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Perspective

Possible aerosol transmission of COVID-19 associated with an outbreak in an apartment in Seoul, South Korea, 2020

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ABSTRACT

Background: Scientists have strongly implied that aerosols could be the plausible cause of coronavirus disease-2019 (COVID-19) transmission; however, aerosol transmission remains controversial.**The study:** We investigated the epidemiological relationship among infected cases on a recent cluster infection of COVID-19 in an apartment building in Seoul, South Korea. All infected cases were found along two vertical lines of the building, and each line was connected through a single air duct in the bathroom for natural ventilation. Our investigation found no other possible contact between the cases than the airborne infection through a single air duct in the bathroom. The virus from the first infected case can be spread to upstairs and downstairs through the air duct by the (reverse) stack effect, which explains the air movement in a vertical shaft.**Conclusions:** This study suggests aerosol transmission, particularly indoors with insufficient ventilation, which is underappreciated.© 2020 The Author(s). Published by Elsevier Ltd on behalf of International Society for Infectious Diseases. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Background

The possibility of aerosol transmission of the severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2) remains controversial. An aerosol is defined as a suspension of particles of <5 μm in the air (or in a gas), which is small enough to reach the respiratory bronchioles and alveoli (Wilson et al., 2020). The WHO merely acknowledged that aerosol transmission might be another transmission route for SARS-CoV-2 without further response, and international and governmental guidelines retain the rule of 2 m of social distance based on droplet transmission (Morawska and Milton, 2020; Wilson et al., 2020). Evidence is necessary to establish the aerosol transmission of coronavirus disease-2019 (COVID-19). However, scientists have strongly implied that aerosols could be the plausible cause of super transmission based on several confirmed cases in Jinyintan Hospital, Wuhan, China (Huang, 2020), a choir practice in Skagit County, US (Hamner et al.,

2020), and a restaurant in Guangzhou, China (Lu et al., 2020), related to the indoor air quality and ventilation. This study describes a detailed investigation of a similar outbreak that occurred along two vertical lines in an apartment in South Korea, which suggests the airborne transmission of COVID-19.

The study

Cases

Recently, 10 cases of COVID-19 in the same two vertical lines in an apartment building were confirmed in Seoul, South Korea. On August 23, 2020, a woman (patient no. 1, see Table 1) living on the 6th floor was diagnosed with COVID-19 infection. Her husband and daughter also tested positive. On the next day, a 19-month-old child (patient no. 4) living just below a unit on the 5th floor visited a hospital with an underlying urological problem, also testing positive for COVID-19. On August 25, 2020, a woman living on the 4th floor (patient no. 5) in the same vertical line as the previous two households was diagnosed with COVID-19. She reported a fever since August 22, 2020. Quarantine authorities decided to take the preemptive COVID-19 PCR test for all residences of the

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Table 1
Patient information on mass infection in an apartment in Seoul, Republic of Korea, 2020.

Patient No.	Age/sex	Floor No/Line No	Mechanical ventilator	First symptom	Date of symptom	Date of diagnosis
1	37/Female	6th/A	Absent	Fever	8/21	8/23
2	36/Male	6th/A	Absent	Fever	8/20	8/24
3	2/Female	6th/A	Absent	Rhinorrhoea	8/18	8/24
4	1/Female	5th/A	Absent	Fever	8/23	8/24
5	36/Female	4th/A	Present	Cough	8/22	8/25
6	39/Female	5th/A	Absent	None	–	8/26
7	48/Female	10th/A	Present	Sore throat	8/16	8/26
8	32/Male	11th/A	Present	Sore throat	8/25	8/26
9	36/Male	2nd/B	Absent	Fever	8/24	8/27
10	56/Female	11th/B	Present	Cough	8/21	8/27

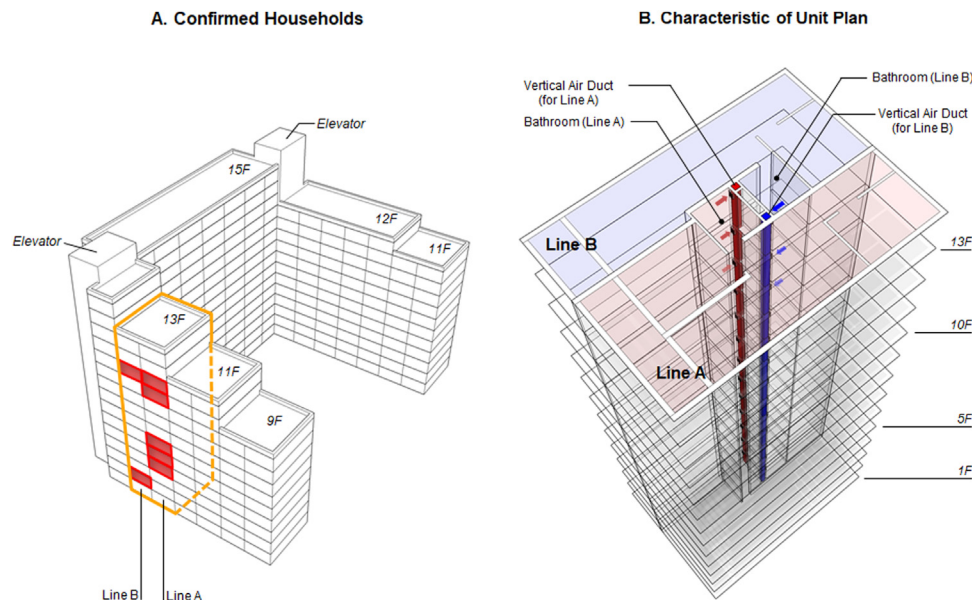


Figure 1. Structure of the apartment building where the infection outbreaks occurred in two vertical lines. (A) Confirmed units, (B) Characteristics of the unit plan.

apartment building. Local quarantine officers set up a temporary tent in front of the apartment and took samples using nasopharyngeal swabs from all residents for three days. A total of 437 residents from 267 households were tested with five more people diagnosed: the mother of the child on the 5th floor, residents living on the 10th and 11th floor of the same vertical line (patient nos. 7 and 8), and residents living on the 2nd and 11th floor of the next vertical line (patient nos. 9 and 10). In total, 10 cases in 7 households were confirmed. In the epidemiological investigation, the sources of exposure outside the apartment were not identified in all cases. All patients reported that they are not acquaintances of each other and denied a history of interpersonal contact. Quarantine authorities also took swab samples from the surfaces of each household's ventilation grilles and drains but not from the lifts, and the SARS-CoV-2 RNA detection was negative.

Building details

The apartment where the outbreak occurred was built in 1988 and consisted of 9–15 floors. Fifteen to twenty-one households are living along the hallway on each floor. Two elevators and entrances are located at both corners of the building (Figure 1A). In this apartment, a natural ventilation shaft is located along each vertical line from the bottom to the rooftop. Each shaft is connected to the units within the same vertical line through the blowhole at the bathroom (Figure 2B).

Potential transmission routes

The transmission has possibly occurred through droplet infection in the common space such as an elevator or indirect contact through the common object such as elevator buttons. However, among the residents of over 200 households who may use the same elevators, all the patients were found in only two vertical lines of the building. All patients responded that they had worn masks outside the unit and two of the patients even denied using elevators. Although droplet or contagious infection may explain the transmission between patients of two lines, it is reasonable to suspect aerosol transmission through the constructional connecting the passage along a vertical line of the building: floor drain or air duct.

McKinney et al. (2006) reported a case of the rapid spread of SARS throughout an apartment in Hong Kong by being drawn into the bathroom through the floor drain. The study suggests another transmission route by aerosol between households. However, unlike the case of Hong Kong, the drains of the toilet were not connected with those of sink, bathtub, or floor, in this case. Also, traps filled with seal water were installed in all drains to prevent the inflow of odors. The vent pipe to protect the water is also connected to a vertical drain. Therefore, it is less likely that virus-contaminated aerosol from the dried feces in sewage pipe can flow back into the room through the drain.

The apartment is vertically connected with a shaft through blowholes at the bathroom. Besides, units do not have a fan

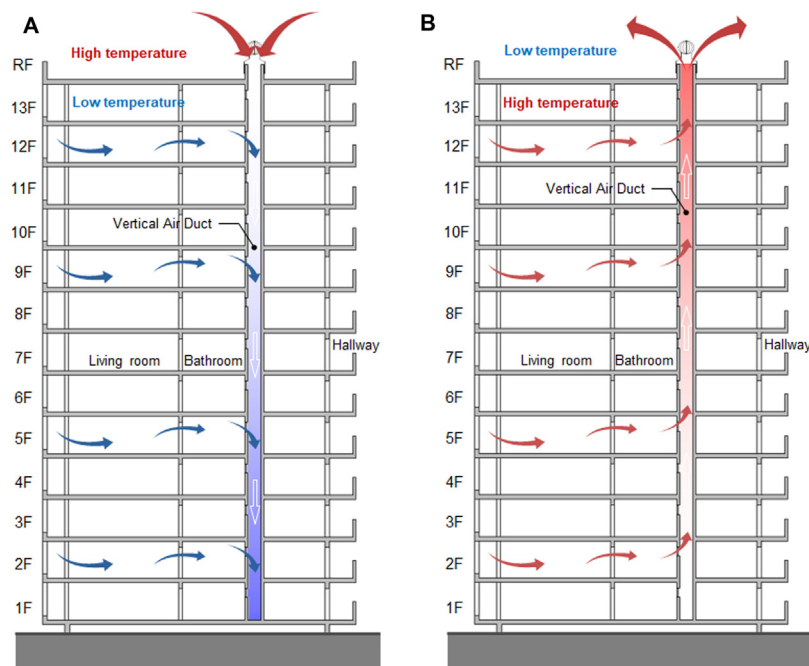


Figure 2. Diagram of the airflow in the air duct. (A) Stack effect (winter), (B) Reverse stack effect (summer).

because this building was built before the installation of an exhaust fan with a backdraft damper in bathrooms became compulsory. Thus, there is no physical block for the air to enter the room from the air duct. This structure can easily make a stack effect that refers to the vertical movement caused by the difference in indoor and outdoor air density due to the difference in temperature inside and outside the building. In this case, patient no. 7 from the 10th floor, whose symptom appeared first, is suspected as the infection source in this cluster, which means that the infection may have spread from the 10th floor to the upper floors and mainly downstairs. The variation in the direction of air movement in the vertical space depends on the season. In summer, as the temperature inside is lower and the density is higher than the outside, the air inside the building moves to the lower part by receiving a downward force; this is called the reverse stack effect (Mijorski and Cammelli, 2016). For example, Lee et al. (2017) showed that external coarse particles ($<10\ \mu\text{m}$) and fine particles ($<2.5\ \mu\text{m}$) were able to travel from upper to lower levels through the vertical channel by a reverse stack effect in summer, which supports the possible viral transmission of the aerosol through the ventilation system.

Discussion

Previous research has shown that SARS-CoV-2 can travel longer through aerosols, similar to SARS and MERS (Setti et al., 2020). The virus was stable with a half-life of more than one hour (van Doremalen et al., 2020), enough to be inhaled by susceptible individuals, causing infection and further spreading the disease. Thus, we infer that the first infected person probably released the virus during a shower in the bathroom by coughing, breathing, singing, or flushing around the time when the symptom arose (Yao et al., 2020). The virus may combine with water vapor and become aerosols in the humid environment, which favors the transmission and survival of SARS-CoV-2 (Raines et al., 2020; Zhou et al., 2007). The mechanical ventilator in the bathroom may force exhaust the aerosols to the air duct, and these spread from the 10th floor to the upper and mainly lower floors in a line by the reverse stack effect

through the air duct that enters bathrooms without a ventilator or bathrooms with a nonfunctional ventilator. Finally, the people who use the bathroom may be more likely to inhale the aerosol when they shower (Zhou et al., 2007). Similar COVID-19 cases within the same vertical line of a residential house or an apartment without interpersonal contacts have been reported in Ordos City, Mongolia (Jung, 2020) and Guangzhou, China (Tang et al., 2020), implying aerosol transmission.

Our study has a limitation. This study is an epidemiological investigation outlining one potential scenario, and it does not include genomic sequencing or air samples to provide robust evidence of SARS-CoV-2 aerosol transmission.

Conclusions

Our study implies that indoor infection risks through aerosols are underappreciated and urgently need attention. More people may have to stay indoors during the pandemic to avoid interpersonal contact. However, some may be exposed to viral infection by inhalation due to inadequate ventilation systems. Our study also implies that the rigid rules of safe distancing that stick to droplet and contact transmission based on an outdated dichotomous notion of respiratory droplet or aerosols should be reconsidered (Jones et al., 2020; Wilson et al., 2020).

Conflict of interest

The authors have declared no competing interest.

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None.

Ethical approval

This study is approved by the Institutional Review Boards of the Seoul Medical Center: SEOUL 2020-09-007.

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