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Major Article

Environmental contamination of SARS-CoV-2 during the COVID-19 outbreak in South Korea

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Key Words:

Novel coronavirus
Surface contamination
Contact precaution
Infection control

Objectives: Although contact precaution is generally recommended in situations where coronavirus disease 2019 (COVID-19) is suspected, there is limited evidence on environmental contamination of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). Therefore, we conducted environmental surveillance on SARS-CoV-2 contamination in 2 different healthcare settings.

Methods: Viral contamination was investigated on the environment of 2 hospitals that had admitted 13 COVID-19 patients. In hospital A, 5 patients with pneumonia occupied negative pressure rooms. In hospital B, 8 asymptomatic patients shared 2 common 4-bed rooms. Most rooms were poorly cleaned or disinfected. Environmental swab were collected from inside and outside the rooms and were tested using real-time RT-PCR for the detection of SARS-CoV-2.

Results: In hospital A, SARS-CoV-2 was detected in 10 of 57 (17.5%) samples from inside the rooms including the Ambu bag and infusion pump. Two samples obtained at more than 2 m from the patients showed positive results. In hospital B, 3 of 22 (13.6%) samples from inside the rooms were positive. Areas outside the rooms, such as the anteroom, corridor, and nursing station, were all negative in both hospitals.

Conclusions: Hospital surfaces surrounding patients were contaminated by SARS-CoV-2. Our findings support the value of strict contact precaution, routine cleaning, and disinfection in the management of COVID-19 patients.

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Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), a novel coronavirus that had not been previously reported, is the causative pathogen of coronavirus disease 2019 (COVID-19), originating from Wuhan, China.¹ Since the first report of COVID-19 in December 2019, this viral respiratory syndrome has spread very rapidly, and the threat of a pandemic has become a reality.² Epidemiological studies have demonstrated that human-to-human transmission is the important route of these massive outbreaks.³

Nosocomial outbreaks of this highly contagious respiratory virus could have a huge impact on public health because there is a risk of collapsing the medical system if healthcare workers

(HCWs) become infected. In data from the Chinese Center for Disease Control and Prevention, 1,716 of 44,672 confirmed cases (3.8%) were HCWs.⁴ In addition, in a study conducted in Wuhan, HCWs accounted for 40 out of 138 patients (29%).⁵ In this regard, appropriate infection control guidelines are essential for the prevention of nosocomial transmission of SARS-CoV-2 to HCWs.

Close contact with SARS-CoV-2-contaminated surfaces is thought to be one of the possible routes of transmission. Thus, the World Health Organization recommends contact precaution in situations where COVID-19 is suspected.⁶ However, our predictions of the contagious nature of SARS-CoV-2 are largely based on past experiences with other human coronaviruses,^{7–9} and there are still undiscovered aspects regarding the transmission pattern of this novel coronavirus. Therefore, we investigated the environmental contamination of SARS-CoV-2 in different settings of hospitals that admitted patients with various severities.

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Conflicts of interest: The authors declare no conflicts of interest.

Funding: No external funding was received.

METHODS

Patients and rooms

In March 2020, 13 confirmed COVID-19 patients were admitted to hospitals A and B in Changwon, South Korea. Hospital A had 5 patients, and 2 of them (patients 1 and 2) were in negative pressure isolation rooms located in the intensive care unit (ICU). Patient 1 had severe pneumonia (defined as fever or suspected respiratory infection plus 1 of the following: respiratory rate >30/min, severe respiratory distress, or SpO₂ ≤93% on room air)¹⁰ and received mechanical ventilator care and vasopressor infusion. Patient 2, who complained of increasing dyspnea, also had severe pneumonia and received oxygen via a nasal prong. The remaining 3 patients (patients 3–5) occupied negative pressure rooms in the isolation ward. Patients 3 and 4 had severe pneumonia, and oxygen was supplied via high-flow nasal cannula (HFNC). Patients 1–4 were classified in the high-risk group according to the NEWS scoring system.¹¹ Patient 5 had mild pneumonia (defined as no signs of severe pneumonia plus no need for supplemental oxygen)¹⁰ without specific symptoms (initial symptoms were resolved at the time of environmental sampling). All isolation rooms in hospital A had anterooms and met the detailed standard for installation and operation of the negative pressure isolation room enacted by the Ministry of Health and Welfare, South Korea. In hospital B, 8 asymptomatic patients (patients 6–13, their initial symptoms were already resolved at the time of environmental sampling) with a stable clinical course were admitted to 2 common 4-bed rooms without negative pressure and ventilation systems because the South Korean government decided to collectively accommodate patients with only mild symptoms due to the lack of negative pressure rooms during the massive epidemic of COVID-19. The beds were placed at 2-m distances in the 4 corners of the room and were divided by curtains. All rooms in hospital B were connected directly to a common corridor without anterooms. Additional information on the patients and rooms is presented in Table 1.

Environmental sampling

Environmental samples were collected from each patient's room and ancillary spaces, such as the anteroom, adjacent common

corridor, and nursing station. Dacron swabs premoistened with viral transport medium (Copan Italia SpA, Brescia, Italy) were used to swab environmental surfaces aseptically.

The swabbed surfaces included the following: (1) patient room (ie, patient monitor, ventilator monitor, HFNC, blood pressure cuff, pillow, suction bottle and line, Ambu bag, infusion pump, wall oxygen supply, fluid stand, door button or knob, bed side rail, head and foot of the bed, nurse call controller, lower part of the window frame, top of the television [TV], air exhaust damper, wall and floor of the room, toilet paper holder, and inside and seat of the toilet); (2) the anteroom (ie, door button, keyboard, mouse, and floor); (3) the floor of an adjacent common corridor; and (4) the nursing station (ie, counter, interphone, keyboard, mouse, chair, and floor).

The standard cleaning procedures of the isolation rooms used 0.1% hypochlorite solution. However, due to the shortage of personal protective equipment (PPE) and vague fears of cleaners, room cleaning, and disinfection were not performed every day. This study was approved by the Institutional Review Board of Gyeongsang National University Changwon Hospital (GNUCH NON2020-0001).

Laboratory procedures

Virus RNA was extracted from environmental swab samples using an ExiPrep 48 Viral DNA/RNA Kit (Bioneer, Daejeon, Korea) and ExiPrep 48 Dx (Bioneer) according to the manufacturer's instructions. Real-time RT-PCR was performed using an Allplex 2019-nCoV Assay (Seegene, Seoul, Korea) and a CFX96 Touch Real-Time PCR Detection System (Bio-Rad, Hercules, CA). The Allplex 2019-nCoV Assay, a multiplex real-time PCR assay, detects the SARS-CoV-2 E gene, RdRp gene, and N gene. When all 3 genes showed positive findings, we interpreted the case as positive. When positive findings were found for 1 or 2 genes, we regarded the case as presumptive positive.

RESULTS

Hospital A (more severe patients in well-equipped isolation rooms)

In hospital A, SARS-CoV-2 RNA was detected in 10 of 57 (17.5%) environmental samples inside the rooms using real-time RT-PCR.

Table 1
Patient and room data at the time of environmental sampling

Hospital	Patient number	Patient status	Patient data					Room data		
			Clinical syndrome	Respiratory symptom	Mask-wearing behavior	Days from		Site	Ventilation with negative pressure	Hours from the last room disinfection
						Symptom onset	Last (+) RT-PCR			
A	1	Mechanical ventilation with vasopressor	Severe pneumonia	N/A	N/A	12	14*	ICU	Yes	32
	2	Nasal cannula	Severe pneumonia	Dyspnea	Good [†]	10	1	ICU	Yes	23
	3	HFNC	Severe pneumonia	Dyspnea	Bad [‡]	3	1	Ward	Yes	24
	4	HFNC	Severe pneumonia	Dyspnea	Bad	9	2	Ward	Yes	1
B	5	Nasal cannula	Mild pneumonia	No	Good	18	1	Ward	Yes	72
	6	Room air	N-S	No	Good	14	14	Ward	No	184
	7	Room air	Mild pneumonia	No	Good	17	1			
	8	Room air	N-S	No	Good	16	16			
	9	Room air	N-S	No	Good	13	13			
	10	Room air	N-S	No	Good	38	11	Ward	No	184
	11	Room air	N-S	No	Good	26	13			
	12	Room air	N-S	No	Good	18	1			
	13	Room air	N-S	No	Good	16	13			

Abbreviations: HFNC, high-flow nasal cannula; ICU, intensive care unit; N/A, not available; N-S, nonspecific.

*Given the strong epidemiologic relationship between a COVID-19 outbreak cluster and patient 1, a PCR test was performed before symptom onset.

[†]Good mask-wearing behavior means wearing a mask to cover nose, mouth, and chin.

[‡]Bad mask-wearing behavior means that the nose, mouth, and chin are not completely covered.

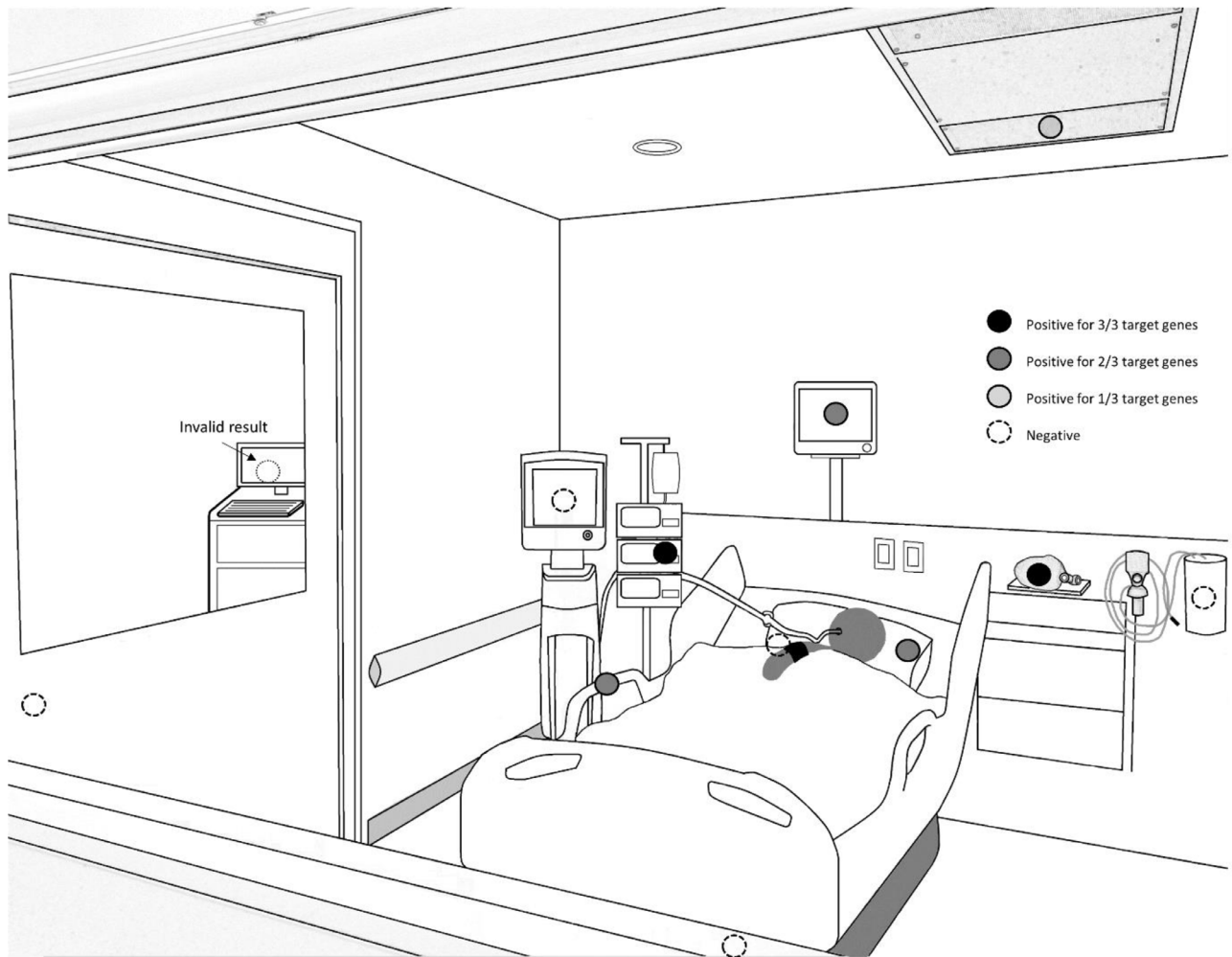


Fig 1. Illustration of the ICU negative pressure isolation room occupied by patient 1. The black circles indicate positivity for all 3 SARS-CoV-2 target genes (= positive). The dark gray circles and light gray circles indicate positive results for 2 and 1 of 3 target genes (= presumptive positive), respectively.

Among those, 6 of 10 (60%) environmental samples obtained from the ICU isolation room occupied by patient 1 were positive. All 3 target genes were detected on the Ambu bag and infusion pump. Two of the target genes were detected on the pillow and patient monitor, and one was detected on the ceiling air exhaust damper (Fig 1). From the rooms of patients 3 and 4, 2 environmental samples each were found to be contaminated with SARS-CoV-2 genes (fluid stand and head of the bed: 2 of 3 genes; top of the TV and patient monitor: 1 of 3 genes). The rooms of patients 2 and 5 were negative by real-time RT-PCR. No viral RNA was detected outside the isolation rooms – in the anteroom, corridor, and nursing station – of hospital A.

Hospital B (less severe patients in common hospital rooms)

Three of 22 (13.6%) environmental samples inside hospital B's rooms were positive for SARS-CoV-2 genes by real-time RT-PCR. The room floor center and toilet seat were found to be positive for all 3 target genes. One target gene was detected on the side rail of a bed. Other objects, such as doorknobs of patient rooms and restrooms, common corridors, and nursing stations, were all negative (Fig 2). Table 2 and Appendix Table 1 present details of the real-time RT-PCR results.

DISCUSSION

Our results clearly show environmental contamination of the COVID-19 patients' surroundings by SARS-CoV-2. Indeed, viruses have been found on various hospital objects, and these surfaces can be sources of nosocomial transmission via direct contact. Therefore, our findings provide an important basis for justification of strict contact precaution.

Compared to the other rooms occupied by "milder" patients, the ICU isolation room of the most severe patient (patient 1 with severe pneumonia who received frequent suction during mechanical ventilation) was more severely contaminated. Viral RNA was detected in 6 of 10 samples (60%) collected from the room, which was a significantly higher contamination rate than those of the 2 common rooms shared by 8 asymptomatic patients (9.1%–18.2%) as well as the 3 isolation rooms of other patients with severe pneumonia (0%–16.7%). Substantial viral dispersion by frequent oral/endotracheal suction could be responsible for this extensive contamination of surrounding environmental surfaces.

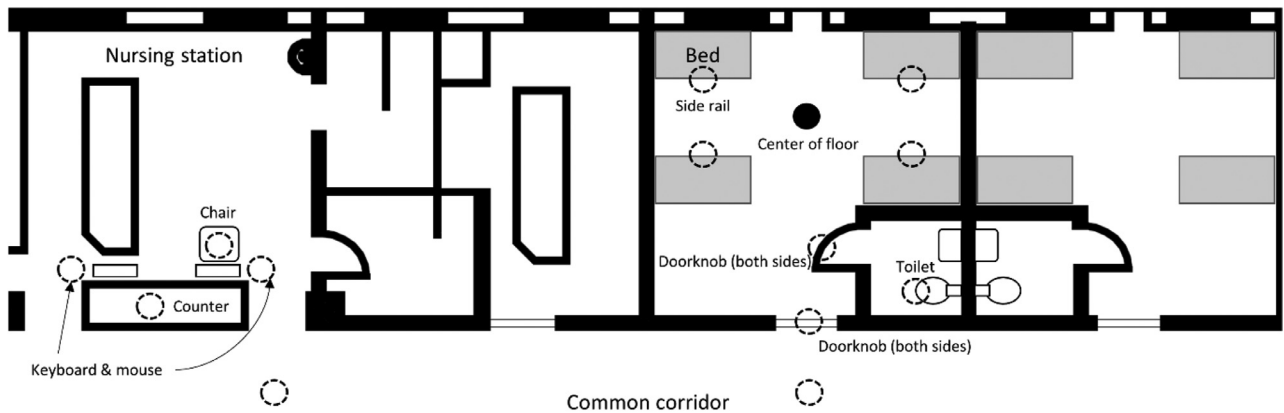
It was somewhat surprising that the viral detection rates of the rooms of the 3 severe pneumonia patients other than patient 1 were not as high as expected. The patients' symptoms, wearing a mask, and cleaning/disinfection of room may have been associated with this finding. Patient 2 coughed intermittently but wore a dental

Table 2
Real-time RT-PCR results of environmental sampling

Hospital	Patient number	Inside the room	Outside the room			Number of real-time RT-PCR-positive samples (collected surface)		
			Anteroom	Corridor	Nursing station	3 of 3 target genes	2 of 3 target genes	1 of 3 target genes
A	1	6/10	0/1*	N/A	N/A	2 Ambu bag Infusion pump	3 Pillow Bed side rail Patient monitor	1 Air exhaust damper
	2	0/10	0/2	N/A	N/A	0	0	0
	3	2/12	0/2	0/1	0/3 [†]	0	1 Fluid stand	1 Upper part of TV
	4	2/13	0/2	0/1		0	1 Head of the bed	1 Patient monitor
	5	0/12	0/1*	0/1		0	0	0
B	6-9	1/11	N/A	0/1	0/5	1 Center of room floor	0	0
	10-13	2/11	N/A	0/1	0/5	1 Seat of toilet	0	1 Side rail of patient 12's bed

Abbreviations: N/A, not available; TV, television.
*One sample with invalid results was excluded from the results.
[†]The isolation rooms of patients 3-5 share the same nursing station.

A) 3rd floor



B) 4th floor

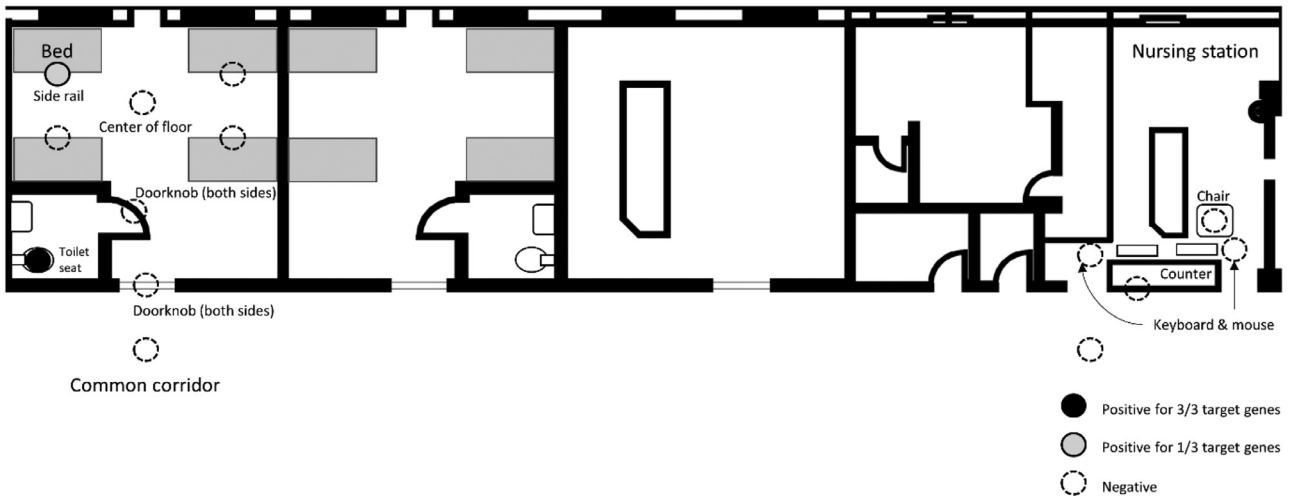


Fig 2. Floor plan of hospital B. Eight asymptomatic COVID-19 patients shared 2 common 4-bed rooms. The black circles indicate positivity for all 3 target SARS-CoV-2 genes (floor center and toilet seat). The light gray circle indicates presumptive positive for 1 of 3 target genes (side rail of patient 12's bed).

mask most of the time; patient 3 had no symptoms other than dyspnea; and patient 4 coughed frequently, did not use a dental mask properly, and had the lowest cycle threshold values (Ct value of 14.48 for the E gene) of the real-time RT-PCR for the respiratory specimen among all the patients (Supplementary Table 1). However, the room of patient 4 was the only place where samples were collected immediately after cleaning/disinfection. Additionally, unique viral kinetics of SARS-CoV-2 – the highest viral load is present during the early phase of infection, and a reduction in viral load occurs at the beginning of pneumonia progression – may also partly support our finding.¹²

The outbreak at a shopping mall in Wenzhou, China, showed indirect clues of airborne transmission of SARS-CoV-2.¹³ According to a report from Singapore, SARS-CoV-2 was found in air outlet fans of a hospital room.¹⁴ In our study, environmental samples from an air exhaust damper in patient 1's room and from the top of the TV in patient 3's room showed "presumptive positive" results. The former is located in the ceiling, and the latter was located more than 2 m from the patient. These findings suggest the possibility of aerosolization of the virus. However, the following arguments may rise against our assessment: (1) frequent respiratory tract manipulation, such as oral/endotracheal suction, produced aerosols, but the chance that strong negative pressure pulled them up to the ceiling exhaust damper cannot be ruled out; (2) the high gas flow of HFNC may trigger aerosol production, although a recently published study showed that HFNC was not associated with increased aerosolization;¹⁵ and (3) patient 3 was able to move, although HFNC might have been uncomfortable, and the TV was at an easily accessible height. Therefore, the relationship between aerosols and the SARS-CoV-2 transmission mode cannot be explained by our observations. Further studies are needed to solve this issue. However, as seen in the precedent of SARS-CoV¹⁶ or MERS-CoV,¹⁷ it would be safe to follow airborne precautions until additional data are available, especially for patients at high risk of aerosol production.

Our study has several limitations. First, actual infectivity by live SARS-CoV-2 was not evaluated using viral cultures. Second, air sampling could not be performed due to the absence of equipment. For this reason, we could not investigate the presence of aerosolized viral particles in ambient air. Third, patients in the early stages of the illness were not sufficiently included, and most of the patients were considered as mid-to-late stage. Fourth, environmental samplings were conducted at different single timepoints for each patient, not periodically collected according to the course of the illness.

In conclusion, there was SARS-CoV-2 contamination of the hospital environment. Strict contact precaution, routine cleaning, and disinfection are mandatory in the management of patients infected with SARS-CoV-2.

SUPPLEMENTARY MATERIALS

Supplementary material associated with this article can be found in the online version at <https://doi.org/10.1016/j.ajic.2020.05.027>.

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