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Foodborne transmission of SARS-CoV-2 is more evident than it has been before

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Abstract

Background:

Although highly strict social distancing and viral spread protection guidelines are in force, the reported numbers of COVID-19 cases across the world are still increasing. This indicates that we are still unable to completely understand the transmission routes of SARS-CoV-2. One of the possible routes that can play a significant role is the fecal-oral transmission since SARS-CoV-2 can replicate in the intestines as demonstrated by isolation of infectious virus from fecal samples of COVID-19 cases.

Scope and approach:

In this review, we compare the characteristics of SARS-CoV-2 with the distinctive characteristics of enteric foodborne viruses. We also discuss and respond to the arguments given in some reports that downplay the importance of foodborne transmission route of SARS-CoV-2.

Key findings and conclusions:

Enteric viruses such as human noroviruses (HuNoVs) and hepatitis A virus (HAV) are known to transmit through foods such as fresh produce and berries, leading to frequent multistate foodborne disease outbreaks all over the world. SARS-CoV-2 was found to share four distinctive characteristics of foodborne viruses that allow them to transmit through foods. This similarity in characteristics, recent report of detecting SARS-CoV-2 particles from frozen food packages in China, and recent suspected foodborne COVID-19 case in New Zealand, indicate that foodborne transmission of SARS-CoV-2 is more evident than previously thought possible. To support or deny this route of transmission, urgent research needs to be undertaken to answer two primary questions and many secondary ones as described in this review.

Keywords:

SARS-CoV-2; COVID-19; foodborne viruses; enteric viruses; fecal-oral transmission; fresh produce, berries, fruits, hepatitis A virus, Norovirus, ready-to-eat foods.

Introduction

A reported familial cluster of pneumonia associated with COVID-19 in hospital and family settings confirmed the direct person-to-person transmission of SARS-CoV-2 through close contact and droplets (Chan et al., 2020 b; Liu et al., 2020). However, indirect transmission routes are also postulated such as via air and contact with contaminated surfaces and fomites (Aboubakr et al., 2020 b). Because of the absence of any confirmed COVID-19 cases associated with food or food-contact surfaces, WHO and CDC have declared that “currently” there is no evidence that people can catch COVID-19 from food or food packaging (WHO, 2020; CDC, 2020). The downplaying of foodborne transmission of SARS-CoV-2 contradicts the earlier classification of similar human coronaviruses (i.e. SARS-CoV-1 and MERS-CoV) among the viruses that have the potential to be transmitted by food (Greening and Cannon, 2016). In addition, it contradicts the conclusion of a detailed risk assessment study by the UK-Food Standards that transmission of SARS-CoV-2 through food and food-contact surfaces cannot be completely excluded (Oakenfull & Wilson, 2020). Furthermore, after 102 days with no local COVID-19 transmission reported, New Zealand recently (first week of August 2020) reported the first COVID-19 cluster in a family in Auckland (Menon, 2020). Investigation of these cases led to a suspicion that virus transmission was through frozen food as the first reported case of this cluster is a cool store worker who handled a frozen food freight imported from Americold Inc., Australia. On August 11, 2020, a Chinese news reported the first detection of SARS-CoV-2 on imported frozen seafood packaging, imported from Ecuador, in the Chinese port city of Yantai (Ho and Chik, 2020). Two days after (August 13, 2020), SARS-CoV-2 was detected in frozen chicken wings, imported from Brazil, in the southern Chinese city of Shenzhen (Gan, 2020). These reports indicate that a thorough review of safety of foods and food packaging should be undertaken.

Coronaviruses have all required characteristics to be foodborne:

Foodborne viruses are mostly enteric viruses which replicate in the human gastrointestinal tract (GIT), excreted in human feces, and transmitted by the fecal-oral route (Greening & Cannon, 2016). Viruses such as human Noroviruses (HuNoVs) and hepatitis A virus (HAV) can be transmitted through food from infected person to the food consumer (Goyal and Aboubakr, 2016). Foodborne viruses cannot replicate in foods (outside their host cells) but foods can act as vehicles that transfer infectious viral particles from an infected person to another person through at least one of two possible scenarios. First, consumption of contaminated food that has been handled by an infected person in poor hygienic conditions. Second, consumption of foods contaminated by virus-containing human excrements such as sewage-contaminated irrigation water or soil, or a contaminated food processing surface (Goyal and Aboubakr, 2016; Hedberg, 2016; Aboubakr and Goyal, 2019). The most implicated foods in foodborne virus outbreaks are those which are consumed fresh, such as fresh produce and berries, or minimally processed foods without thermal cooking such as frozen foods (Aboubakr et al., 2020 a). The main characteristics of the foodborne viruses are: **(i)** they are mostly enteric in nature and hence can replicate in the gastrointestinal tract (Greening & Cannon, 2016); **(ii)** can retain their infectivity for a substantial period of time in a wide variety of environmental conditions (Sánchez and Bosch, 2016), **(iii)** are highly contagious and have a low minimum infective dose (MID); and **(iv)** can tolerate the hostile environment of the human GIT, namely, low pH and presence of proteolytic enzymes and bile juice (Morrison and Fields, 1991; Holmes, 2001). In fact, coronaviruses share all these attributes, as described below, which indicates that they have the potential to be foodborne.

1- ***Enteric replication of SARS-CoV-2***

Several studies have reported the association of gastroenteritis and infection with SARS-CoV-1 and MERS-CoV (Chan et al., 2015; Cheng et al., 2004); up to 10.6% and 30% of patients infected with SARS-CoV-1 and MERS-CoV, respectively, had diarrhea (Fan et al., 2019; Chan et al., 2020). Likewise, diarrhea and gastroenteritis symptoms have also been reported in some cases of SARS-CoV-2 infection (Chan et al., 2020; Song et al., 2020). This phenomenon is attributed to the high expression of the receptor of these viruses, angiotensin-converting enzyme 2 (ACE2), in epithelia of small intestine as seen in Fig. 1 (Hamming et al., 2004; Christian et al., 2004; Vabret et al., 2020). The spike (S) protein of SARS-CoV-2 binds to ACE2 in a way similar to that of SARS-CoV-1. Strikingly, SARS-CoV-2 is more pathogenic, partially because it has higher (10-20% more) binding affinity to ACE2 (Hoffmann et al., 2020; Wrapp et al., 2020). This binding leads to the entry of the virus into the host cell in concert with S-protein priming by the cell protease TMPRSS2 (Bourgonje et al., 2020). Consistent with this explanation, RNA of SARS-CoV-2 was detected in anal swabs and urine samples collected from COVID-19 patients by two independent laboratories in China (Chen et al., 2020; Zhang et al., 2020). Also, the RNA of SARS-CoV-2 was detected in 41 of 74 (55%) fecal samples collected from COVID-19 patients and the fecal shedding continued for approximately 28 days after the onset of symptoms (Wu et al., 2020 b).

In addition, RNA of SARS-CoV-2 has been detected in sewage and wastewaters collected from several cities across the world during the current COVID-19 pandemic (Ahmed et al., 2020; Peccia et al., 2020; Randazzo et al., 2020; Wu et al., 2020 a; Wang, et al., 2020). Furthermore, infectious SARS-CoV-2 virus was isolated recently from the feces of a COVID-19 patient in China, which indicates the potential for fecal-oral route of transmission (Xiao et al., 2020). To date, no data are available on the survival of SARS-CoV-2 in human excrements. However, its prolonged persistence in human feces is manifested from the prolonged survivability of various animal and human coronaviruses (more than 35 days in some cases) in human excrements such as stool, urine, sputum, and sewage (Aboubakr et al., 2020 b).

One of the reports that downplayed the foodborne transmission of SARS-CoV-2 has used the argument that CoVs mainly spread through the respiratory tract and not through GIT (Li et al., 2020 a). However, the facts we provided above show that SARS-CoV-2 is both enteric and respiratory in nature and has the potential for fecal-oral mode of transmission like the foodborne viruses. Thus, this route of transmission should not be ignored (Ding and Liang, 2020; Han et al., 2020 b).

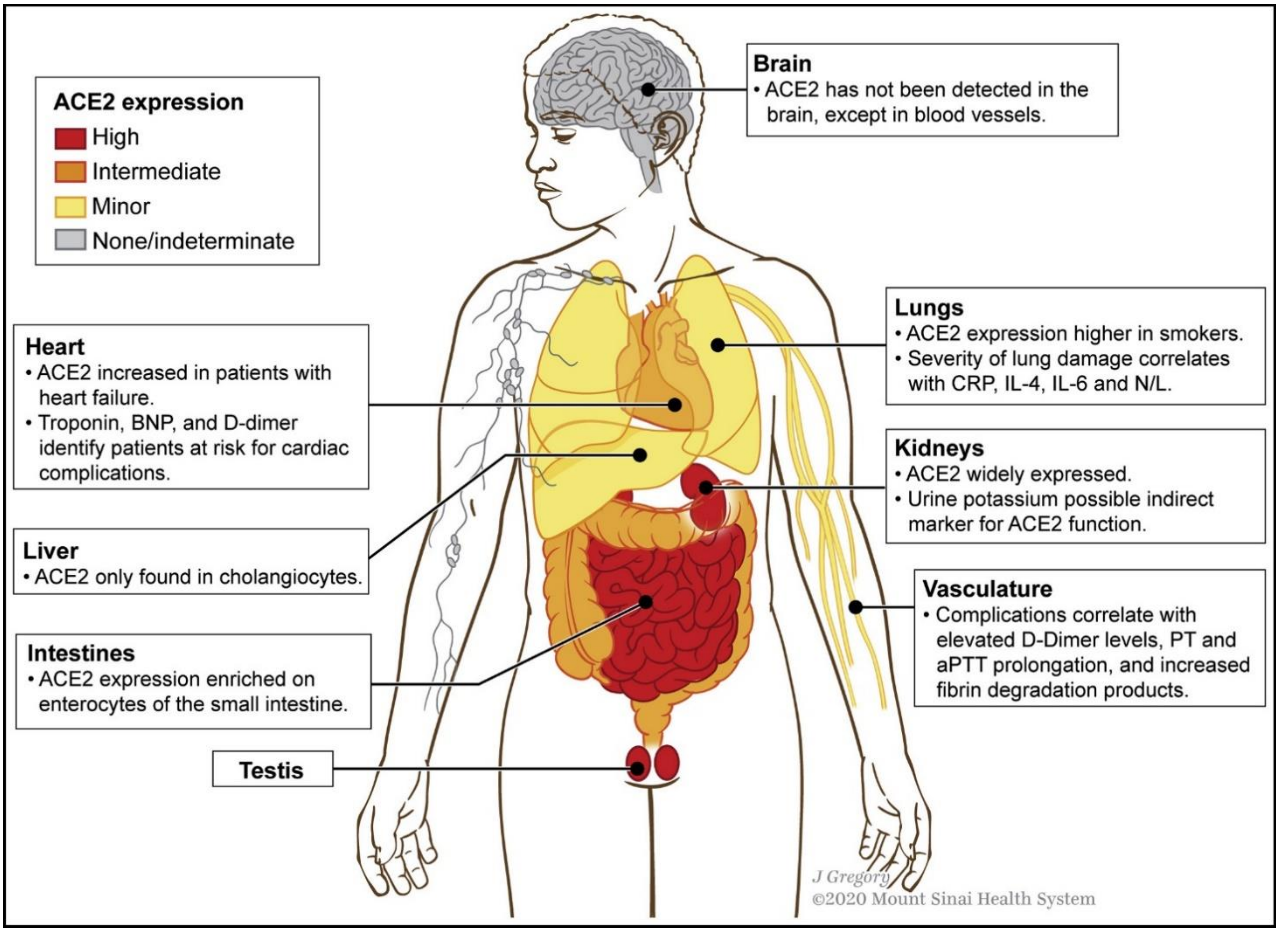

Fig. 1:
ACE2 Expression in Organs and Systems Most Frequently Implicated in COVID-19 Complications. **Source:** Vabret et al. (2020)

2- *Long stability of SARS-CoV-2 in environmental conditions*

Outside their hosts, viruses are inert particles. Hence, the chance of transmission from host to host is determined mainly by the degree of robustness of these viral particles in the environment. The degree of infectivity retained during the extreme conditions encountered in environmental matrices such as foods determines if the virus can be transmitted by the indirect route or not (Sánchez and Bosch, 2016). Numerous physical, chemical, and biological factors influence virus persistence in the environment such as temperature, pH, relative humidity, exposure to sunlight, salinity, and desiccation, etc. (Sánchez and Bosch, 2016). Thus, foodborne viruses, such as HuNoV and HAV, can survive for several days on different environmental matrices (e.g., soil, water, wastewater, various fomites, food contact surfaces, and human hands) (Arthur and Gibson, 2016; Elmahdi et al., 2018; Fallahi and Mattison, 2011; Kotwal and Cannon, 2014; Samandoulgou et al., 2015).

Until now, there is no available study on the stability of SARS-CoV-2 or other human infectious coronaviruses on foods. However, long persistence (for days to several weeks) of MERS-CoV, SARS-CoV-1, and SARS-CoV-2 on a wide verities of fomites, surfaces, and environmental matrices has been reported (Chin et al., 2020; van Doremalen et al., 2013; van Doremalen et al., 2020). We comprehensively reviewed almost all available data on the stability of coronaviruses in the environment and described factors influencing their persistence (Aboubakr et al., 2020 b). In light of the available data, we found no difference between the stability of SARS-CoV-2 in the environment and on fomite surfaces than that of other foodborne viruses, which suggests that the stability of SARS-CoV-2 on foods is similar to that of foodborne viruses. In addition, the long persistence of SARS-CoV-2 on surfaces of materials similar to those used in food packaging, food processing, and utensils (e.g. plastics, paper, cardboard, ceramic, and stainless steel) indicates that SARS-CoV-2 may follow transmission routes similar to those of foodborne viruses (van Doremalen et al., 2020; Chin et al., (2020). The long persistence of SARS-CoV-2 on surfaces at low temperatures is worth noticing here as demonstrated by the recent cluster of COVID-19 cases in New Zealand, which is suspected to be transmitted through handling of imported frozen food freight.

3- Low infective dose of SARS-CoV-2

It is thought that the number of viral particles which a shedding individual might leave on food, food-processing surface, or food packaging is too low to initiate an infection (Oakenfull & Wilson, 2020; Mole, 2020). However, to accurately assess this type of risk, we should look at the number of viral particles contaminating food commodities in view of the very low infective dose of coronaviruses; which can inform us if these low numbers are enough to initiate an infection.

The minimum infective dose (MID) of a viral pathogen is defined as the minimum dose of virus particles that can initiate infection in the tested population. The lower the MID of a virus, the more the contagiousness and ease of transmission. Most human MIDs have been expressed as HID_{50}, which indicates viral concentration required to infect 50% of the tested population and hence this value is always greater than the MID (Ward et al., 1984). One of the important characteristics of enteric viruses that makes them easily transmitted through food is that they have low infective doses and are shed by the infected person in high numbers. For instance, HuNoV, the leading cause of foodborne outbreaks, is highly contagious to humans since the HID_{50} of HuNoV GI.1 strain in humans is estimated to be as low as 18 particles (Teunis et al., 2008). However, this estimation was followed by another study with an enhanced model that estimated the HID_{50} of HuNoV to be approximately 1,320 genomic equivalents (Atmar et al., 2013).

Similar to enteric foodborne viruses, respiratory viruses are shed in high numbers by the infected individuals even when the infection is asymptomatic (Yizli and Otter al., 2011). Until now, the infective dose of SARS-CoV-2 is unknown. However, the use of animal models indicate that the estimated ID_{50} of SARS-CoV-1 is 280 viral particles (Schröder, 2020; Watanabe et al., 2020). As indicated above, SARS-CoV-2 was found to have 10-20% more binding affinity to the host cells than SARS-CoV-1 (Hoffmann et al., 2020; Wrapp et al., 2020), which indicates that, theoretically, it has a lower infective dose as compared to that of SARS-CoV-1. In the best scenario, we can assume that the infective dose of SARS-CoV-2 is the same as that of SARS-CoV-1 (280 viral particles). Thus, SARS-CoV-2 appears to have higher infectivity and contagiousness than HuNoV, a leading cause of foodborne outbreaks. These arguments indicate the possible role that contaminated food, food-processing surfaces, or food packaging can play in spreading SARS-CoV-2 infection.

4- Stability of SARS-CoV-2 in the extreme environment of the human GIT

Foodborne viruses spread through the fecal-oral transmission route. To be able to infect, they have to survive the harsh environment of the human GIT, where they are exposed to proteolytic enzymes, bile juice, and extreme pH (Morrison and Fields, 1991; Holmes, 2001). Therefore, foodborne viruses such as HuNoV and HAV are stable in high the high acidity and alkalinity (Li et al., 2013; Scholz, 1989; Mormann et al, 2010). In addition, many studies have reported the stability of foodborne viruses in bile juice *in vivo* (Ross et al., 1991; Gust, 2018). The resistance to bile salts is attributed to the absence of a lipid bilayer envelope in these viruses (Goswami and Kulka, 2006). The stomach and intestinal proteases, low pH, and/or a combination of these processes leads to the cleavage of viral capsid protein of a foodborne virus such as HAV, which is essential for the enhancement of vial infectivity and antigenicity (Lemon et al., 1991; Bishop, 1999). A similar effect of stomach proteases and acidity was found on HuNoV-like particles by exposing the receptor binding sites in the viral capsid proteins thereby enhancing infectivity and pathogenicity (Hardy et al., 1995). Without these important features, viral particle might be easily destroyed and lose its infectivity in the human GIT.

Recently, several studies found that SARS-CoV-2 has the potential to resist the extreme conditions of human GIT due to the heavy glycosylation of S protein, which provides substantial resistance to low pH and digestive enzymes (Burrell et al., 2017; Ding and Liang, 2020). For instance, SARS-CoV-2 retained its infectivity to cell cultures after exposure to high acidity and high alkalinity (pH 3 to 10) for one hour (Chin et al., 2020) indicating that SARS-CoV-2 can tolerate the pH range encountered in human GIT (pH 1 to 3.5 in stomach and pH 6 to 9 in small intestine) (Fallingborg, 1999). Two mucosa-specific serine proteases, TMPRSS2 and TMPRSS4, were found important for SARS-CoV-2 binding with its receptor protein, to facilitate fusogenic activity of its spike and to promote virus entry into host cells (Hoffmann et al., 2020; Zang et al., 2020). This also indicates that SARS-CoV-2 can resist the action of proteolytic digestive enzymes.

Resistance of coronaviruses to bile juice was reported despite having a lipid bilayer envelope (Holmes, 2001; Quinn et al., 2011). For instance, MERS-CoV infectivity survived fed-state simulated intestinal fluid containing a high concentration of bile salts (Zhou et al., 2017). Therefore, bile juice resistance of SARS-CoV-2 is hypothetical as a coronavirus and because of the high similarity with MERS-CoV. The detection of high load of SARS-CoV-2 RNA in bile juice from COVID-19 patient also supports this hypothetic resistance to bile juice (Han et al., 2020 a). The resistance of coronaviruses to bile juice was also attributed to the heavy glycosylation of S protein and/or the distinct composition of the lipid bilayer envelope of coronaviruses (Burrell et al., 2017; van Genderen et al., 1995). Most of the enveloped viruses form their envelopes by budding from the plasma membrane (Fig. 2). On the contrary, the envelopes of coronaviruses are acquired by budding of the nucleocapsid at membranes of pre-Golgi complex called the budding compartment where viral glycoproteins S, M, E, and HE are incorporated into the viral envelope (Fig. 3; Bos et al., 1997). The lipid composition of coronavirus envelope is different from that of the plasma membrane of the same cell since it reflects the composition of the membrane of the budding compartment (van Genderen et al., 1995). This distinct lipid composition of coronavirus envelope may play a role in making them more resistant to degradation by bile than envelopes of unrelated viruses that bud from the plasma membrane (Holmes, 2001). Considering the above discussion, we believe that SARS-CoV-2 can be transmitted through contaminated foods and food packaging. Although no COVID-19 case has so far been linked directly to contaminated food or food packaging, the reality may be totally different because no efforts have been devoted to screen foods for SARS-CoV-2 contamination or for performing trace-back investigations on the cases to know the real infection point.

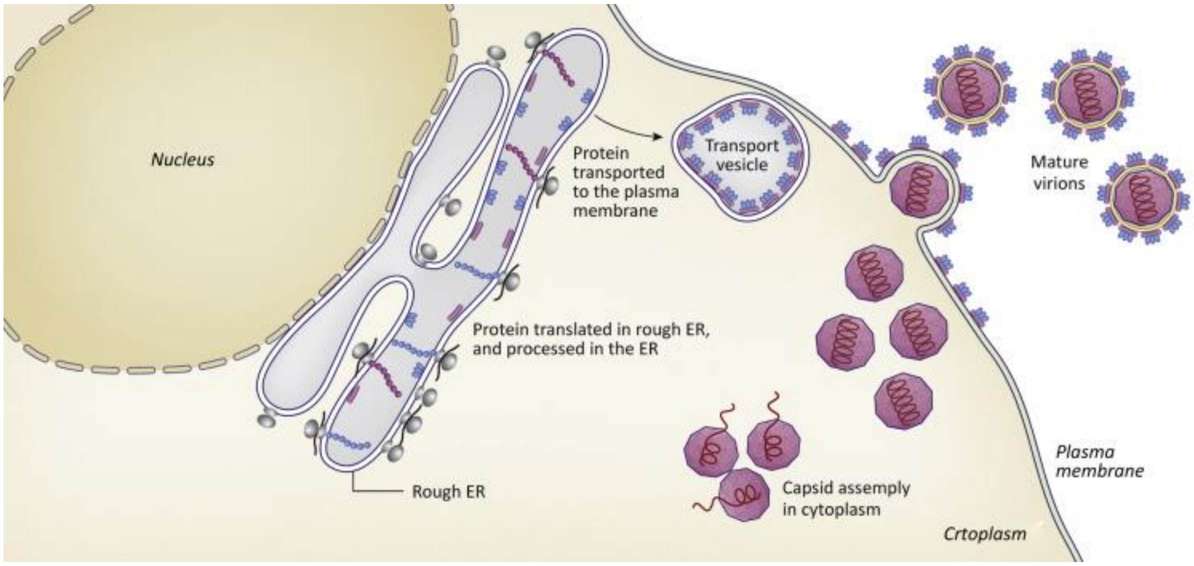

Fig. 2.
Illustration showing the process of assembly and budding of an enveloped virus particle from the plasma membrane. **Source:** Payne (2017)

<u>Long incubation period of SARS-CoV-2 infection and its implication on trace-back investigations</u>

Incubation period of SARS-CoV-2 infection was thought to extend to 14 days from exposure to onset of symptoms, with a median time of 4-5 days (Guan et al., 2020; Li et al., 2020 b). Another study has estimated that 97.5% of SARS-CoV-2 infected persons will show COVID-19 symptoms after 11.5 days (Lauer et al., 2020). This is a very long incubation period as compared to the incubation period of enteric foodborne viral pathogens such as HuNoV for which the incubation period was estimated to be 1.2 and 1.7 days for genogroup I and genogroup II, respectively (Lee et al., 2013). The long incubation period before the symptoms of COVID-19 become observable could be one of the reasons for making it very difficult to perform a trace-back investigation in order to link a specific case with a specific food.

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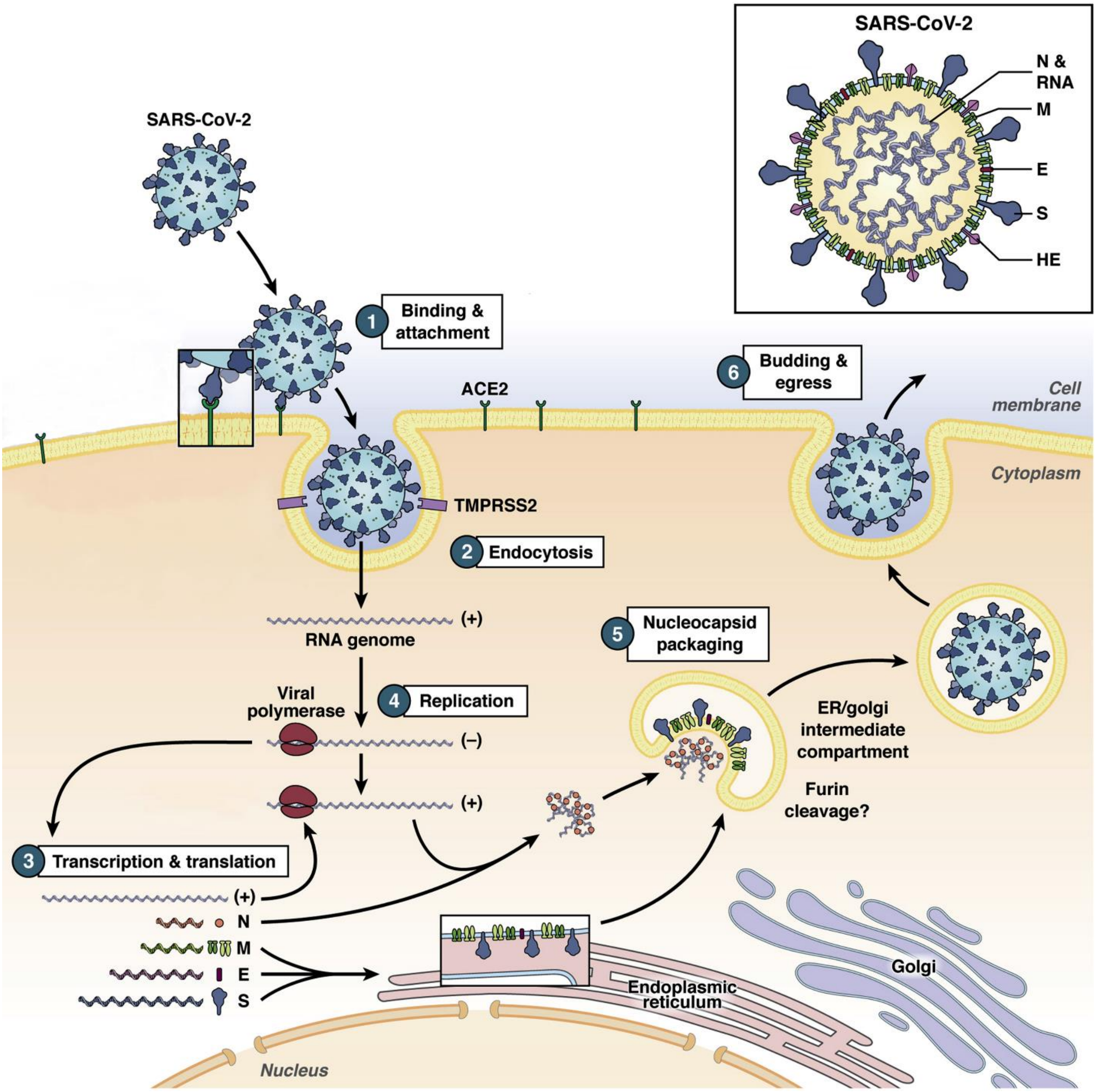

Fig. 3.
Illustration showing SARS-CoV-2 replication cycle including virus assembly and budding from membranes of pre-Golgi complex. (*1*) Interaction between viral S protein and host ACE2 mediates virus binding to the host cell. (*2*) S protein is cleaved by host serine proteases, such as TMPRSS2, allowing the fusion of viral membrane with the host membrane and single-stranded RNA (ssRNA) (+) genome release into the cytoplasm. (*3*) Transcription and translation of viral proteins from genomic and subgenomic RNAs. (*4*) Replication occurs within the replicative membranous compartment, where new ssRNA(+) are synthesized. (*5*) Virus assembly at the endoplasmic reticulum (ER), the intermediate compartments, and/or the pre-Golgi complex. (*6*) Release of new virions by exocytosis. E, envelope protein; HE, hemagglutinin-esterase glycoprotein; M, membrane protein; N, nucleocapsid protein. **Source:** Ding and Liang (2020)

Candidate foods that might be implicated in foodborne transmission of SARS-CoV-2

Green produce and fruits (such as berries) were found to be the most implicated foods in foodborne viral outbreaks (Hall et al., 2012; Marsh et al., 2018). This is because they are consumed mostly without any heat treatment or cooking. Therefore, the chance of thermal destruction of viral contamination is not possible if the food is consumed fresh or minimally processed. Although washing thoroughly with water might reduce the number of viral particles, it is still not enough to ensure significant removal of the viral load even with adding acetic acid or other chemical disinfectants to the washing water (Baert et al., 2009). The physical effect of washing cannot remove the viral particles that might be located in the stomata, surface cracks, irregularities, or grooves on the surface of green leaves or berries (Berger et al., 2010; Wei et al., 2010; DiCaprio et al., 2015).

The fresh produce and berries grow on the surface of the planting soil with very close contact. So, there is a possibility for these foods to be contaminated by viral pathogens directly from the contaminated soil fertilized by untreated sewage fertilizers from sewage-contaminated irrigation water (Goyal and Aboubakr, 2016; Aboubakr and Goyal, 2019; Mans et al., 2016). These viral contamination incidences are common in developing countries, which use sewage-contaminated irrigation water or partially treated wastewaters for irrigation and land fertilization.

Given that SARS-CoV-2 replicates in human intestine and was detected in human feces and in wastewater, the contamination scenarios explained above become very realistic and do not only occur in the developing countries but may also occur in developed countries such as the US and EU. The developed countries usually import these foods in large amounts from developing countries and frequently these imported foods have been implicated in foodborne viral outbreaks. For instance, an increasing number of foodborne viral disease outbreaks caused by imported foods was reported in the US between 1996 and 2014 (Gould et al., 2017). In 2016, a multistate HAV outbreak in the US was attributed to consumption of fruit smoothie that was prepared from imported frozen strawberries (CDC, 2016). Produce imported into Canada between 2001 and 2009 caused at least eight produce-associated outbreaks (Kozak et al., 2013). Tavoschi et al. (2015) and Aboubakr and Goyal. (2019) have reported many foodborne viral outbreaks that are caused by foods imported into the EU from developing countries. In addition, fresh produce and berries can be contaminated at the service point indirectly from asymptomatic infected handlers, who shed the virus (Hardstaff et al., 2018; Thornley et al., 2013). In fact, this particular scenario can occur not only in developing countries but also in the developed nations.

The recent report of Li et al. (2020 a) downplayed the role of food commodities in SARS-CoV-2 transmission. Although they provided proof of similarities between the characteristics of SARS-CoV-2 and HuNoVs, they stated that the former seems to be less persistent than HuNoVs towards common disinfection practices with alcohols, chlorine and ultraviolet (UV). Hence, they used this as an argument that there was no clear evidence showing CoVs can follow fecal-oral routes like HuNoVs and other foodborne viruses. In this context, we believe that this argument might apply on the outside of the packaged foods that the customers can easily disinfect the package prior to opening it using chemical disinfectants. However, foods like fresh produce are sold mostly as unpackaged items. So, the customers cannot disinfect them using chemical disinfectants; they can only wash them thoroughly under running water, which is not very effective in removal of viral particles that contaminate these foods (Baert et al., 2009).

Berries are usually sold in a primary plastic package. However, the customer also cannot disinfect the package by chemical disinfectants since these packages are usually perforated in order to allow gas exchange and to avoid the accumulation of water vapor and moisture inside the package to discourage microbiological decay (Danish Technological Institute of Packaging and Transport, 2008; Koyuncu, 2004). More importantly, the risk of viral contamination of fresh produce and berries fruits is related to their direct contamination, as described above, but not the packaging. These facts show the invalidity of the argument of Li and his colleagues, particularly in the case of fresh produce and berries fruits.

Gap in knowledge and future research opportunities

The information given herein about the possible role that foods can play in spreading SARS-CoV-2 will stay hypothetical unless two things are done. First, an effort to detect and/or isolate SARS-CoV-2 from vulnerable food samples, and second to confirm (or reject) the notion that consumption of SARS-CoV-2-contaminated food can lead to infections. To meet the first objective, we suggest performing a surveillance study to detect the presence of SARS-CoV-2 on fresh produce and berries that are imported from developing countries or grown in areas with high rate of SARS-CoV-2 infections. To meet the second objective, we suggest conducting an animal study using a non-human primates model such as *Rhesus macaques* (Shan et al., 2020; Munster et al., 2020) to determine if this model can be infected by eating SARS-CoV-2 contaminated food. These two suggested research areas should be supported by trace-back epidemiological studies with an attempt to confirm (or deny) association of COVID-19 cases with consumption of food or of handling food packaging. In reality, this type of research will be difficult because of the long incubation period of SARS-CoV-2. To make it easier, we suggest that a short questionnaire be administered to all suspected cases of SARS-CoV-2. The question to be asked is, "do you have any suspicion that you were infected from eating a food?" If the answer is "yes", then what type of food was eaten and where. This approach may serve as a primary initiation point of effective trace-back investigations.

If the two suggested areas of research mentioned above provide strong conclusion that the virus can be transmitted through foods, we think that other studies should be conducted. For instance, there are a few studies on the stability of SARS-CoV-2 on fomites including plastic, paper, and cardboards (Chin et al., 2020; van Doremalen et al., 2020). These materials are similar to those used in food packaging. However, until today we have no idea about the survivability of SARS-CoV-2 on foods such as fresh produce and berries. We also have no idea about the virus removal efficiency of the minimal food processing operations such as washing, cooling, and freezing. The food decontamination efficacy against SARS-CoV-2 of different non-thermal technologies such as UV irradiation, cold gaseous plasma, pulsed electric field, and high hydrostatic pressure is not known. Tackling these research ideas will be very helpful in mitigating this route of transmission if it is confirmed.

Conclusions

With a deep look at the characteristics of enteric foodborne viral pathogens such as HuNoV and HAV, we found that there are four main characteristics that give them the capability to transmit through specific types of foods. These four features are **(i)** they are enteric and can replicate in the GIT; **(ii)** their infectivity is stable for a long period of time in a wide variety of environmental conditions **(iii)** they are highly contagious because of their low infective dose ; and **(iv)** they can tolerate the hostile environment of the human GIT. We found that SARS-CoV-2 shares these four features. Along with the recent news of detecting SARS-CoV-2 from food packaging in China and a suspected foodborne COVID-19 case in New Zealand, the possible foodborne transmission of SARS-CoV-2 becomes more evident than thought of earlier. Fresh produce and berries grown in or imported from developing countries can play a role in the transmission of SARS-CoV-2 as is true for their role in transmission of foodborne viruses such as HuNoVs and HAV. Even with this strong evidence, the possible role of foods in spreading SARS-CoV-2 will stay hypothetical unless two essential studies are conducted, e.g., **(i)** performing a surveillance study to detect the presence of SARS-CoV-2 on fresh produce and berries imported from developing countries or grown in areas with high infection rate and **(ii)** conducting an animal study using non-human primate models to know whether or not they will be infected after eating SARS-CoV-2-contaminated foods. Other questions that are urgently in need of research are how survivable SARS-CoV-2 is on foods such as fresh produce and berries, and how efficient food processing operations are in removing SARS-CoV-2 particles from the surface of fresh produce and berries.

Acknowledgments:
None

Funding:
None

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