



# Transmittance and Survival of SARS-CoV-2 in Global Trade: The Role of Supply Chain and Packaging

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## Abstract

We are living in uncertain times and facing a paradigm shift in human health and sustainability. The number of SARS-CoV-2 victims is rising daily and all nations are going through dramatic effects and exploring various solutions to this imminent calamity facing the humanity. The world is confronting a public health issue that has forced it to come to a halt and evaluate the future of our modern society and our way of living. It can be stated that the sustainability of our societies inextricably depends on the performance of our global trade and supply chains. This review article is the first published assessment on the global trade and especially packaging's role in the transmittance of SARS-CoV-2 virus. Surprisingly, based on our findings, the lack of knowledge on transmittance and survival of SARS-CoV-2 in supply chain and packaging is substantial. Although there are several existing and available technologies that can be used for the risk mitigation, our assessment shows a major and timely need for broad conceptual advancements and necessary understanding of the supply chain risks associated with the viral surface transmittances. The specificity to the current and possibly future pandemics demands an increasing amount of multidisciplinary research and involvement of public and private sectors. This proposed erudition is imminent and may be highly critical in safeguarding and the sustainability of the critical supply chains in our society now and in the future.

**Keywords** SARS-CoV-2 · Transmittance · Survival · Supply chain · Packaging · Health · Risk management

## Introduction

The COVID-19 crises can be stated to have redefined the three pillars of sustainability adding a fourth pillar 'Human Health' to its very concept [12]. In December 2019, the health authorities in Wuhan, China received the first information on tens of patients with unknown cause for pneumonia symptoms. The first case of novel coronavirus outside of China was confirmed January 13th [38]. Ever since then, the world has faced an evolving wave of coronavirus disease, COVID-19, and as of August 23, 2020, over 23,574,130 confirmed cases with 812,104 deaths have been reported globally [40]. As viruses and diseases often have different names, this virus is called severe acute respiratory syndrome coronavirus 2 or SARS-CoV-2 [38]. The public perception of

the novel virus is can be considered even mysterious, and it has created a lot of concern on its transmissibility including its stability on surfaces and transmission through air. From an individual perspective, concrete protective action items including use of surgical and N95 masks, bandanas, and gloves have become an everyday discussion topic. Citizens have started to disinfect their mail, parcels, and other packages. The uncertainty in protective measures and actions is partially due to the limited information and research available on coronavirus transmittance and survival. This clearly increases public uncertainty and fear. In this review, the current understanding on SARS-CoV-2 transmittance risks from fomite-to-human was critically assessed with the specific focus on the global supply chain in connection to parcel shipments and specifically fiber-based packaging. The consumer-faced viral contamination and transmittance risks related to packaging are also discussed reflecting on the existing and available research results.

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## Global Trade and Supply Chain

The role of shipments of letters and parcels in the global security risks on transmittance of biological and chemical threats is not new. Last wave of concern was during the 2001 anthrax attacks [7]. Most remarkably, letters containing *Bacillus anthracis* were sent to political figures raising national and international concerns of the safety of the postal service and the entire parcel shipping system. These concerns have perhaps been less in public media, but certainly considered by the national agencies such as US CDC (Centers for Disease Control and Prevention) and other agencies working on national security.

The biohazards and related risks in the shipping and postal service system are increasing as consumers have become more and more reliant on these services. Globalization and the growth of trade and shipping have grown the parcel shipping quantities to a staggering number of more than 90bn in parcel volume globally. The estimated global shipping volumes reaching \$200bn in 2025 and the parcel shipping revenues have increased to more than \$300bn [24]. The related supply chains have also faced major changes in the way they operate. For example, the traditional approach was to transport bulk products to brick-and-mortar retail stores or distribution centers that then could handle smaller volumes of direct-to-consumer catalog orders. Major change occurred when a rapid development of e-commerce enabling infrastructure took place. This included electronic funds transfer, Internet marketing, online transactions processing, electronic data interchange (EDI), and inventory management systems. These developments enabled the online shopping, which significantly increased the amount of direct-to-consumer trade [32]. Within the traditional system, the market was more characterized by scarcity and ensuring essential availability of products.

The modern e-commerce requires more and the need to maintain inventory has reduced dramatically. For example, the suppliers or the shippers are locating distribution centers that are closer to consumers and are more economical and reliable. The new supply chain model also has to meet the changing needs of the consumer using the power of the big data analytics and the Internet of things and to leverage artificial intelligence capabilities. The growth in e-commerce creates expectations to deliver goods inexpensively and, promptly, the retailers have established dedicated dot-com fulfillment centers, which then service the end customer via UPS, the DHL international, or any national postal services in question. Some larger e-commerce companies can orchestrate inbound freight moving into one of the regional distribution centers with shipments and then moved to customers, for example, via private fleet. These

changes in global trade and parcel shipping are critical to understand when analyzing biological threats and SARS-CoV-2 transmittance.

Recent studies show that the SARS-CoV-2 virus is highly contagious and has an unusual long surface stability [22, 32]. This creates significant risks and concerns from the global trade perspective. The parcel shipments from globally contaminated areas are fast and the storage time in warehouses mainly does not exist. The shipped goods may potentially have surfaces where SARS-CoV-2 virus survives the whole duration of the shipment and transmits to the supply chain workers and ultimately the consumer. This risk is becoming more and more imminent and a public concern as the COVID-19 pandemic continues.

## Role of Packaging

There are different packing materials that are used in global trade. In this article, we concentrate on the most consumer relevant materials in the modern supply chains. The materials used in commercial packaging include plastics, aluminum, cardboard, glass, and foam. Although the shipping trends have been towards smaller packing for transportation efficiency gains, plastic or flexible packaging has not successfully replaced cardboard as the main packaging material. The main surface a consumer gets exposed to in home deliveries is the cardboard box or also called corrugated box. This type of material is used in smaller parcel boxes and larger shipping boxes. The material surface (secondary packaging) that the consumer or supply chain worker is exposed to is fiber-based linerboard which is mainly made of softwood (pine tree or pinus) pulp or more specifically unbleached softwood kraft with long and strong ligno-cellulosic fibers that bond well and give ideal strength to the box. Often OCC (Old Corrugated Container) recycled pulp is also used for the surface material of the cardboard boxes reducing the cost and increasing the sustainability and recycling aspects of the boxes. The other fiber-based packaging types (primary packaging) include paperboard which is a paper-based material that is lightweight, yet strong. This material comes in various grades, each suitable for different packaging requirements. This type of fiber-based packaging includes WLC (White-lined Chipboard), typically made from layers of recycled fibers, SBS (solid bleached sulfate) carton, CUK (coated unbleached kraft) carton or FBB (folding box board) carton that is considered the most sustainable and made from several layers of chemical and mechanical pulp. In addition, a rigid box which is made of a highly condensed paperboard (even four times thicker than FBB or SBS carton) is used for boxes that hold for example Apple's iPhones and iPads. For the surface stability of SARS-CoV-2, it is important to understand that these carton types may be coated with a

mixture of materials including polymers. The coatings are used to impart certain qualities to the carton, including haptics such as smoothness and grip and weight, surface gloss, or ink absorbency. There are various materials that are used including kaoline, calcium carbonate, bentonite, and talc. From polymer side, styrene acrylic and acrylic polymer emulsions, styrene-butadiene latex, or carboxylated styrene-butadiene emulsions can be used, all of them designed to accept ink, create gloss, and form a barrier to grease and moisture. The box material from a surface perspective can therefore be a complicated mix of several ceramic materials and polymers. All these various materials can potentially have a different viral surface stability and transmittance that the supply chain nor the consumer is aware off.

## Viral Stability and Transmittance on Surfaces

With severe acute respiratory syndrome (SARS) coronavirus and Middle East respiratory syndrome (MERS) coronavirus, the novel coronavirus SARS-CoV-2 is the third highly pathogenic human coronavirus that has emerged within the last 2 decades [10]. Although MERS-CoV and SARS-CoV-1 resulted in deaths, neither had such global impact as SARS-CoV-2, resulting in the World Health Organization to declare it a global pandemic on March 11, 2020. Since SARS-CoV-2 is novel, research on understanding its transmission from human-to-human and fomite-to-human is ongoing. However, investigations have been performed on other emerging coronaviruses, such as MERS, SARS, endemic human coronavirus strain HCoV, as well as veterinary coronaviruses, such as gastroenteritis virus (TGEV), mouse hepatitis virus (MHV), and canine coronavirus (CCV) giving an indication on SARS-CoV-2 stability on surfaces. Most of the studies have concentrated more on hospital related surfaces, such as stainless steel, plastic, glass, gloves, and gowns. In addition, most of the available research published has been on SARS-CoV-1. Indicatively, the survival and stability in case of SARS-CoV-1 can be exceptionally long as in plastics where it has been reported to persist at room temperature up to 6 days in suspension and 9 days in dried state [25]. Surprisingly, SARS-CoV-1 RNA was detected from carpet after 3 months an infected person had stayed at a hotel in Hong Kong [37]. Although detection of RNA is not indicative of viability of the virus, it does suggest that the virus can survive longer periods of time when the material of the inanimate object can act as a protective barrier [9].

Only a few investigations have specifically reported on the survival of coronaviruses on wood- and paper-related materials. Lai reported that SARS-CoV-1 survived 24 h to less than 5 min on laboratory form paper depending on the viral titer of  $10^6$  TCID<sub>50</sub>/ml and  $10^5$  TCID<sub>50</sub>/ml, respectively [16]. On the other hand, Duan [11] detected low levels of

SARS-CoV-1 on wood board, press paper, and filter paper at room temperature even at 72, 96, and 120 h with initial viral concentration of  $10^5$  TCID<sub>50</sub>/ml. As of now, only one study has been conducted on survival of SARS-CoV-2 on cardboard. According to van Doremalen with an initial infectious titer of  $10^3$  TCID<sub>50</sub>/ml at 21°C–23°C and 40% relative humidity, SARS-CoV-2 survived longer than SARS-CoV-1 with no detection at 24 h versus 8 h [35]. With  $10^5$  TCID<sub>50</sub>/ml, virus was inactivated within 1 h for cotton gowns rather than 24 h for disposable gowns [16]. Cotton contains natural fibers resulting in faster absorption of liquid than a disposable gown made of plastic components such as polypropylene and polyethylene. Not only are the packaging surface components and the viral exposure titer important, but also temperature and relative humidity of the package delivery chain is crucial. For example, dried SARS-CoV-1 on plastic surface survived up to 2 weeks in a typical air-conditioned environment (22–25 °C, 40–50% relative humidity), while at 38 °C with high relative humidity of >95% had a faster effect on the viability [8]. At 4 °C, veterinary coronaviruses MHV and TGEV in cell culture medium resembling human secretion survived up to 28 days at a range of 20–80% relative humidity on stainless steel (Casanova 2010). Interestingly, heat treatment of 90 min at 56 °C or 30–45 min at 75 °C with or without the presence of 20% protein additive FCS (fetal calf serum) completely inactivates the virus [9, 11, 25].

## Mitigation of Risks

There are several approaches in developing effective antibacterial and antiviral solutions to various surfaces [3, 17, 30, 41]. However, most of the solutions are aiming at a system that kills or inhibits the growth of microorganisms and with a purpose of extending the shelf life of food products that are perishable and, thus, to enhance the safety of packaged products [1, 13, 22, 26]. Many of these well-researched alternatives are also bacteria and virus specific which reduces the applicability in a broader scale. If the solution has to be tailor-made for each viral threat, the adaptability for the whole supply chain will be highly challenging. For the purpose of viral transmittance, suppressions, and mitigations, the packaging surface may demand hybrid surface structures with different layers of antiviral and bacterial performance and specificity. Especially in the case of fiber-based packaging, as earlier indicated, the surface of the package can be porous and absorbent. At first, this may seem to be beneficial for the reduced risk on immediate human contact; however, it may also create an additional risk if a virus such as SARS-CoV-2 has exceptionally long survival rates [4, 16, 27, 28, 31, 34]. One solution may be to use functional surfaces. Carpenter reported antimicrobial efficacy of photomicrobicidal paper

surfaces [5]. This photodynamic therapy (PDT) approach was also proven to inactivate several viruses including for example dengue-1 virus, influenza A, and human adenovirus-5. This research demonstrated the potential of cellulose materials to serve as anti-infective or self-sterilizing materials against both bacteria and viruses [5, 36]. It can be stated that all antiviral solutions for packaging that include surface coatings and functionalization demand added cost and complexity to the value chain of packaging materials. The volumes, for example, of the global fiber-based packing market exceed more than 400 billion tons annually. This vast industry with a globally fragmented supplier, converter, and end-user market makes impactful value chain innovations difficult to implement [21]. The other approaches for inactivation of viruses on surfaces that can be used in the supply chain include ultraviolet germicidal irradiation (UVGI) [34]. The UVGI works also on airborne viruses and is well known and used in healthcare settings and public washrooms [15, 18, 19]. Irradiation of packaging with an appropriate wavelength and light intensity for an effective duration can potentially give a desired effect in warehouses, packaging transport systems, and in final destinations including household use. One drawback is that UVGI is always a line of sight process, which makes the light source positioning critical. Other approach includes chemical surface treatments such as Lysol disinfectant, bleach, quaternary ammonium-based products, and phenol-based products [14, 18, 20, 29]. The chemical treatments, unfortunately, have many health, safety, and environmental issues that need to be considered. In addition, most harsh chemicals do have a deteriorative effect on the surface of the packaging material used and the product themselves may also be at risk. If possible, time is one clear antiviral remedy; unfortunately, the environmental conditions including humidity and temperature affect the survival rates of viruses on surfaces. The possible solution may lay in the intersection of many of these alternative approaches and thus demand further studies. Clearly, the need for this knowledge and different elucidations is imminent, and more inventions and innovations are needed to secure the safety and sustainability of our global supply chains.

## Conclusions

Coronaviruses have shown to survive for extended period, especially in the presence of human secretions and other materials that possibly offer a protective component and promote its persistence. In this review, the survivability of SARS-CoV-1 and SARS-CoV-2 on the surface of different packaging materials and in different environments has not been reviewed in detail. The current COVID-19 pandemic has shown the global importance of understanding of the viral stability and transmittance on packaging surfaces.

More and more consumers are dependent on e-commerce and ordering online and having items delivered directly to their homes. This change in the e-commerce penetration rate also includes the consumer exposure to a variety of packaging materials. The reviewed research data indicate that fast liquid absorption surfaces including cardboard boxes and uncoated other fiber-based packages would potentially have a higher likelihood to inactivate the virus more effectively. However, the viral load and the dry form may also be an important aspect influencing the viral stability. On the other hand, polymer-coated rigid boxes and carton board may give the longest stability to the virus. The environmental conditions used in the referenced studies show that air-conditioned warehouses and transportation logistics may increase the survivability of the SARS-CoV viruses. Thus, many of the researched environmental factors specify higher risk for the modern e-commerce supply chain than the traditional system. Clearly our review suggests that there is a major lack of existing research related to the transmittal and survivability of the SARS-CoV-2 virus on packaging and the supply chain. More data are needed on the impact of different packaging surface properties (including coatings and fillers) to the viral survival. The current increase in funding for SARS-CoV-2 or COVID-19 research is an opportunity to advance the understanding of the role of supply chain and packaging in the survival and transmittance of the SARS-CoV-2 and to further advance the science related to the consumer-related health risks. Based on our findings, the lack of existing information creates unnecessary public fear and the inability to mitigate the global health risks of COVID-19 that we all are facing during these unusual times. The scientific knowledge of the transmittance and survival of SARS-CoV-2 or other putative future viral sources in the global supply chains and on packaging surfaces is more important now than ever.

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**Data availability** All data and material used for this article can be from the article and the references.

## Compliance with ethical standards

**Conflict of interest** The authors declare no competing interests.

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