to influenza, tuberculosis, pneumonia, scarlet fever, diphtheria, whooping cough, trench mouth, typhoid, dysentery, human noroviruses and hepatitis A virus. The infective agents causing these diseases are transmitted by direct and indirect contact from an infected individual. To illustrate the potential transfer at food bars, a controlled inoculation study found an average of 10% and a maximum of 66% of the bacteria on hands were transferred to tong handles and then 5% and a maximum of 56% of the bacteria on tongs were transferred back to clean hands during simulated handling.[93]

5. Conclusion

Food bacterial pathogens and some viral diseases can be transferred to food then to other humans via cross contamination. The epidemiology of typical foodborne pathogens is linked to a single food source, while respiratory diseases are linked to a human source. This does not eliminate the possibility that respiratory disease agents can be spread through food. A classic example of a human being the source for spreading disease through food is Mary Mallon infamously known as "Typhoid Mary" who despite being asymptomatic caused 47 illnesses and 3 deaths from typhoid fever (*Salmonella* Typhii).[94] Hepatitis A is an example of a virus known to be spread by food handlers infected with the virus.[95] However, both of these pathogens despite one being a bacterium and the other a virus are spread through the fecal-oral route. There is still some debate whether respiratory diseases that originate from mucous can be passed through food from mucous droplets. Influenza transmission occurs through the airborne route[96] however hand contact with a contaminated surface followed by self-inoculation by touching the face is also an important factor.[97] Thomas et al. (2013)[98] reported that the influenza virus could survive up to 30 min on fingers and that skin and finger contamination directly from the respiratory tract or from environmental surfaces followed by self-inoculation is possible. This conclusion is supported by the decrease in the spread of respiratory viral diseases due to hand washing.[99] Another respiratory disease rhinovirus (common cold), was transferred from contaminated coffee cup handles and tile to subjects by touching the contaminated surface then the nose and eyes.[100] With the overwhelming evidence that respiratory diseases can be transmitted through self-inoculation by touching the face with contaminated hands and that oral bacteria are transferred to food, it is highly likely that a similar pathway exists to transfer respiratory diseases by consuming food that has been contaminated either directly or indirectly immediately prior to consumption (Table 2).

Table 2. Potential microbial transmission routes via food

Mode of transfer	Relevant transfer data	references
Direct transfer to food		
Blowing out birthday candles	Up to 37,000 CFU transferred by blowing out candles	22
Double-dipping	150-1000 CFU/ml transferred to dip by double-dipping	38
Sharing beverages	100,000 CFU transferred to cup rim and >1,500 CFU transferred to water by drinking from a cup	39
Transfer from hands/utensils		
Sharing food	Bacteria transferred 79% of the time when taking a handful of popcorn. 73,000 oral bacteria transferred to soup and 340,000 transferred to rice when sharing with a spoon or chopstick	36,50
Beer pong	>95% of CFU on ping pong balls transferred to beer	51
Drink garnishes/ice	10 to 85% of the bacteria on hands and tongs are transferred to beverages during handling lemons and ice	52
Transfer from objects to hands		
Menus	10% of the bacteria on menus transferred to hands	90
Food bars	10% of bacteria on hands transferred to tongs and 5% of bacteria on tongs were transferred to hands	91

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