Interdisciplinary Research in Medical Sciences Specialty
ISSN: 3062-4401
2024, Volume 4, Issue 1, Page No: 1-10

Available online at: www.galaxypub.co/page/journals

Galaxy Publication

Transmission Pathways and Mitigation Strategies for COVID-19

Antoine Danchin[1,2], Tuen Wai Ng[3*], Gabriel Turinici[4]

[1]Institut Cochin, INSERM U1016-CNRS UMR8104-Université de Paris, 75006 Paris, France.
[2]School of Biomedical Sciences, Li Ka Shing Faculty of Medicine, The University of Hong Kong, Pokfulam, Hong Kong SAR, China.
[3]Department of Mathematics, The University of Hong Kong, Pokfulam, Hong Kong SAR, China.
[4] CEREMADE UMR 7434 CNRS, Université Paris Dauphine-PSL, 75016 Paris, France.

***E-mail** ✉ ntw@maths.hku.hk

Received: 16 November 2023; **Revised:** 27 January 2024; **Accepted:** 28 January 2024

ABSTRACT

Coronavirus disease (COVID-19) is a highly infectious respiratory illness that has rapidly spread around the world. The primary mode of transmission is through respiratory droplets expelled when an infected individual coughs or sneezes. This paper explores the potential indirect transmission routes of COVID-19, including water, food, air, and paper. Regarding food, we examine the possible spread through meat, frozen products, food packaging, and marketplaces, with case studies from different regions. The air section discusses the components contributing to airborne transmission, particularly the role of fine particulate matter (PM 2.5). Furthermore, the detection of SARS-CoV-2 in wastewater samples from countries such as the United States, India, Australia, the Netherlands, and France suggests that sewage could be a route of transmission. The handling and circulation of paper by infected individuals may also act as a medium for virus spread. These findings suggest that SARS-CoV-2 can be indirectly transmitted through contaminated food handled by infected workers or in food markets. Implementation of general hygiene practices—such as wearing masks, using hand sanitizers, disinfecting surfaces, and maintaining physical distance—combined with the use of disinfectants such as ethanol (67–71%), sodium hypochlorite (0.1%), and hydrogen peroxide (0.5%), as well as vaccination, can help reduce the transmission of the virus.

Keywords: COVID-19, Food, Wastewater, Transmission, Mitigation

How to Cite This Article: Danchin A, Wai Ng T, Turinici G. Transmission Pathways and Mitigation Strategies for COVID-19. Interdiscip Res Med Sci Spec. 2024;4(1):1-10. https://doi.org/10.51847/p0YhQPxvkW

Introduction

In December 2019, the World Health Organization (WHO) provisionally named a pneumonia-like illness emerging from Wuhan, China, as coronavirus disease (COVID-19), caused by the SARS-CoV-2 virus [1]. Since then, the pandemic has swept across the globe in multiple waves—three major ones globally, with some countries also experiencing a fourth wave—leading to widespread loss of life and economic disruption. As of December 19, 2022, there have been 649,038,437 confirmed COVID-19 cases and 6,645,812 related deaths reported across more than 200 countries (https://covid19.who.int/).

Coronaviruses are enveloped, positive-sense, single-stranded RNA viruses belonging to the *Coronaviridae* family. These viruses are pleomorphic in shape and range from 80 to 220 nanometers in diameter. SARS-CoV-2 is the most recent coronavirus to cause a global outbreak. This pandemic has heightened awareness around the various transmission pathways of the virus responsible for severe acute respiratory syndrome (SARS-CoV-2) [2]. COVID-19 is primarily a respiratory illness that spreads via close contact with infected individuals, including through touch, bodily fluids, and droplets expelled during coughing or sneezing. However, transmission via food, water, insects, and contaminated surfaces (fomites) is also considered possible. Unlike some viruses, SARS-CoV-2 can survive for a period outside the host, although the exact duration varies. The virus's stability depends on

surface material and environmental conditions such as temperature, humidity, light exposure, and weather patterns [3, 4]. Research by Chin *et al*. [3] and Van Doremalen *et al*. [5] indicates that SARS-CoV-2 can remain viable for up to seven days on plastic and four days on stainless steel at room temperature. However, it has a much shorter lifespan on paper, currency, and mail packaging.
This paper explores the potential indirect transmission routes of COVID-19, including water, food, air, and paper.

Results and Discussion

Transmission of Coronavirus Through Food
SARS-CoV-2 has demonstrated the ability to survive gastrointestinal fluids and enzymes, allowing it to infect the intestines. This supports the theory that transmission through food and water is plausible [6]. Contamination can occur at various points in the food supply chain, including production, distribution, handling, and final preparation. Epidemiological data have linked several early cases to the Huanan South Seafood Market in Wuhan, China, suggesting that COVID-19 may be the first respiratory outbreak with a potential foodborne origin [7]. In July 2020, China reported evidence of virus transmission from frozen foods and their packaging, with two re-emergent cases linked to contaminated food items. **Table 1** lists documented cases of such transmissions.

Table 1. Incidence of COVID-19 transmission through food

Country	No. of individuals/ positive cases	Duration	Food type	Reference
China	38	July 2020 – August 2020	Seafood	[8]
Auckland, New Zealand	4	August 2020	Frozen food	[9]
Beijing, China	1	June 2020	Frozen salmon	[10]
China	9	July-August 2020	Imported frozen raw foods	[2]
Tianjin, China	3	November 2020	Imported foods	[9]
America	117 crew members	June 2020	Seafood	[11]
Singapore	-	January 2020	Sharing of food	[12]
Llangefni, UK	204	June 2020	Chicken factory	[13]
China	6	February-March 2020	Family dinner	[14]

Individuals in the latent phase or those with asymptomatic COVID-19 infections may contaminate cold chain food during stages such as preparation, packaging, handling, and shipping, especially in high-risk areas. This can facilitate the survival of SARS-CoV-2 on frozen foods and their packaging surfaces, as illustrated in **Figure 1**.

Figure 1. Transmission of coronavirus through foods and food packaging

Chin *et al.* reported that low temperatures enhance the stability of SARS-CoV-2, indicating that frozen and refrigerated foods may act as potential vectors for virus transmission [3]. Meats such as seafood, beef, and chicken contain heparin and heparan compounds that facilitate the virus's attachment to host tissues, which raises the possibility that consumption of animal products could contribute to the spread of the virus [15, 16]. A notable example occurred at the Xinfadi wholesale market in Beijing, where SARS-CoV-2 was detected on a chopping board used for preparing imported salmon on June 12, 2020 [17]. These findings suggest that cold chain foods may enable cross-border transmission of SARS-CoV-2, as the virus has repeatedly been detected on imported frozen food and packaging materials [2, 10].

Transmission via Meat

Hu et al. documented several COVID-19 outbreaks linked to the fresh meat and seafood sectors in different countries, raising concerns about potential foodborne transmission. Among the first 53 individuals to test positive in one outbreak, 48 were workers at a seafood market in Beijing, three had visited the market, and two were indirectly connected to it [9]. Similar outbreaks were observed in the fish processing industry in Portugal [18] and in slaughterhouses across Germany and Australia. Additionally, some studies suggest that pigs and rabbits may be susceptible to SARS-CoV-2 infection, implying a possible risk of transmission via meat products. One proposed route of infection is the consumption of meat from infected palm civets [19]. Pangolins, which are used for both their meat and medicinal purposes in traditional Chinese practices, have also been suggested as a potential viral source [20].

Transmission via Frozen Foods

The detection of SARS-CoV-2 in frozen seafood, meat, and packaging materials has raised global concerns [2]. The cold and consistent conditions maintained during the transportation and storage of frozen foods provide an environment that prolongs the virus's viability. Contamination has been found in products such as frozen shrimp, pork, salmon, and shellfish, presenting a broader risk during the pandemic [18]. Studies have shown that viral particles can remain infectious on chilled or frozen foods. Notably, Han *et al*. [2] reported SARS-CoV-2 contamination in frozen chicken wings imported from Brazil, suggesting that frozen foods may play a significant role in facilitating long-distance transmission of the virus.

Transmission via Food Packaging

SARS-CoV-2 RNA has been detected on the packaging of Ecuadorian shrimp and inside shipping containers [2, 21]. Since July 2020, surface contamination of cold chain food packaging from South America has been observed in various Chinese cities such as Dalian and Qingdao [22]. For instance, SARS-CoV-2 was identified on the outer packaging of frozen cod and South American white shrimp from Ecuador. These findings indicate that the virus could potentially be introduced via imported frozen goods. Investigations into the Qingdao outbreak suggested contamination occurred during production or international cold chain transport [22, 23].

The virus has been shown to remain infectious on packaging surfaces even after long-distance shipping. In the second half of 2020, the importation of frozen goods became a notable route for potential virus spread [23–25]. Given that cold chain products are often stored at below 18 °C, SARS-CoV-2 may persist for extended periods on outer surfaces, enabling global transmission. Although comprehensive research is still limited and such incidents are relatively rare, these occurrences have led to increased public vigilance regarding the role of cold chain foods in virus spread [26].

Surfaces that come into contact with food, such as cutting boards, utensils, and equipment made of stainless steel, plastic, wood, rubber, ceramics, or glass, can also harbor pathogens. These contact points, found throughout food preparation, processing, and packaging stages, may facilitate the transfer of viruses and bacteria to both food items and workers handling them [15].

Transmission Through Food Markets

Grocery stores and supermarkets represent significant potential hotspots for COVID-19 transmission due to several contributing factors. These include enclosed spaces, challenges in maintaining social distancing, and frequent touching of products and surfaces by multiple individuals [2]. In the first half of 2020, the United Food and Commercial Workers union reported that 12,405 supermarket employees had contracted COVID-19.

Transmission Through Air

Environmental elements can influence the transmission and persistence of viruses, alongside human movement and social interactions. For instance, air pollution may exacerbate virus spread and should be considered when planning disease control strategies. Airborne viruses like SARS-CoV-2 can travel long distances [27].

Most COVID-19 patients experienced severe respiratory symptoms such as fever, cough, and breathing difficulties, sometimes resulting in death. While surface transmission is possible, the behavior of aerosolized viruses also warrants attention. In one study, SARS-CoV-2 remained detectable in aerosols for up to three hours, though its infectious dose declined from $10^{3.5}$ to $10^{2.7}$ $TCID_{50}$ per liter of air. This pattern was similar to that of SARS-CoV-1, and both viruses demonstrated comparable half-lives when suspended in aerosols [5].

Weather conditions—including temperature, humidity, wind speed, and rainfall—play a role in COVID-19 spread. Several studies found an inverse relationship between case counts and wind speed, humidity, and temperature [28–30]. A significant association between air pollution (measured by the air quality index) and virus spread was observed in Chinese cities, using Poisson regression analysis [31]. Cases may continue to rise under varying humidity levels [32], suggesting that environmental changes alone are not enough to curb transmission without strong public health interventions.

Under laboratory conditions, SARS-CoV-2 (HCoV-19) and SARS-CoV demonstrated similar stability, with the virus remaining viable in aerosols for hours and on surfaces for days [5]. Chronic exposure to air pollutants like nitrogen dioxide (NO_2) can worsen lung conditions, potentially increasing COVID-19 mortality rates [33]. Both indoor and outdoor exposure to fine particulate matter (PM2.5) has been associated with higher COVID-19 death rates, reinforcing the need for further research into the impact of air quality on viral transmission [34]. In addition, SARS-CoV-2 has been reported to spread through HVAC systems in both indoor and outdoor settings, indicating that controlling this transmission pathway could strengthen efforts to contain the virus [35].

Transmission Through Wastewater

SARS-CoV-2 can also spread via respiratory droplets and aerosols [36], and the surrounding environment plays a role in determining how easily the virus is transmitted. Bodily fluids like saliva, sputum, and feces can contain active SARS-CoV-2 particles and viral RNA, which can enter wastewater systems upon disposal, as illustrated in **Figure 2**.

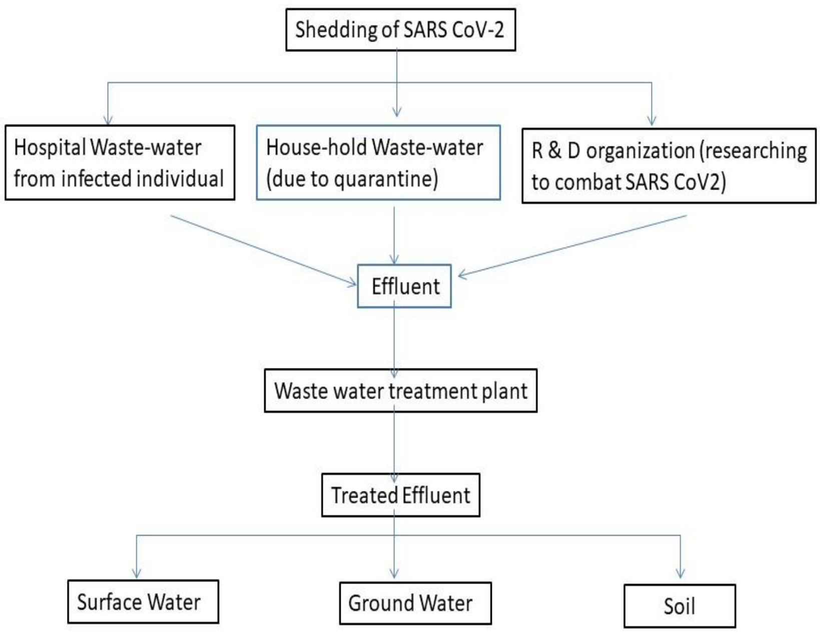

Figure 2. Schematic representation of the transmission of coronavirus through wastewater

Transmission Through Wastewater

Although enveloped viruses are typically present in low concentrations in municipal sewage, have limited transmission potential through human waste, and are easily inactivated in aquatic environments, some can survive for extended periods. Certain enveloped viruses shed from infected individuals can persist in water systems for days to even months [36, 37]. For instance, SARS-CoV has been shown to survive for over 17 days at 4 °C, and for 3 to 17 days in feces and urine at 20 °C. It can also persist for up to 3 days at 20 °C in untreated hospital and municipal wastewater, as well as in potable water lacking chlorine [1]. These findings led to growing concerns about the presence of SARS-CoV-2 in wastewater.

Indeed, SARS-CoV-2 RNA has been detected in influent samples from wastewater treatment facilities worldwide, with its levels often correlating with the number of infected individuals in the surrounding population [38, 39]. This makes wastewater-based epidemiology a promising tool for predicting local infection trends [40, 41]. Notably, the virus's RNA may be detected in sewage systems before the first clinical cases are officially reported, highlighting the sensitivity of this method [42].

In light of these findings, the World Health Organization (WHO) has emphasized the critical need for safe handling of human waste. Recommendations include preventing hand contamination with fecal matter, reducing aerosolization of feces, and properly managing fecal sludge, especially in pandemic settings. In low-income regions with inadequate sanitation infrastructure, fecal shedding of SARS-CoV-2 poses a greater risk of environmental spread. Although studies in developing countries are limited, SARS-CoV-2 RNA has recently been found in wastewater from municipal treatment plants in India [43, 44]. Furthermore, a linear relationship was observed between the viral RNA load in sewage and the number of confirmed COVID-19 cases in India [45].

Poor wastewater management practices in such regions amplify public health risks. Individuals can be exposed to the virus due to improper sewage disposal, particularly where sanitation systems are lacking [46]. SARS-CoV-2 has been detected in the feces and urine of both symptomatic and asymptomatic individuals, suggesting that open defecation may contribute to the spread of the virus [47–49]. Even asymptomatic carriers may shed the virus through feces for several days [50].

In both developing and developed countries, untreated wastewater has been shown to contain traces of coronavirus [38, 42], raising the possibility of waterborne transmission. This concern is heightened in areas without proper sanitation or wastewater treatment systems [1, 46]. Because SARS-CoV-2 RNA can persist in sewage even after patients have tested negative, the virus is increasingly viewed as a possible waterborne pathogen [51]. Thus, monitoring sewage and wastewater for SARS-CoV-2 provides a cost-effective surveillance strategy for tracking COVID-19 spread.

Transmission Through Paper

Manual processes, such as paper-based lab request forms, are still widely used in healthcare settings. As a result, doctors, nurses, chemists, and lab professionals are frequently exposed to paper documents, increasing their risk of contracting COVID-19. Research shows that the SARS-CoV strain P9 can survive on non-living surfaces, including paper, for 4–5 days at room temperature [52]. Another study by Lai *et al*. [53] found that SARS-CoV strain GVU6109 remained viable on paper for up to 24 hours. In general, SARS-CoV is known to persist on inanimate objects for up to 9 days, and on paper for 1–5 days. Since SARS-CoV-2 shares similar characteristics, it is expected to behave comparably.

A study by Hasan *et al*. [54] investigated the risk of transmission via laboratory paper and found that 83% (432 out of 520) of lab forms were submitted within 24 hours of issuance, while the remaining 17% (88 forms) were delayed. Receptionists, technicians, and pathologists spent an average of 2.7, 5.5, and 54.6 minutes per day, respectively, handling these forms. Notably, 80% of the documents were handled by lab staff within a day, with 21% originating from high-risk departments such as emergency rooms, ICUs, and quarantine wards. The remaining 79% came from moderate-risk areas like inpatient wards, outpatient clinics, and operating rooms. This highlights a significant risk of viral transmission through paperwork, especially in high-exposure zones.

To minimize this risk, healthcare facilities should implement electronic systems for managing lab requests [55]. Moreover, hospitals must follow the World Health Organization's guidelines for lab safety and best clinical practices to protect staff from exposure through contaminated documents.

Risk Factors

Compared to previous outbreaks like Ebola, MERS, and H1N1, COVID-19 has demonstrated a notably higher transmissibility. Its basic reproduction number (R_0) ranges from 1.4 to 6.5, with an average of 3.6, making it highly contagious [56]. Furthermore, the virus can survive for extended periods on frozen surfaces, enabling its transmission via exported or transported frozen foods. This poses a significant risk to both food handlers and consumers [9]. Since only a small viral load is needed to initiate infection, the virus can persist on packaged food products, potentially facilitating its spread through international trade.

Frozen foods and meat processing plants, due to their cold environments and high human activity, may serve as "hotspots" for COVID-19 transmission [2]. While transmission through food is less common than through air, water, or paper, it remains a public health concern, especially considering the large-scale global distribution of frozen goods. Despite widespread vaccination efforts, preventive measures are still crucial due to the ongoing evolution of the virus.

Alleviation of COVID-19

Strategies for mitigating the impact of COVID-19 are outlined in **Figure 3** (not shown here). These measures include enhanced hygiene, digitalization of healthcare processes, strict food safety protocols, and adherence to WHO guidelines. Effective implementation of these strategies can significantly reduce transmission risk across different routes.

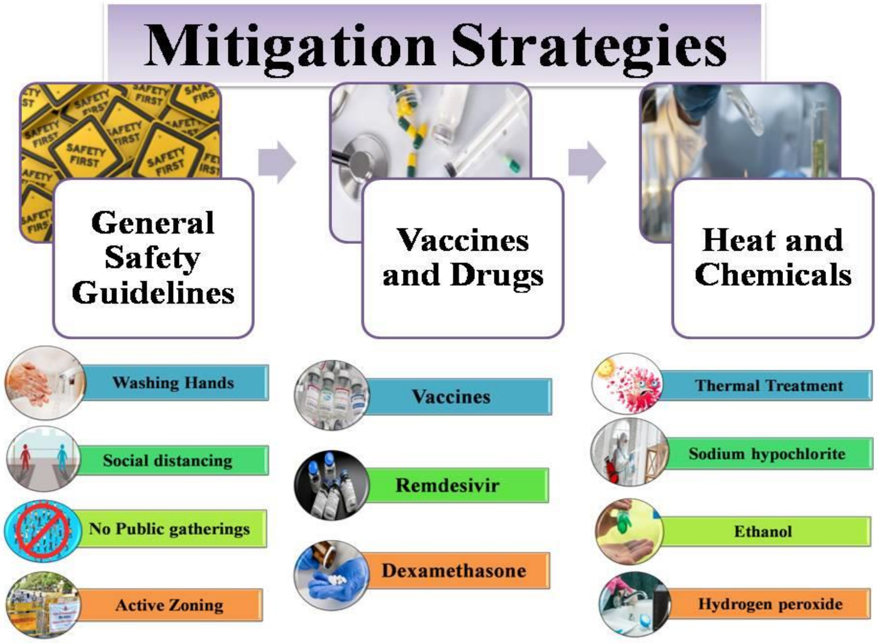

Figure 3. Mitigation strategies to combat COVID-19

General Safety Guidelines

Basic hygiene practices remain one of the most effective ways to reduce the spread of COVID-19. These include washing hands for at least 20 seconds, sneezing or coughing into the elbow, avoiding unnecessary contact with surfaces, opting for contactless payments, and adhering to household waste management protocols. It is also crucial to prevent waste handlers from coming into contact with infectious materials and to provide them with proper protective equipment [57].

Mobility restrictions are another critical strategy to curb the virus's spread. These measures aim to reduce transmission from both symptomatic and asymptomatic individuals by limiting human movement [58]. Examples include zoning of affected areas, suspending or limiting public transport, imposing temporary or permanent air travel bans, restricting private vehicle use, and minimizing outdoor activities. In parallel, physical distancing must be maintained—generally between 1.5 and 2 meters—even as virtual forms of social connection are encouraged, particularly to protect vulnerable groups like the elderly.

Inactivation by Heat and Chemicals

Heat and chemical disinfection are proven methods to deactivate coronaviruses. A study by Kampf et al. reported that five different coronaviruses, including SARS-CoV-1 and MERS-CoV, could be inactivated by heat treatments—such as 60 °C for 30 minutes, 65 °C for 15 minutes, or 80 °C for 1 minute—achieving at least a four-log reduction in viral load [59]. Chin et al. further showed that SARS-CoV-2 could be inactivated with a seven-log reduction after exposure to 70 °C for just 5 minutes [3].

The French Agency for Food, Environmental and Occupational Health & Safety (ANSES) determined that heating food to 63 °C for 4 minutes is sufficient to eliminate the virus [60]. However, since freezing is used for preservation rather than disinfection, SARS-CoV-2 may remain viable under frozen conditions.
Regarding chemical disinfectants, exposure to agents such as 0.1% sodium hypochlorite, 0.5% hydrogen peroxide, and 62–71% ethanol for just one minute at room temperature significantly reduces the virus's presence on surfaces [61]. These results are consistent with findings on SARS-CoV-2 [3]. Several international organizations have published approved lists of disinfectants: Health Canada, the European Chemicals Agency (ECA), and the U.S. Environmental Protection Agency (USEPA) maintain updated databases of effective COVID-19 disinfectants. Among the most effective are halogen-based agents, quaternary ammonium compounds, and oxidants, which have demonstrated strong efficacy against SARS-CoV-2 [62].

Vaccines and Therapeutics

A range of vaccine platforms has been developed to combat SARS-CoV-2. Notably, Moderna and the NIAID developed the mRNA-based vaccine mRNA-1273 [63]. Pfizer and BioNTech also introduced promising candidates using self-amplifying and nucleoside-modified mRNA technologies [64]. Other vaccines in preclinical phases include IntelliStem (IPT-001), Bharat Biotech/FLUGEN (CoroFlu), Seqirus (MF59), IRBP (RespiResponse IR101C), Dynavax (CpG 1018), Takeda (TAK-888), and Tonix (TAK-888) [65]. Vaccination is currently the most effective public health intervention to achieve herd immunity and control the pandemic.
Among the therapeutic options, Remdesivir—a nucleotide analogue—has shown encouraging antiviral activity in both in vitro and animal studies, particularly against SARS and MERS, supporting its continued use for treating SARS-CoV-2 infections [66]. Another notable drug, Dexamethasone, is an affordable corticosteroid that reduces inflammation by limiting neutrophil activity and cytokine production. It has been especially effective for critically ill COVID-19 patients who require supplemental oxygen or mechanical ventilation.
As of January 12, 2022, the World Health Organization (WHO) has granted Emergency Use Listing (EUL) to several COVID-19 vaccines, including:

- Pfizer/BioNTech (Comirnaty)
- SII/COVISHIELD and AstraZeneca (AZD1222)
- Janssen/Johnson & Johnson (Ad26.COV2.S)
- Moderna (mRNA-1273)
- Sinopharm and Sinovac (CoronaVac)
- Bharat Biotech (COVAXIN)
- Covovax and Nuvaxovid (NVX-CoV2373)

Vaccination remains a cornerstone of the global strategy to prevent and control COVID-19.

Conclusion

Our comprehensive review highlights the significant risk of SARS-CoV-2 transmission throughout the fresh and frozen animal products supply chain, from breeding to processing and final sales. The virus can potentially be transmitted indirectly through food, primarily via workers involved in food packaging or handling in markets. It is essential to clean and disinfect food contact surfaces thoroughly, as touching infected surfaces and then touching the face (mouth, nose, or eyes) remains a common transmission pathway for SARS-CoV-2.
Environmental factors, in addition to human interactions, can influence virus transmission and survival, though limited information is available on this novel pathogen. While there are still gaps in our understanding of SARS-CoV-2 transmission via potable water, sewer systems, and ambient air, current research suggests a potential for environmental spread through these routes. Therefore, further research into various environmental transmission pathways is needed.
To mitigate the spread of SARS-CoV-2, it is essential to follow general safety guidelines, such as wearing masks, using sanitizers, disinfecting contact surfaces, and practicing social distancing. Additionally, heat treatments and chemical disinfectants, such as ethanol (67-71%), sodium hypochlorite (0.1%), and hydrogen peroxide (0.5%), can effectively reduce the presence of the virus on environmental surfaces. Vaccination and the use of recommended drugs are also crucial components in combating the disease. We are optimistic that, with widespread vaccination and adherence to these safety precautions, the fourth wave of COVID-19 can be effectively controlled.

Acknowledgments: None

Conflict of Interest: None

Financial Support: None

Ethics Statement: None

References

1. Wang J, Shen J, Ye D, Yan X, Zhang Y, Yang W, et al. Disinfection technology of hospital wastes and wastewater: Suggestions for disinfection strategy during coronavirus Disease 2019 (COVID-19) pandemic in China. Environ Pollut. 2020;262:114665.
2. Han J, Zhang X, He S, Jia P. Can the coronavirus disease be transmitted from food? A review of evidence, risks, policies and knowledge gaps. Environ Chem Lett. 2021;19(1):5-16.
3. Chin AWH, Chu JTS, Perera MRA, Hui KPY, Yen HL, Chan MCW, et al. Stability of SARS-CoV-2 in different environmental conditions. Lancet Microbe. 2020;1(1):e10.
4. Hoseinzadeh E, Javan S, Farzadkia M, Mohammadi F, Hossini H, Taghavi M. An updated min-review on environmental route of the SARS-CoV-2 transmission. Ecotoxicol Environ Saf. 2020;202:111015.
5. Van Doremalen N, Bushmaker T, Morris DH, Holbrook MG, Gamble A, Williamson BN, et al. Aerosol and Surface Stability of SARS-CoV-2 as Compared with SARS-CoV-1. N Engl J Med. 2020;382(16):1564-7.
6. Lee B, Damon CF, Platts-Mills JA. Pediatric acute gastroenteritis associated with adenovirus 40/41 in low-income and middle-income countries. Curr Opin Infect Dis. 2020;33(5):398-403.
7. Duda-Chodak A, Lukasiewicz M, Zięć G, Florkiewicz A, Filipiak-Florkiewicz A. Covid-19 pandemic and food: Present knowledge, risks, consumers fears and safety. Trends Food Sci Technol. 2020;105:145-60.
8. CGTN. Officials rule out domestic transmission as origin of Dalian COVID-19 cluster. 2020. Available from: https://news.cgtn.com/news/2020-08-03/Epidemic-in-Dalian-is-presumed-to-be-caused-by overseasimports-SEiVRpdoEE/idex.html
9. Hu L, Gao J, Yao L, Zeng L, Liu Q, Zhou Q, et al. Evidence of Foodborne Transmission of the Coronavirus (COVID-19) through the Animal Products Food Supply Chain. Environ Sci Technol. 2021;55(5):2713-6.
10. Pang X, Ren L, Wu S, Ma W, Yang J, Di L, et al. Cold-chain food contamination as the possible origin of COVID-19 resurgence in Beijing. Natl Sci Rev. 2020;7(12):1861-4.
11. KUCB. Crew of American seafood vessel tests negative for COVID-19 in Unalaska. 2020. Available from: https://www.kucb.org/post/crew-american-seafoods-vessel-tests-negative-covid-19unalaska #stream/0.
12. Pung R, Chiew CJ, Young BE, Chin S, Chen MI, Clapham HE, et al. Investigation of three clusters of COVID-19 in Singapore: implications for surveillance and response measures. Lancet. 2020;395(10229):1039-46.
13. BBC News. Coronavirus: Almost 100 staff at food factories test positive. 2020. Available from: https://www.bbc.com/news/uk-wales-53091149. Accessed 26 January 2021
14. Lam TS, Wong CH, Lam WH, Lam HY, Lam YC, Leung EC, et al. Coronavirus disease 2019 (COVID-19) outbreak during a Chinese New Year dinner in a restaurant, Hong Kong Special Administrative Region SAR (China), 2020. Western Pac Surveill Response J. 2021;12(1):32-4.
15. Pressman P, Naidu AS, Clemens R. COVID-19 and food safety. Nutr Today. 2020;55(3):125-8.
16. Mycroft-West C, Su D, Elli S, Li Y, Guimond S, Miller G, et al. The 2019 coronavirus (SARS-CoV-2) surface protein (Spike) S1 Receptor Binding Domain undergoes conformational change upon heparin binding. BioRxiv. 2020. doi:10.1101/2020.02.29.971093
17. Times G. Beijing supermarkets stop selling salmon after wholesalers test positive for coronavirus. 2020. Available from: https://www.globaltimes.cn/content/1191462.shtml.Accessed 26 January 2021
18. Fisher D, Reilly A, Zheng AK, Cook A, Anderson D. Seeding of outbreaks of COVID-19 by contaminated fresh and frozen food. BioRxiv. 2021:2020-08. doi:10.1101/2020.08.17.255166

19. Lam HY, Lam TS, Wong CH, Lam WH, Leung CME, Au KWA, et al. The epidemiology of COVID-19 cases and the successful containment strategy in Hong Kong-January to May 2020. Int J Infect Dis. 2020;98:51-8.
20. Ye ZW, Yuan S, Yuen KS, Fung SY, Chan CP, Jin DY. Zoonotic origins of human coronaviruses. Int J Biol Sci. 2020;16(10):1686-97.
21. Korban D, Sapin R. China's Chongqing detects new cases of COVID-19 on Ecuadorian shrimp packaging. 2020. Available from: https://www.intrafish.com/coronavirus/chinas-chongqing-detects-new-case-of-covid-19-on ecuadorian-shrimp-packaging/2-1.
22. Liu P, Yang M, Zhao X, Guo Y, Wang L, Zhang J, et al. Cold-chain transportation in the frozen food industry may have caused a recurrence of COVID-19 cases in destination: Successful isolation of SARS-CoV-2 virus from the imported frozen cod package surface. Biosaf Health. 2020;2(4):199-201.
23. Yuan Q, Kou Z, Jiang F, Li Z, Zhang L, Liu H, et al. A Nosocomial COVID-19 Outbreak Initiated by an Infected Dockworker at Qingdao City Port - Shandong Province, China, October 2020. China CDC Wkly. 2020;2(43):838-40.
24. Health Commission of Dalian. 2020. Available from: https://hcod.dl.gov.cn/art/2020/8/2/art_1853_462210.html.Accessed on 7 August 2021
25. Health Commission of Liaoning Province. 2020. Available from: http://wsjk.ln.gov.cn/wst_zdzt/xxgzbd/yqtb/202012/t20201218_4051961.html. Accessed on 7 August 2021
26. Ji W, Li X, Chen S, Ren L. Transmission of SARS-CoV-2 via fomite, especially cold chain, should not be ignored. Proc Natl Acad Sci U S A. 2021;118(11):e2026093118.
27. Hoseinzadeh E, Taha P, Sepahvand A, Sousa S. Indoor air fungus bioaerosols and comfort index in day care child centres. Toxin Rev. 2017;36(2):125-31.
28. Sahin M. Impact of weather on COVID-19 pandemic in Turkey. Sci Total Environ. 2020;728:138810.
29. Wu Y, Jing W, Liu J, Ma Q, Yuan J, Wang Y, et al. Effects of temperature and humidity on the daily new cases and new deaths of COVID-19 in 166 countries. Sci Total Environ. 2020;729:139051.
30. Yao M, Zhang L, Ma J, Zhou L. On airborne transmission and control of SARS-Cov-2. Sci Total Environ. 2020;731:139178.
31. Xu H, Yan C, Fu Q, Xiao K, Yu Y, Han D, et al. Possible environmental effects on the spread of COVID-19 in China. Sci Total Environ. 2020;731:139211.
32. Luo W, Majumder SM, Liu D, Poirier C, Mandl KD, Lipsitch M, et al. The role of absolute humidity on transmission rates of the COVID-19 outbreak. MedRxiv. 2020. doi:10.1101/2020.02.12.20022467
33. Ogen Y. Assessing nitrogen dioxide (NO2) levels as a contributing factor to coronavirus (COVID-19) fatality. Sci Total Environ. 2020;726:138605.
34. Mehmood K, Saifullah Iqbal M, Abrar MM. Can exposure to PM2.5 particles increase the incidence of coronavirus disease 2019 (COVID-19)? Sci Total Environ. 2020;741:140441.
35. Correia G, Rodrigues L, Gameiro da Silva M, Gonçalves T. Airborne route and bad use of ventilation systems as non-negligible factors in SARS-CoV-2 transmission. Med Hypotheses. 2020;141:109781.
36. Peng X, Xu X, Li Y, Cheng L, Zhou X, Ren B. Transmission routes of 2019-nCoV and controls in dental practice. Int J Oral Sci. 2020;12(1):9.
37. Wigginton KR, Ye Y, Ellenberg RM. Emerging investigators series: the source and fate of pandemic viruses in the urban water cycle. Environ Sci Water Res Technol. 2020;1(6):735-46.
38. Ahmed W, Angel N, Edson J, Bibby K, Bivins A, O'Brien JW, et al. First confirmed detection of SARS-CoV-2 in untreated wastewater in Australia: A proof of concept for the wastewater surveillance of COVID-19 in the community. Sci Total Environ. 2020;728:138764.
39. La Rosa G, Iaconelli M, Mancini P, Bonanno Ferraro G, Veneri C, Bonadonna L, et al. First detection of SARS-CoV-2 in untreated wastewaters in Italy. Sci Total Environ. 2020;736:139652.
40. Gonzalez R, Curtis K, Bivins A, Bibby K, Weir MH, Yetka K, et al. COVID-19 surveillance in Southeastern Virginia using wastewater-based epidemiology. Water Res. 2020;186:116296.
41. Hart OE, Halden RU. Computational analysis of SARS-CoV-2/COVID-19 surveillance by wastewater-based epidemiology locally and globally: Feasibility, economy, opportunities and challenges. Sci Total Environ. 2020;730:138875.
42. Medema G, Heijnen L, Elsinga G, Italiaander R, Brouwer A. Presence of SARS-Coronavirus-2 RNA in Sewage and correlation with reported COVID-19 prevalence in the early stage of the epidemic in the Netherlands. Environ. Sci Technol Lett. 2020:7(7):511-6.

43. Arora S, Nag A, Sethi J, Rajvanshi J, Saxena S, Shrivastava SK, et al. Sewage surveillance for the presence of SARS-CoV-2 genome as a useful wastewater based epidemiology (WBE) tracking tool in India. Water Sci Technol. 2020;82(12):2823-36.
44. Kocamemi BA, Kurt H, Sait A, Sarac F, Saatci AM, Pakdemirli B. SARS-CoV-2 detection in Istanbul wastewater treatment plant sludges. MedRxiv. 2020b:2020-05. doi:10.1101/2020.05.12.20099358
45. Kumar M, Patel AK, Shah AV, Raval J, Rajpara N, Joshi M, et al. First proof of the capability of wastewater surveillance for COVID-19 in India through detection of genetic material of SARS-CoV-2. Sci Total Environ. 2020;746:141326.
46. Usman M, Farooq M, Hanna K. Existence of SARS-CoV-2 in wastewater: Implications for its environmental transmission in developing communities. Environ Sci Technol. 2020;54(13):7758-9.
47. Foladori P, Cutrupi F, Segata N, Manara S, Pinto F, Malpei F, et al. SARS-CoV-2 from faeces to wastewater treatment: What do we know? A review. Sci Total Environ. 2020;743:140444.
48. Lescure FX, Bouadma L, Nguyen D, Parisey M, Wicky PH, Behillil S, et al. Clinical and virological data of the first cases of COVID-19 in Europe: a case series. Lancet Infect Dis. 2020;20(6):697-706.
49. Haramoto E, Malla B, Thakali O, Kitajima M. First environmental surveillance for the presence of SARS-CoV-2 RNA in wastewater and river water in Japan. Sci Total Environ. 2020;737:140405.
50. Wu F, Zhao S, Yu B, Chen YM, Wang W, Song ZG, et al. A new coronavirus associated with human respiratory disease in China. Nature. 2020;579(7798):265-9.
51. Quilliam RS, Weidmann M, Moresco V, Purshouse H, O'Hara Z, Oliver DM. COVID-19: The environmental implications of shedding SARS-CoV-2 in human faeces. Environ Int. 2020;140:105790.
52. Duan SM, Zhao XS, Wen RF, Huang JJ, Pi GH, Zhang SX, et al. Stability of SARS coronavirus in human specimens and environment and its sensitivity to heating and UV irradiation. Biomed Environ Sci. 2003;16(3):246-55.
53. Lai MY, Cheng PK, Lim WW. Survival of severe acute respiratory syndrome coronavirus. Clin Infect Dis. 2005;41(7):e67-71.
54. Hasan A, Nafie K, Abbadi O. Histopathology laboratory paperwork as a potential risk of COVID-19 transmission among laboratory personnel. Infect Prev Pract. 2020;2(4):100081.
55. Luna FG, Contreras IH, Guerrero AC, Guitarte FB. Integrating electronic systems for requesting clinical laboratory test into digital clinical records: design and implementation. Health. 2017;9(4):622-39.
56. Liu Y, Gayle AA, Wilder-Smith A, Rocklöv J. The reproductive number of COVID-19 is higher compared to SARS coronavirus. J Travel Med. 2020;27(2):taaa021.
57. Semple S, Cherrie JW. Covid-19: Protecting Worker Health. Ann Work Expo Health. 2020;64(5):461-4.
58. Gostic K, Gomez AC, Mummah RO, Kucharski AJ, Lloyd-Smith JO. Estimated effectiveness of symptom and risk screening to prevent the spread of COVID-19. Elife. 2020;9:e55570.
59. Kampf G, Todt D, Pfaender S, Steinmann E. Persistence of coronaviruses on inanimate surfaces and their inactivation with biocidal agents. J Hosp Infect. 2020;104(3):246-51.
60. ANSES (French Agency for Food, Environmental and Occupational Health and Safety). Opinion on an urgent request to assess certain risks associated with COVID-19. 2020. Accessed August 7, 2021.
61. Kampf G, Voss A, Scheithauer S. Inactivation of coronaviruses by heat. J Hosp Infect. 2020;105(2):348-9.
62. Choi H, Chatterjee P, Lichtfouse E, Martel JA, Hwang M, Jinadatha C, et al. Classical and alternative disinfection strategies to control the COVID-19 virus in healthcare facilities: a review. Environ Chem Lett. 2021;19(3):1945-51.
63. Moderna C. Moderna announces funding award from CEPI to accelerate development of messenger RNA (mRNA) vaccine against novel coronavirus. 2020.
64. Arena CT. BioNTech and Pfizer get German approval for Covid-19 vaccine trial. 2020. Available from: https://www.clinicaltrialsarena.com/news/biontechpfizer-covid-19-vaccine-trial/.
65. Chen WH, Strych U, Hotez PJ, Bottazzi ME. The SARS-CoV-2 Vaccine Pipeline: an Overview. Curr Trop Med Rep. 2020;7(2):61-4.
66. Alvi MM, Sivasankaran S, Singh M. Pharmacological and non-pharmacological efforts at prevention, mitigation, and treatment for COVID-19. J Drug Target. 2020;28(7-8):742-54.