

## COVID-19 Outbreaks Linked to Imported Frozen Food in China: Status and Challenge

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### ABSTRACT

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) RNA contamination was reported on China's imported frozen foods and packaging materials. However, there was no evidence of this disease initiated by environment-to-human transmission until the outbreak of coronavirus disease 2019 (COVID-19) in Beijing in June 2020. This article aimed to analyze and summarize COVID-19 outbreaks related to cold-chain foods to provide a scientific basis for tracing the epidemiological trajectory of the pandemic, providing risk assessments, and mitigation policies. Overall, 37 COVID-19 outbreaks and 5,741 infected cases were reported within the study period. It was found that 7 outbreaks and 689 cases were linked to imported frozen foods. The first index case among the 7 outbreaks was exposed to SARS-CoV-2-contaminated outer packaging of frozen food, triggering the subsequent community transmission. This study supported the speculation that cold-chain foods act as a pathway for SARS-CoV-2 and might present a risk for virus transmission between countries and regions. Handlers and processors exposed to the imported frozen foods should be effectively self-protected, daily monitored for clinical manifestations of COVID-19, and tested for SARS-CoV-2 nucleic acid at regular intervals.

### INTRODUCTION

The coronavirus disease 2019 (COVID-19) is caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) (1). It was primarily thought to spread mostly person-to-person through respiratory droplets (2). COVID-19 infections can occur by touching a surface or object, including food or food packaging, containing the virus, and then touching the mouth, nose, or eyes. However, there was no evidence that food was associated with spreading

SARS-CoV-2 until COVID-19 cases resurged in Xinfadi Market, Beijing, in June 2020. Fomite transmission has been proposed, and it has attracted extensive attention worldwide since then (3–4).

SARS-CoV-2 has been reported to persist in conditions similar to the ones found in frozen food, packaging, and cold-chain products. It was noted that the infectivity of SARS-CoV-2 on cold-chain products did not decrease after 21 days at 4 °C (refrigerated food) or at –20 °C (frozen food) (5). SARS-CoV-2 was isolated from the outer packaging of frozen cod in Qingdao City, Shandong Province (6), and the investigations of the outbreak in Dalian City, Liaoning Province, strongly suggested that the infection source was from a virus-contaminated packaging of frozen seafood (7), providing evidence that the contaminated cold-chain foods and packaging might be the vector in the virus transmission.

This article evaluated and reviewed COVID-19 outbreaks linked to cold-chain products as a source of SARS-CoV-2 infection and virus transmission from imported cold-chain products in China.

### DATA COLLECTION

China has established the Joint Prevention and Control Mechanism of the State Council in early 2020 in response to SARS-CoV-2. It is a multi-ministerial coordination mechanism and work platform at the central level (or at the provincial and local levels). A total of 32 departments are involved. This joint mechanism is responsible for data collection and releasing information regarding the COVID-19 pandemic. It includes big data collection and mining, epidemiological investigation, tracing the origin of outbreaks and virus sources, vaccination, and press release.

All data were obtained from the Joint Prevention and Control Mechanism of the State Council.

## OUTBREAKS LINKED TO IMPORTED FROZEN FOOD DISTRIBUTION AND ANALYZE

Although COVID-19 has been effectively controlled in China since the Wuhan epidemic, several outbreaks or clusters of COVID-19 cases linked to either importation of cases or virus contaminated products occurred, as shown in [Table 1](#). In China, 37 COVID-19 outbreaks and 5,741 cases were reported from June 2020 to July 15, 2021. Among them, 7 outbreaks and 689 infected cases were linked to imported cold-chain foods. Investigations demonstrated that all 7 outbreaks were suspected of having occurred due to handling or exposure to SARS-CoV-2-positive imported cold-chain foods, especially their outer packaging materials. In total, 368 people infected with SARS-CoV-2 were reported in Beijing in June 2020. These infected people are all directly or indirectly related to Xinfadi Market: 169 people were market staff, and 103 people were visitors to the market less than 14 days before the symptoms appeared. The remaining 96 people were in close contact with the abovementioned individuals. No other early independent transmission chain beyond the market was found, indicating that Xinfadi Market was the unique source of the outbreak. Notably, five surface-swabbing samples collected from salmon in the original sealed package in the company's cold storage, a unique imported food supplier of Xinfadi Market located outside the market, were positive for SARS-CoV-2. The virus in the fish swab shared at least seven mutations with that of Xinfadi Market. This is the first time it has been proposed that environment-to-human transmission originated from contaminated imported food.

Thereafter, clusters of COVID-19 cases linked to cold-chain foods were frequently reported in China. The outbreak in Dalian, on July 22, 2020, was associated with imported cold-chain foods ([7](#)). The porter was first infected by having contact with the outer packaging of imported frozen cod contaminated with SARS-CoV-2. The virus was subsequently introduced to a local seafood company through the infected porter's wife, and then spread further. However, active and infectious viruses were not successfully isolated from the samples of cold-chain food in Beijing and Dalian. Hence, the role of SARS-CoV-2-contaminated cold-chain foods in the spread of the COVID-19 epidemic could not be confirmed.

Afterwards, 2 infected dock workers who transported the imported frozen cod for 10 hours in 2 separate storage warehouses on the same freighter in Qingdao, were reported to be infected with the virus, although they had never been to any high-risk areas of COVID-19 and had no contact histories with either COVID-19 patients or overseas visitors. They took off their masks and smoked without washing their hands during work. However, the other 69 dockers who handled the frozen cod simultaneously, but did not take off their masks, were not infected. An active SARS-CoV-2 sample was successfully isolated from a virus-contaminated outer packaging sample of the imported frozen cod. A comparison of the virus gene sequence showed that the virus isolated from the infected port handlers was the progeny of that isolated from the outer packaging of frozen imported cod, further indicating that SARS-CoV-2-contaminated outer packaging of the imported frozen cod was the source of the COVID-19 epidemic in Qingdao ([6](#)). Therefore, SARS-CoV-2 posed a significant health risk to essential workers maintaining the cold-chain food supply.

The first infected cases of two COVID-19 outbreaks in Tianjin Municipality in November 2020 were all porters who were in close contact with the virus-contaminated outer packaging of imported frozen food, or exposed to the virus-contaminated environment during the handling of frozen foods from the cabin to the deck. The COVID-19 resurgence in Dalian, in December 2020, also originated from the infected dockers due to the handling of the imported cold-chain cargoes that further triggered large-scale community transmission.

The virus sequence that resulted in the Yingkou City, Liaoning Province, and Liuan City, Anhui Province, COVID-19 outbreaks in May 2021 was highly homologous to the virus linked to the Dalian COVID-19 outbreak on July 22, 2020, mentioned above. Further epidemiological investigation illustrated that the virus on the outer packaging material of the imported frozen cod that caused the COVID-19 epidemic in Dalian in July 2020 was also the source of the Yingkou and Liuan outbreaks. These SARS-CoV-2 contaminated frozen cod were stored in cold storage for nearly 11 months in Dalian since July 2020, but still infected the workers during handling. This further elucidates that SARS-CoV-2 can maintain its infectivity for a long time (at least 11 months) at a low temperature of  $-18^{\circ}\text{C}$ .

TABLE 1. Summary of COVID-19 outbreaks linked to the imported cold-chain food between June 2020 and May 2021 in China.

Location & time	Cases	Confirmed cases n, %			Duration of epidemic		Age median & range	Ratio of male to female	Source of infection	Path of infection
		Mild case/moderate case	Sever case/critical case	Asymptomatic patient n, %	Onset time of the first & last cases	Days				
2020-6, Fengtai, Beijing	402	362, 90.0	0, 0	40, 10.0	2020/6/5–7/9	35	42, 1–86	1:0.8	Virus-contaminated imported cold-chain food	It may be initially caused by the introduction of virus into Xinfadi Wholesale Market via the imported cold-chain foods contaminated with SARS-CoV-2.
2020-7, Dalian-1, Liaoning	135	99, 73.3	0, 0	36, 26.7	2020/7/9–8/6	29	43, 0–73	1:1.2	Virus-contaminated outer packaging of imported frozen cod	A dockworker exposed to SARS-CoV-2-contaminated outer packaging of the imported frozen cod during the inbound unloading transferred the infection to his wife who worked at a cold-chain product processing and storage company, resulting in a community spread of COVID-19.
2020-9, Qingdao, Shandong	14	12, 85.7	1, 7.1	1, 7.1	2020/9/24–10/14	21	47.5, 23–83	1:0.8	Virus-contaminated outer packaging of the imported frozen cod	A dockworker exposed to SARS-CoV-2-contaminated outer packaging of the imported frozen cod during inbound unloading and caused the subsequent community transmission via personal contact during his health check in hospital.
2020-11, Binhai, Tianjin-1	2	2, 100.0	0, 0	0, 0	2020/11/5–11/10	6	48.5, 38–47	male only	Virus-contaminated cold-chain food or environment	Porters were infected via exposure to the imported frozen food or environment contaminated by SARS-CoV-2, causing a community transmission.
2020-11, Binhai, Tianjin-2	10	7, 70.0	1, 10.0	2, 20.0	2020/11/17–11/27	11	38.5, 6–61	1:0.4	Virus-contaminated cold-chain food	Porters were infected via exposure to the imported frozen foods or environment contaminated by SARS-CoV-2, causing a community transmission.
2020-12, Dalian-2, Liaoning	83	51, 61.5	0, 0	32, 38.6	2020/12/15–2021/1/8	25	46, 0–88	1:1.8	Virus-contaminated cold-chain goods.	Porters were infected by contact with cold-chain goods, causing a wide community transmission.
2021-5, Liaoning-Anhui	43	24, 55.8	0, 0	19, 44.2	2021/5/3–5/24	22	29, 2–82	1:2.3	Virus-contaminated imported frozen cod	Porters were infected with SARS-CoV-2 during the handling of cold-chain foods in a cold storage, resulting in a local transmission of COVID-19 and spread to other areas.

## DISCUSSION

The persistence of SARS-CoV-2 on the objects' surfaces was different depending on the materials (5). A recent study showed that the titer of SARS-CoV-2 in artificially contaminated pieces of salmon, chicken, and pork with  $3 \times 10^6$  TCID<sub>50</sub> (median tissue culture infectious dose) was stable at 4, -20 °C, and -80 °C over 24 hours (8). This indicated that for some countries that appear to have eradicated the virus, there is a potential fear of re-emergence of COVID-19. Clusters of COVID-19 cases related to cold-chain foods in China, as described in this study, suggested that SARS-CoV-2 can survive on the contaminated surface of foods and packaging materials and maintain its infectivity for at least 11 months at a temperature of -18 °C. Although the virus genome sequences from the cold-chain foods were identical to those of the cases, there is still no direct evidence that the virus caused the local epidemic. As Koch postulates, four criteria are needed to establish a causative relationship between a microbe and a disease. One of them states: "The microorganism must be found in abundance in all organisms suffering from the disease, but should not be found in healthy organisms." Nucleic-acid-based detection methods led to the revisions of Koch's postulates, but these modifications were still controversial as they do not account well for established disease associations.

Additionally, even when no active virus was detected, the RNA extract of the package sample could cause infections in animals (data not published). Therefore, active virus isolation is complex and influenced by many factors. The outbreak of COVID-19 in Qingdao gave direct evidence that the virus could be transmitted from frozen food packaging material to humans after long-distance transportation across borders (4). Further studies are required to evaluate the presence and persistence of infectious SARS-CoV-2 and its RNA in frozen food compartments, sample conditions, and the intervention strategies for reducing the virus infection.

It is difficult to protect the workers efficiently when they work for several hours in cold storage or refrigerated cargo cabin at a temperature of -20 °C or below. Sweat and deep breathing deposit ice on workers' masks, face shields, and goggles. This reduces the effect of protective facilities and makes workers take off their masks to breathe, increasing the

probability of being infected by the virus on the outer packaging materials. In addition, many aerosols generated during frozen food handling, processing, or selling in a high-humidity, poorly ventilated environment facilitate COVID-19 transmission from person to person. Therefore, this study supports the speculation that the infected COVID-19 cases among cold-chain food handling and operating groups are likely related to occupational risk. China is a vast country, and the number of workers exposed to virus-contaminated cold-chain foods and their packaging is still significant, although the prevalence of SARS-CoV-2 contamination is very low. Therefore, it is essential to strengthen personal protective equipment development available for use in a cooling or freezing environment. All these elements mentioned above should be considered when implementing workplace interventions to ensure that communication and training are culturally and work-specifically tailored. Meanwhile, it is necessary to perform a comprehensive mass testing for SARS-CoV-2 nucleic acids, contact tracing, and symptom screening in the food of animal origin handling and processing facilities to identify high proportions of asymptomatic or pre-symptomatic infections.

**Conflicts of interest:** No conflicts of interest.

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