Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

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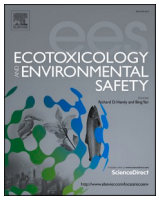

Microfiber pillow as a potential harbor and environmental medium transmitting respiratory pathogens during the COVID-19 pandemic

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The number of infections by the novel coronavirus (SARS-CoV-2) continues to increase in many parts of the world. SARS-CoV-2 causes infections in human respiratory tract and spreads through breathing, talking, coughing, sneezing, and drooling (Yoon and Yoon, 2020). Among the everyday items, pillows are likely to be in close contact with user's mouth and nose for several hours a day (CDC, 2017). During the current pandemic, people are advised to wear masks or alternative face coverings when they are in public, especially in areas of community transmission and settings where physical distancing is difficult to maintain (CDC, 2020a; WHO, 2020a). Wearing masks during sleep, however, may cause discomfort and difficulty in breathing (Shenal and Radonovich, 2012), and masks can easily fall off during sleep. As a result, pillows could be exposed to droplets exhaled from mouth and nose as well as saliva (*e.g.*, from drooling), making them a potential harbor where SARS-CoV-2 could reside and accumulate.

Most contemporarily made pillows adopt a common design which consists of a fabric envelope with microfibers filled inside. Our survey on 100 products sold by major online retailers in the U.S. and mainland China showed that pillows with microfiber fillings are the most popular type (49%) among the U.S. and Chinese consumers (Table 1). Given the prolonged and close contact with human airways, respiratory pathogens can not only land on the cover, but may penetrate the fabrics, especially when people sleep on their stomach or side which increases the likelihood of drooling (Watson, 2019). Following a modified standard test procedure by the U.S. National Institute for Occupational Safety and Health (NOISH), Zhao et al. assessed several common household materials for respiratory protection (Zhao et al., 2020). The study found that cotton pillow cover and polyester cloth both exhibited high permeability (82%–95%) for NaCl aerosols below 0.1 μm. Konda et al. (2020) reported that aerosol permeability depended on both the particle size and the weaving density of fabrics. Specifically, cotton fabrics with a weaving density of 80 threads per inch showed high permeability (86% on one layer, 56% on two layers) for polydisperse NaCl aerosols in the range of 0.3–10 μm, with similar results (75%) obtained on the synthetic silk (*i.e.*, polyester). Given that there are numerous microfibers packed inside the pillow, once the viruses travel through its surface, via exhalation or saliva, it will be difficult to achieve thorough disinfection by regular cleaning and disinfection methods such as spraying surfaces with disinfectants and laundering fabrics in warm water (CDC, 2020b; WHO, 2020b). It is particularly worth noting that, despite their proximity with human airways, current cleaning and disinfection protocols for aircrafts, trains, and lodging facilities do not make specific recommendations on pillows, such as their filling materials or envelopes, while focusing on surfaces, towels, and linens (CDC, 2020b; CDPH, 2020; WHO, 2020b). Meanwhile, studies have shown that SARS-CoV-2 could survive for hours to several days on fibrous materials under ambient conditions (Chin et al., 2020). A study on the Porcine Reproductive and Respiratory Syndrome Virus (PRRSV), an enveloped positive-sense single-stranded RNA virus as SARS-CoV-2, found that it could survive for 72 hours on polyester and cotton fibers on common tip swabs at 20°C (Fan and Gerber, 2019). Under the same temperature, Lai et al. (2005) found that it took 24 hours to inactivate SARS-CoV-1 on a cotton cloth inoculated with the virus at a $TCID_{50}$ (Median Tissue Culture Infectious Dose) of 10^6 mL^{-1}.

Although travel-related activities have considerably reduced, there are still needs for people to travel long distances (*e.g.*, by plane, train) and use hotel accommodation in the current pandemic. Under the current protocols, these activities can be carried out normally for individuals who show no COVID-19 symptoms and wear masks or alternative face coverings (AfA, 2020; AHLA, 2020, NRPC, 2020). Without being requested to present valid nucleic acid amplification test results for detection of SARS-CoV-2, however, it will be difficult to screen asymptomatic or pre-symptomatic individuals in those places. Although in some countries such tests have become mandatory for arriving passengers from international flights (CAAC, 2020; France Diplomacy, 2020), currently they are only required by certain countries and generally not needed for domestic travelers or hotel occupants showing no symptoms and having a normal body temperature. Temperature checks are recommended for guests at hotels, lodging, and short-term rentals in California (CDPH, 2020), while public health authorities in some other states in the U.S., the current epicenter of the COVID-19 pandemic, do not require such measure as per their latest

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Table 1
Prevalence of microfiber pillows in best-selling products in the U.S. and mainland China.

Pillow fillings	Walmart.com (n = 25)	Amazon.com (n = 25)	Taobao.com (n = 25)	JD.com (n = 25)
Microfibers (polyester)	14	9	13	6
Microfibers (other or unknown material type)	2	4	1	0
Other materials (foams, down, gel, etc.)	9	12	11	19

Notes: Information on filling materials was compiled from product descriptions on various retailers' websites. The best-seller designation of products was based on sales statistics published on retailers' websites as of August 6–7, 2020, when our survey was conducted (Surveyed products, 2020).

guidelines (IDPH, 2020; VDH, 2020). According to the industry-wide standards by the American Hotel & Lodging Association (AHLA), temperature checks or negative COVID-19 tests are currently not a required criterion for guest screening (AHLA, 2020). In the U.S., domestic travelers taking airplanes, trains, or automobiles face few restrictions, apart from the common requirement on wearing masks or alternative face coverings when using public transport (AfA, 2020; NRPC, 2020). Some states have started implementing travel orders which require domestic travelers and returning residents from certain parts of the country to quarantine for 14 days or present negative COVID-19 test results obtained within 72 hours upon their arrival (CT, 2020; MA, 2020).

The U.S. Centers for Disease Control and Prevention (CDC) estimated that 35% of COVID-19 patients in the United States do not show symptoms. Viral loads in the upper respiratory specimens of asymptomatic patients were found to be comparable to those of symptomatic patients, and asymptomatic patients also showed a strong ability to transmit the virus (Huff and Singh, 2020). The CDC has given specific precautions to the public on potential contact-route transmission of SARS-CoV-2 in public spaces, with a list of surfaces including tables, doorknobs, light switches, keyboards, and touch screens (CDC, 2020b). As a common sleep aid, pillows are provided on airplanes (*e.g.*, in business-class cabins), couchette trains, and in various types of lodging facilities as reusable personal items. In an investigation between March 19–20, 2020, researchers examined the hotel rooms of two pre-symptomatic individuals and found that both of the occupants' pillow covers accumulated high viral loads of SARS-CoV-2 within 24 hours of stay (Jiang and Jiang, 2020). Based on the timeline of events, those viruses survived for at least 3 h on pillow covers, although it was likely to be longer (<24 hours).

In accordance with recommendations by public health authorities (CDC, 2020b; WHO, 2020b), reusable items on airplanes, trains and in lodging facilities are regularly cleaned and disinfected during the current pandemic. While the removable covers or cases are routinely cleaned for reusable pillows, the efficacy of these methods in eliminating SARS-CoV-2 left on the underneath surfaces or penetrated into filling materials remains unknown. As a further note, bedding on couchette trains in China is generally not replaced until the train arrives at the final destination (MoR, 1994). Passengers who board the train at stops along the route are likely to be exposed to used items, including pillows, which could then become an environmental medium transmitting respiratory pathogens given their proximity with the human airways. Similar risks exist in airplane cabins, although to a lesser extent because airplanes usually do not offer intermediate stops and would only take a certain group of people from the point of departure to a common destination, with all passengers and crews staying on board. This lowers the risks of virus transmission via unintentional exposure to used bedding items by other passengers. According to the CDC's current guideline, if any symptomatic passengers are identified during or immediately after the flight, routine cleaning procedures should be followed, and items that cannot be cleaned, such as pillows, should be properly disposed of. Such a protocol, however, does not rule out the possibility of virus transmission via pillows after being used by asymptomatic or pre-symptomatic individuals who do not develop symptoms during or shortly after the flight. Without appropriate personal protection or adequate disinfection, SARS-CoV-2 left on the pillow cover may cause infection for the cleaning personnel, and those penetrated and accumulated on the underneath surface or microfiber fillings may cause infection for the next user.

Pillows are known to be a source of human respiratory pathogens. Adenoviruses, fungi, and bacteria have been detected at substantial loads on the surfaces (Russell et al., 2006; Woodcock et al., 2005), seams and possibly filling materials (Yacht et al., 2020) of used pillows. To date, there has been only one study on the detection of SARS-CoV-2 on pillow covers (Jiang and Jiang, 2020). There are no data in current literature on the presence of SARS-CoV-2 or other enveloped viruses on the underneath surface or fillings in pillows where viruses could potentially survive and accumulate. The infectivity of SARS-CoV-2 in pillows resulted from use and inadequate disinfection is also unknown. Although it is possible to incinerate them after use, this would create additional wastes and potentially cause more environmental pollution. Specifically, studies showed that emissions from the combustion of polyester fabrics contain a plethora of pollutants, including carbon oxides, volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), and fine particulate matter (PM2.5) (Moltó et al., 2006; Reisen et al., 2014). A more realistic way to solve the current dilemma is by wrapping the pillow in a large-size Ziplock bag, or other reusable plastic wrapping with an air-tight seal, to isolate it from respiratory droplets and saliva from user's mouth and nose. Those wrappings should be replaced after use, which can be disinfected afterwards and checked for air-tightness before reuse. The flat and smooth surfaces of Ziplock bags make it easy to disinfect them using liquid disinfectants, ultraviolet radiation, or hot water. Our experiences showed that common Ziplock bags made by low-density polyethylene can be kept in hot water baths at 50–70 °C for several days without affecting the integrity of their body material or "zips" at the opening. Chin et al. (2020) showed that, at 56°C, SARS-CoV-2 was disinfected within 30 min with a 6.5-log reduction. At 70°C, the disinfection time was reduced to 5 min. When sleeping on the plastic-wrapped pillow, a removable fabric cover can be used on top to maintain user's comfort. Cleaning personnel who handle used pillow covers, cases, and plastic wrappings must wear appropriate personal protection equipment to avoid possible contact with viruses left on these items. For frequent travelers, it is also advisable to bring their own travel pillows to protect them from this potential medium of virus transmission and others who may come into contact with their used pillows. These precautionary measures may help lower the risk of human-to-human transmission in pandemics and epidemics caused by respiratory pathogens.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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