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Ying Cai
Xiaojing Wu
Yi Zhang
Jingen Xia
Min Li
Yingying Feng
Xin Yu
Jun Duan
Xing Weng
Yan Chen
Zhenshun Cheng
Qingyuan Zhan (drzhanqy@163.com)
China-Japan Friendship Hospital

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Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) Contamination in Air and Environment in Temporary COVID-19 ICU Wards

Ying Cai[1,†], Xiaojing Wu[1,†], Yi Zhang[1,†], Jingen Xia[1], Min Li[1], Yingying Feng[1], Xin Yu[1], Jun Duan[2], Xing Weng[3], Yan Chen[3], Zhenshun Cheng[4], Qingyuan Zhan[1,5*]

[*]Correspondence: drzhanqy@163.com

[1] Department of Pulmonary and Critical Care Medicine, Center of Respiratory Medicine, China-Japan Friendship Hospital, National Clinical Research Center for Respiratory Diseases, Yinghuayuan East Road, Chaoyang District, Beijing, 100029, China

Full list of author information is available at the end of the article.

[†] Equal contributors

ABSTRACT

Background: Coronavirus disease 2019 (COVID-19), caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), has recently spread worldwide partly through environmental and airborne contamination. The number of patients requiring intensive care unit (ICU)-based healthcare services exceeds the available negative-pressure isolation ICU room capacity. Some general wards of Wuhan hospitals have been temporarily converted into

COVID-19 ICU wards and pose safety concerns. We explored the safety of these temporary COVID-19 ICU wards.

Methods: Fifteen air samples and 128 environmental surface swabs were collected from 14 patients in 4 departments with temporary COVID-19 ICU wards. Quantitative real-time PCR (RT-PCR) methods confirmed the existence of COVID-19 pathogens.

Results: Four of the 15 air samples were obtained during aerosol-generating medical procedures (1 tracheostomy, 1 high-flow nasal cannula [HFNC], 1 HFNC+nebulization, 1 non-invasive positive pressure ventilation). Five patients were administered invasive positive pressure ventilation through tracheostomy. All air samples tested negative for SARS-CoV-2 by RT-PCR. Viruses were detected on the surface of a patient's gastric tube, and an anal tube swab tested positive. Five days later, the anal swab of the patient remained positive, although viral RNA of the nasopharyngeal swap turned negative.

Conclusions: Establishing temporary isolation COVID-19 ICU wards is a safe and effective method to increase surge capacity in a hospital. SARS-CoV-2 sheds from the enteric canal after viral clearance in the respiratory tract. Reinforcing disinfection of tubes and circuits given to the patients is essential in COVID-19 isolation wards to decrease nosocomial transmission.

Keywords: COVID-19; SARS-CoV-2; temporary wards; containment; transmission

The outbreak of coronavirus disease 2019 (COVID-19), which was caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), occurred in Wuhan, China in December 2019 [1]. Coronaviruses have been implicated in nosocomial outbreaks [2], with air and environmental contamination

as a route of transmission [3,4]. Moreover, hospital-related transmission of SARS-CoV-2 has been reported [5]. SARS-CoV-2 remained viable for 3 hours in aerosols and 4 — 72 hours on environmental surfaces throughout the duration of experiment [6] and may transmit through airborne and environmental contamination in humans [7,8].

The COVID-19 epidemic has spread to many countries, territories, and areas and resulted in 693,224 confirmed cases and 33,106 deaths reported (until March 30, 2020). Due to its increasing threat to global health, the World Health Organization (WHO) has declared the COVID-19 epidemic a global public health emergency. The number of patients who need intensive care unit (ICU)-based healthcare services may exceed the available negative-pressure isolation ICU room capacity similarly as it did in Wuhan; therefore, temporary COVID-19 ICU wards may need to be constructed. However, there are many aerosol-generating medical procedures (AGMPs) within ICU surroundings, such as noninvasive positive-pressure ventilation (NPPV), endotracheal intubation, high-flow nasal cannula (HFNC), tracheostomy, nebulizer treatment, sputum suction, bronchoscopy, etc. [9]. Temporary COVID-19 ICU wards that cannot meet the safety standards for airborne-infection-isolation rooms are of concern and may pose a threat to the safety of medical staff. Therefore, we obtained air and environmental samples in four departments with temporary COVID-19 ICU wards in Wuhan to detect the virus by reverse transcription polymerase chain reaction (RT-PCR) to investigate the safety of the temporary ICU wards.

METHODS

This was a prospective study. From February 27 to March 12, 2020, during the COVID-19 outbreak in Wuhan, China, we collected air and environmental samples from four temporary COVID-19 ICU departments (managed by different medical corps from Beijing) in the new Sino-French Ward, Tongji Hospital, Tongji Medical College, Wuhan, Hubei Province, People's Republic of China. The general wards were converted COVID-19 ICU wards by installing 1–2 exhaust ventilation fans (size 300 mm, ventilation rate 18 m^3/min; Aimeite XF3060P, Jiujiang, Jiangxi Province, China) on the window of each ward of approximately 6 × 3 × 3 m^3 size. Fourteen temporary COVID-19 ICU wards admitted severely or critically ill confirmed patients who had tested positive on SARS-CoV-2 RT-PCR tests of nasopharyngeal and/or anal swabs up to the time of sampling with informed consent. The average temperature and humidity of the 14 rooms were maintained at 18.0°C and 54.2%. High-touch surfaces and the floors were cleaned twice-daily with chlorine-containing disinfectant (the effective concentration of chlorine was 1000 mg/L).

We collected 15 air samples using a dry-filter air sampler (52-mm electret filters, InnovaPrep ACD-200 Bobcat, America) operating at a speed of 200 L/min for 60 minutes in the 14 temporary ICU wards. The filters were eluted in 7-mL elution fluid (comprising water, a low-concentration surfactant [0.075% Tween 20], and a pH buffer [20mM Tris (hydroxymethyl) aminomethane or phosphate-buffered saline]; InnovaPrep, America), which was mixed with viral transport medium (sterile Hank's fluid). In addition, 128 sterile swabs premoistened with viral transport medium were used to swab surfaces that were frequently touched by patients or healthcare workers. Environmental sample-collection sites included doorknobs, bathroom doorknobs, faucet handles, sinks and toilets, light switches, bed rails, bedside tables, bed sheets, floors, and exit vents. Moreover, gastric tubes, anal tubes, and breathing circuits were swabbed.

Air samples and swabbed specimens were stored at −20°C and analyzed within 3 days of collection.

We used specific RT-PCR targeting the RNA-dependent RNA polymerase and orf1a/b [10] gene to detect the presence of SARS-CoV-2. A 200-μL air or environmental sample was centrifuged at 1500*g* for 30 min at 4°C to reduce human-derived nucleic acid before extraction. Then, we separated 140 μL supernatant for extraction of RNA by using the QIAamp Viral RNA Mini Kit (52904#, Qiagen, Germany) in accordance with the manufacturer's instructions. The 30-μL reagent comprised 10 μL RNA and 20 μL PCR Mix (containing 18.5 μL COVID-19-PCR-Reaction Mix and 1.5 μL of COVID-19-PCR-Enzyme Mix; BGI, China). Thermal cycling was undertaken at 50°C for 20 min for reverse transcription, followed by 95°C for 10 min, followed by 40 cycles of 95°C for 15 s and 60°C for 30 s. A sample was considered positive when the RT-PCR cycle threshold value was ≤38.

RESULTS

Air and environmental samples of 14 patients were collected, and patient characteristics and environmental test results from the temporary COVID-19 ICU wards hospitals are summarized in Table 1. The duration from illness-onset to sample collection ranged from 15 to 47 days. At the time of sample collection, all patients suffered from pneumonia and were being managed by different respiratory support strategies as follows: nasal cannula (n=6), HFNC (n=2), NPPV (n=1), invasive positive-pressure ventilation (IPPV) through tracheostomy tube (n=1), IPPV and extracorporeal membrane oxygenation (ECMO; n=2), and IPPV through tracheostomy tube and ECMO (n=2). Nasopharyngeal swab testing for SARS-CoV-2 by RT-PCR were positive for all patients at the

time of sampling. Only Patient 7 tested positive on an anal swab by RT-PCR for SARS-CoV-2.

Fifteen air samples from 14 patients were obtained; 2 of the 15 air samples were collected from Patient 1 before and during (within 1 hour) tracheostomy. Patient 6 was being administered nebulization when the sample was collected. All air samples tested negative. Of the 128 swab samples collected, 2 samples tested positive for SARS-CoV-2 on RT-PCR testing. One of the positive samples was swabbed from the gastric tube of Patient 1 with a cycle threshold value of 34.7 within 1 hour of tracheostomy. The other positive sample was swabbed from the anal tube of patient No. 7 with a cycle threshold value of 30.39 and viral RNA was detected from the anal swab until the time of surface swab collection. Five days later, the anal swab of the abovementioned patient remained positive, but the viral RNA of the nasopharyngeal swab was reported negative. Environmental sampling of the rooms occupied by patients 1–3 and 9–11 was undertaken 6–8 hours after the daily routine cleaning, whereas those of patients 6–8 and 12–14 were conducted 3–5 hours after the daily routine cleaning; samples of patients 4 and patient 5 were collected 13 and 18 hours after the daily routine cleaning.

DISCUSSION

Jiang et al. and Liu et al. collected air samples that tested SARS-CoV-2 positive on RT-PCR, indicating that viruses are present in the air of COVID-19 wards and the transmission of SARS-CoV-2 in humans may occur through airborne contamination [7,8]. In the present study, 4 of the 15 air samples were obtained during AGMPs (tracheostomy, 1; HFNC, 1; HFNC and nebulizer treatment, 1; and NPPV, 1). Furthermore, 5 patients were administered IPPV and 3 of them were via tracheostomy tubes. Procedures such as replacing breathing circuits and/or respirator filters, tracheostomy tube maintenance, etc., may

generate SARS-CoV-2 aerosols. Therefore, the safety of medical staff in COVID-19 ICU wards remains threatened and should receive greater attention. Standard negative-pressure airborne infection isolation rooms should satisfy at least two conditions: the pressure difference between the ward and the corridor should be −2.5 Pa, and there should be an air-change rate of at least 12 air changes per hour (ACH), of which 2 ACHs must comprise outside air in the ward [11]. The wards in the present study were converted from general wards by installing 1–2 exhaust vent fans with a ventilation rate of 18 m^3/min on the window of each ward, measuring 6 × 3 × 3 m^3. Therefore, each room may have had an air-change rate of 20–40 ACHs. However, we are unsure about the amount of outside air in those 20–40 ACHs because the ventilator is not part of an all-fresh direct air-conditioning system. All 15 air samples collected from the COVID-19 ICU wards tested negative, attesting to the safety of the temporary COVID-19 ICU wards in our study center. An inventory of isolation rooms for highly infectious disease capabilities in European countries showed that high-level isolation rooms were available in at least 211 hospitals, constituting at least 1789 hospital beds [12]. However, the number of patients requiring healthcare services may rapidly exceed such small isolation room capacities for highly infectious diseases during an airborne transmissible pandemic or bioterror event [13], which is presently evident worldwide during the COVID-19 pandemic. Therefore, establishing temporary negative-pressure isolation COVID-19 ICU wards is a safe and effective method to increase surge capacity in a hospital.

A gastric tube swab tested positive with a higher cycle threshold value after tracheostomy, which was accorded with a negative conversion of the nasopharyngeal swab soon after surface samples were collected. Gastric tubes are very close to the tracheostomy site, mouth, and nose. Therefore, respiratory

95 droplets or virus-laden aerosol generated from tracheostomy, mouth and nose may be directly deposited on the surface of the gastric tube. An anal tube sample
96 tested positive and may be attributed to the positive anal swab sample of the patient who tested SARS-CoV-2 on RT-PCR. This provides evidence that viral
97 shedding in the enteric tract could be a potential route of transmission. In addition, the anal tube swab tested positive with a lower cycle threshold value,
98 which suggests a higher viral load. Five days later, anal swabs from the patient remained positive, although the viral RNA of the nasopharyngeal swab turned
99 negative; this indicates that the viral enteric infection and the potential fecal–oral transmission can persist after viral clearance in the respiratory tract [14].
100 Besides, the remaining 126 high-touch surface swabs were all negative, suggesting that regular cleaning was effective and persistent when undertaken by
101 using 1000 mg/L of chlorine-containing disinfectant twice daily. However, reinforcing disinfection of tubes and circuits provided to the patients is essential in
102 COVID-19 isolation wards to decrease nosocomial transmission.

103 There are several limitations of this study. First, it was conducted late in the Wuhan outbreak; patients with 1 week of symptom onset were not included.
104 However, Zhou et al. reported that the median duration of viral shedding was 20.0 days (interquartile range 17.0–24.0) in survivors, whereas SARS-CoV-2
105 was detectable until death in non-survivors [15]. The time from illness onset to sample collection in our study was between 15 and 47 days, with different
106 stages of disease progression. Second, viral culture was not undertaken to demonstrate viability, and the methodology was inconsistent at the time of the
107 pandemic. Third, due to practical limitations during an outbreak, the pressure in the wards could not be measured, although the resistance was high during
108 door closure of the ward, which suggests that the direction of the flow was correct. Fourth, we could not obtain the viral RNA cycle threshold value of

nasopharyngeal and anal swabs; therefore, we cannot compare the possible viral shedding between surface swabs and patient samples. Further studies are required to confirm these preliminary results.

This study indicates that establishing temporary isolation COVID-19 ICU wards is a safe and effective method to increase surge capacity in a hospital. SARS-CoV-2 sheds from the enteric canal even after viral clearance in the respiratory tract. Regular cleaning of high-touch surfaces is effective and should be persistently undertaken using 1000 mg/L chlorine-containing disinfectant. Reinforcing disinfection of tubes and circuits given to the patients is essential in COVID-19 isolation wards to decrease nosocomial transmission.

DECLARATIONS

Ethics approval and consent to participate

Medical ethics committee of Tongji Hospital, Tongji Medical College's; committee's reference number: TJ-IRB20200353. Written informed consent was obtained from all the participants before air and environment sample collection.

Consent for publication

Not Applicable.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare no competing interests.

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Author's contributions

All authors made substantial contributions to the conception and design of the study, data acquisition, review and approval of the final manuscript and agreements both to be personally accountable for the author's own contributions and to ensure that questions related to the accuracy or integrity of any part of the work. Drs. YC, XW and YZ contributed equally to the article. Drs. YC, XW, YZ, JX, ML, YF, XY, JD, XW, YC, ZC and QZ performed experiments. Drs. YC, XW, YZ, JX, ML, YF, XY and QZ analyzed data. Drs. YC, QZ, XW and YZ were responsible for the drafting of the manuscript.

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Author details

[1] Department of Pulmonary and Critical Care Medicine, Center of Respiratory Medicine, China-Japan Friendship Hospital, National Clinical Research Center for Respiratory Diseases, Yinghuayuan East Road, Chaoyang District, Beijing, 100029, China. [2] Department of Surgical Intensive Care Unit, China-Japan Friendship Hospital, Yinghuayuan East Road, Chaoyang District, Beijing, 100029, China. [3] BGI PathoGenesis Pharmaceutical Technology Co., Ltd, BGI-Shenzhen, Hong'an Third Street, Yantian District, Shenzhen, 518083, China. [4] Department of Pulmonary and Critical Care Medicine, Zhongnan Hospital of Wuhan University, East Lake Road, Wuchang District, Wuhan, 430071, China. [5] Department of Respiratory Medicine, Capital Medical University, You'an Men, Fengtai District, Beijing, 100069, China.

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177 **Table 1.** Patient characteristics and environmental test results in temporary COVID-19 ICU wards in Wuhan, China

Patient data						Air and environmental data		
Department	No.	Days of illness when samples were collected	Strategies of respiratory support	SARS-CoV-2 RT-PCR (+)[j] sample types	AGMPs within 1 hours	Sample types and/or sites	RT-PCR of samples[e]	Cycle threshold value[i]
A[a]	1	37	IPPV through tracheostomy tube	Nasopharyngeal swap	Tracheostomy	Air sample[f] surface swab[h]	0/2 1/8	34.7
	2	38	ECMO and IPPV through tracheostomy tube	Nasopharyngeal swap	-	Air sample[g] surface swab	0/1 0/8	-
	3	18	HFNC	Nasopharyngeal swap	HFNC	Air sample[g] surface swab	0/1 0/10	-
	4	48	ECMO and IPPV through tracheostomy tube	Nasopharyngeal swap	-	Air sample[g] surface swab	0/1 0/8	-
	5	46	nasal cannula	Nasopharyngeal swap	-	Air sample[g] surface swab	0/1 0/10	-
B[b]	6	15	HFNC	Nasopharyngeal swap	HFNC Nebulizer treatment	Air sample[g] surface swab	0/1 0/8	-
	7	47	IPPV and ECMO	Nasopharyngeal swap; Anal swap	-	Air sample[g] surface swab	0/1 1/8	30.39
	8	37	IPPV and ECMO	Nasopharyngeal swap	-	Air sample[g] surface swab	0/1 0/8	-
C[c]	9	39	Nasal cannula	Nasopharyngeal swap	-	Air sample[g] surface swab	0/1 0/10	-
	10	38	Nasal cannula	Nasopharyngeal swap	-	Air sample[g]	0/1	-

						surface swab	0/10	
	11	36	Nasal cannula	Nasopharyngeal swap	-	Air sample[g]	0/1	-
						surface swab	0/10	
D[d]	12	26	Nasal cannula	Nasopharyngeal swap	-	Air sample[g]	0/1	-
						surface swab	0/10	
	13	47	NPPV	Nasopharyngeal swap	NPPV	Air sample[g]	0/1	-
						surface swab	0/10	
	14	47	Nasal cannula	Nasopharyngeal swap	-	Air sample[g]	0/1	-
						surface swab	0/10	

[a,b] The wards in department A and B were converted by installing 2 exhaust vent fan s on the window of each ward.

[c,d] The wards in department C and D were converted by installing an exhaust vent fan on the window of each ward.

[e] Data are presented as no. of samples with a positive test result/no. of samples tested.

[f] Two air samples were obtained from the patient's room before and during tracheostomy.

[g] Air samples were collected from each patient's room.

[h] Surface swabs were obtained after tracheostomy.

[i] Cycle threshold refers to the number of cycles required for the fluorescent signal to cross the threshold in RT-PCR; a lower cycle threshold value indicates a higher viral load.

[j] Nasopharyngeal or anal swabs of SARS-CoV-2 tests of all the patients by RT-PCR were positive at the time of sampling.

Abbreviations: COVID-19, coronavirus disease 2019; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2; RT-PCR, reverse transcription polymerase chain reaction; (+), positive result; AGMPs, aerosol-generating medical procedures; IPPV, invasive positive pressure ventilation; ECMO, extracorporeal membrane oxygenation; HFNC, high flow nasal cannula; NPPV, noninvasive positive pressure ventilation; -, no procedures or results.