**The role of the healthcare surface environment in SARS-CoV-2 transmission and potential control measures**

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**Key points:**

The healthcare environment can be contaminated with SARS-CoV-2 and serve as a fomite, leading to possible nosocomial transmission to healthcare personnel or patients. We review the role of the healthcare environment in SARS-CoV-2 transmission and environmental disinfection of SARS-CoV-2.

**Abstract**

The healthcare environment serves as one of the possible routes of transmission of epidemiologically important pathogens, but the role of the contaminated environment on SARS-CoV-2 transmission remains unclear. We reviewed survival, contamination, and transmission of SARS-CoV-2 via environmental surfaces and shared medical devices as well as environmental disinfection of COVID-19 in healthcare settings. Coronaviruses, including SARS-CoV-2, have been demonstrated to survive for hours to days on environmental surfaces depending on experimental conditions. The healthcare environment is frequently contaminated with SARS-CoV-2 RNA in most studies but without evidence of viable virus. Although direct exposure to respiratory droplets is the main transmission route of SARS-CoV-2, the contaminated healthcare environment can potentially result in transmission of SARS-CoV-2 as described with other coronaviruses such as SARS-CoV and MERS-CoV. It is important to improve thoroughness of cleaning/disinfection practice in healthcare facilities and select effective disinfectants to decontaminate inanimate surfaces and shared patient care items.

**Key words:** SARS-CoV-2; COVID-19; healthcare environment; transmission; control measures

## Introduction

As of 1 August 2020, more than 17,000,000 confirmed cases of coronavirus disease 2019 (COVID-19) have been reported worldwide leading to more than 677,000 deaths [1]. In the era of COVID-19 pandemic, healthcare facilities face challenges for infection prevention. Ongoing healthcare-associated transmission of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) in many countries and COVID-19 outbreaks in different healthcare settings have been described [2, 3], which necessitates urgent actions to be taken on infection prevention strategies against COVID-19.

As described in studies on severe acute respiratory syndrome (SARS) and Middle East respiratory syndrome (MERS), person-to-person transmission in COVID-19 occurs mainly via respiratory droplets through close contact with persons infected with SARS-CoV-2 [4]. Viable virus has rarely been demonstrated in feces and there have been no reported cases of COVID-19 acquired via aerosolization of feces. SARS-CoV-2 may also be transmitted via contact with contaminated environmental surfaces followed by self-delivery to eyes, nose, or mouth [4]. The infectious period of SARS-CoV-2 in symptomatic cases with mild to moderate disease ranges from ~2 days before onset of symptoms up to 10 days after onset of symptoms and for patients with more severe disease or immunocompromised for up to 20 days [5]; thus transmission from pre-symptomatic or asymptomatic persons could occur in healthcare settings.

SARS-CoV-2 can survive and persist on environmental surfaces, and, the environmental surfaces in healthcare facilities caring for patients with COVID-19 can be contaminated with SARS-CoV-2 RNA [6, 7]. Over the past decade, there have been increasing evidences that the healthcare environment serves as a mode of transmission of epidemiologically important pathogens in healthcare facilities [8]. However, the role of the contaminated healthcare environment on the transmission of SARS-CoV-2 among patients

and/or healthcare personnel remains unclear but this is not thought to be the main way the virus spreads. The aim of this article was to review survival and contamination of SARS-CoV-2 in the healthcare environment as well as healthcare-associated transmission and infections of SARS-CoV-2 through environmental surfaces and shared medical devices. Based on currently available literature, we also summarized infection prevention strategies against COVID-19 with a focus on environmental disinfection in healthcare settings.

**Survival of SARS-CoV-2 on environmental surfaces**

Survival times for SARS-CoV and MERS-CoV ranged from days to weeks, or even months, depending on experimental conditions such as viral titer and volume of virus applied to surfaces, suspending medium, surface substrates, temperature, and relative humidity [9]. Human coronavirus can remain infectious on different types of inanimate surfaces from 2 hours to 9 days [10]. For instance, human coronavirus strain 229E persisted on inanimate surface materials (e.g., glass, stainless steel, polytetrafluoroethylene, polyvinylchloride, ceramic tiles) at room temperature for at least 5 days [11].

van Doremalen et al. demonstrated that SARS-CoV-2 can be viable on environmental surfaces for 3 days (more stable on plastic and stainless steel ~2-3 days than on cardboard ~24 hours), suggesting that potential transmission of SARS-CoV-2 via fomites may occur [12]. Chin et al. reported that SARS-CoV-2 can be stable in the following environmental conditions: 1) on smooth surfaces (e.g., glass, stainless steel, plastic) at room temperature of 22°C with a relative humidity of 65% for 4-7 days; and 2) in virus transport medium at 4°C for 14 days [13], while Kratzel et al. described no remarkable differences in the stability of SARS-CoV-2 on inanimate surfaces by a carrier test at 4 °C, room temperature, and 30 °C [14]. The amount of $10^7$ viral particles inoculated on a small surface in experimental studies are likely higher than that of virus deposited on surfaces in the real

world of healthcare settings, but there have been no published studies on survival of SARS-CoV-2 in the actual healthcare environment [15].

**Contamination of SARS-CoV-2 on environmental surfaces and medical devices in healthcare settings**

The prolonged survival of SARS-CoV and MERS-CoV on dry environmental surfaces, especially in a suspended status in human secretions, can contaminate touchable surfaces in the healthcare environment [9]. Contamination of the healthcare environmental surfaces and medical devices with SARS-CoV-2 RNA as ascertained by reverse transcription polymerase chain reaction (RT-PCR) has been documented [16-37], including bed rail, bedside table, chair, doorknob, light switches, call bell, sink, floor, toilet seat and bowl, stethoscope, pulse oximetry, blood pressure monitor, electrocardiogram monitor, oxygen regulator, oxygen mask, CT scanner, ventilator, infusion pump, fluid stand, hand sanitizer dispenser, trash can, self-service printers, desktop, keyboard, telephone, pager, and computer mice (Table 1). Overall, the contamination rate of the healthcare environment with SARS-CoV-2 varies from 0-75% (median 12.1%), depending on the status of cleaning/disinfection in environmental sampling rather than the symptomatic status of COVID-19 patients. Environmental studies sampled before cleaning/disinfection reported infrequent to frequent contamination [16, 20, 22, 24-26, 30, 33, 36], while studies sampled after cleaning/disinfection revealed zero to infrequent contamination [17, 20, 23-25, 29, 31, 36].

Ryu et al. reported that the environmental surfaces and medical equipment in intensive care unit (ICU) isolation room occupied by severely ill patients were more contaminated, suggesting that contamination of the nearby healthcare environment can be affected by viral dispersion through frequent oral or endotracheal suction in the ICU [27]. Environmental surfaces in patient care areas, especially the ICU, obstetric isolation wards, and isolation wards caring for COVID-19 patients, and in non-patient care areas as well as

medical equipment and common hospital items were broadly contaminated with SARS-CoV-2 RNA, which raises concerns that contaminated surfaces may lead to contamination of the gloves or hands of healthcare personnel (HCP) [34]. SARS-CoV-2 RNA was detected more frequently on environmental surfaces in medical areas of designated COVID-19 hospitals (24.8%) (e.g., beepers, water machine buttons, elevator buttons, computer mice, telephones, and keyboards, ventilators, monitors, and X-ray machines) than in living quarters (3.6%), suggesting the need for dedicated use of medical devices and strict cleaning/disinfection of shared patient care items [33]. Environmental surfaces in a single room occupied by a COVID-19 patient with mild upper respiratory tract symptoms were extensively contaminated with SARS-CoV-2 RNA prior to cleaning/disinfection (17/28, 61%) except for the air exhaust outlets but surfaces in two rooms occupied by two different COVID-19 patients with moderate severity were negative after cleaning/disinfection [25]. Wei et al. reported that asymptomatic COVID-19 patients can contaminate their environment [32]. The contamination of high-touch surfaces occurred more extensively within the first week of illness than after the first week of illness, and decreased with increasing duration of illness and lower SARS-CoV-2 RNA levels as measured by PCR cycle threshold values [16], which supports previous studies describing the peak of SARS-CoV-2 viral loads and active viral replication in the upper respiratory tract of the COVID-19 patients during the first week [38, 39].

However, other studies have not demonstrated extensive environmental contamination. Colaneri et al. reported that most healthcare environments were negative for SARS-CoV-2 RNA, and that only two environmental samples (2/26, 7.7%) taken from plastic of the continuous positive airway pressure helmet was positive. Further, none of the environmental samples demonstrated viable SARS-CoV-2 [17], suggesting that environmental contamination of SARS-CoV-2 may be less extensive and infectious in real

world conditions than in experimental conditions when cleaning/disinfection of the healthcare environment is implemented effectively. SARS-CoV-2 RNA was not detected on environmental surfaces in clean, semi-contaminated, or contaminated areas of isolation wards after routine cleaning/disinfection, and was positive in sewage samples but was negative by viral culture, which suggests that the routine cleaning/disinfection with chlorine and hand hygiene by HCP is effective and the hospital sewage may not contribute to transmission of this virus [31].

In most studies on environmental contamination of SARS-CoV-2 in healthcare settings, the detection of SARS-CoV-2 was performed using RT-PCR (Table 1). Of four studies tested concurrently by viral culture, viable SARS-CoV-2 was not confirmed from the environmental samples [17, 28, 31, 37]. Santarpia et al. observed the presence of intact SARS-CoV-2 virions by transmission electron microscopy of a windowsill sample after 3 days of cell culture [28]. Although the substantial contamination of the healthcare environment with SARS-CoV-2 RNA has been described, it is likely that detection of SARS-CoV-2 RNA does not represent the presence of viable virus. Further, even the detection of viable virus, does not mean that an infectious dose of SARS-CoV-2 is present [40].

**Transmission and infection of SARS-CoV-2 through environmental surfaces and medical devices in healthcare settings**

Environmental surfaces contaminated with SARS-CoV and MERS-CoV can lead to contamination of HCP hands or medical equipment, then indirect contact transmission via contact with nose, eyes, or mouth or transfer from contaminated hands to patients [9]. Healthcare-associated outbreaks caused by SARS-CoV or MERS-CoV through environmental contamination have been documented [41, 42]. Booth et al. reported that SARS-CoV was detected by RT-PCR but not by viral culture on high-touch surfaces of the healthcare environment (e.g., bed table, television remote control) in SARS outbreak units of

Toronto healthcare facilities, highlighting the need for appropriate respiratory protection as well as enhanced hand hygiene and environmental cleaning/disinfection [42]. Bin et al. described that potential healthcare-associated transmission of MERS-CoV was led by persistent contamination of environmental high-touch surfaces and medical equipment, that was detected by RT-PCR and viral culture in clinical areas caring for MERS patients in South Korea hospitals, and recommended that rigorous infection prevention measures should be taken during recovery after clinical symptoms resolved and patient care items should be cleaned and disinfected thoroughly to prevent cross contamination and further spread [41]. The transmissibility of coronaviruses from contaminated surfaces-to-hands, frequency of coronavirus contamination on hands, contamination level on hands after patient contact or after touching contaminated surfaces, or efficacy of hand hygiene against hand contamination have not been well established [10].

Healthcare-associated transmission, infections, and outbreaks of SARS-CoV-2 among patients and HCP have been documented [2, 3, 43-47]. The risk factors for COVID-19 in HCP comprised lack of awareness in the early phase, deficit of a diagnostic system for SARS-CoV-2, longer work times in high-risk environments, shortages of PPE supply, inappropriate use of PPE, and increased healthcare-, community-, and household-associated exposures [43, 48-50]. Although the transmission mechanism of SARS-CoV-2 in healthcare settings has not been fully elucidated, SARS-CoV-2 can be transmitted via direct and likely indirect contact by touching contaminated surfaces or medical equipment, followed by touching the mouth, nose, or eyes. There have been increasing studies on contamination of the healthcare environment with SARS-CoV-2 RNA but few studies assessed the presence of viable virus. Further, no study has definitely described healthcare-associated transmission and infections via environmental surfaces and medical devices as a fomite.

**Environmental infection prevention against COVID-19**

Although direct exposure to respiratory droplets is a main transmission route of SARS-CoV-2, some investigators have suggested that COVID-19 may be transmitted via aerosols beyond 6 feet [51, 52]. However, the Centers for Disease Control and Prevention (CDC) has not changed their recommended distances for physical distancing of 6 feet [53] after reviewing these concerns. The healthcare environment contaminated with SARS-CoV-2 may also play a role in transmission of SARS-CoV-2. Multiple studies have revealed that environmental surfaces and patient care items have not been properly cleaned and disinfected; therefore, the healthcare environment can be contaminated and result in transmission of multidrug-resistant pathogens, putting the next patient at risk for a pathogen derived from the previous patient [8, 54]. Thus, the environmental surfaces in rooms occupied by patients with COVID-19 and shared patient care items should be regularly and rigorously cleaned and disinfected by well-trained HCP using PPE and appropriate disinfectants with an emerging viral pathogen claim to prevent healthcare-associated transmission of SARS-CoV-2 (Table 2).

Currently, the perfect hospital-grade disinfectants against all pathogens, including SARS-CoV-2, do not exist but, there are a variety of excellent disinfectants [54]. The susceptibility of human coronaviruses, including SARS-CoV, MERS-CoV, and surrogate viruses, to disinfectants and antiseptics has been reviewed [10, 55]. Various hospital-grade disinfectants, including alcohol, hypochlorites, quaternary ammonium compounds, and

accelerated hydrogen peroxide, with appropriate contact time and concentration per the manufacturer's instruction, are basically active against human coronavirus, but the germicidal activities are affected by several factors (e.g., type of environmental surfaces, application of product, organic matter) [9]. Disinfection with 62-71% ethanol or 0.1-0.5% sodium hypochlorite demonstrated inactivation of coronavirus in carrier tests (>3-$\log_{10}$ reduction) within an exposure time of 1 minute, while 0.06% sodium hypochlorite or 0.04% benzalkonium chloride was less effective [10]. Using surface and suspension methodologies per American Society for Testing and Materials (ASTM) and European Standards (ENs), a study on virucidal activity against SARS-CoV-2 demonstrated that the germicidal products tested, which were formulated with ethyl alcohol, quaternary ammonium compounds, or para-chloro-meta-xylenol, achieved ≥4-$\log_{10}$ reduction of infectious virus within a contact time of 1-5 minutes and were effective against SARS-CoV-2 [56].

The CDC recommends that an Environmental Protection Agency (EPA)-registered disinfectant on the EPA's List N that has qualified under emerging viral pathogens program for use against SARS-CoV-2 be chosen for the COVID-19 patient care in healthcare settings [53]. SARS-CoV-2 and other coronaviruses are enveloped viruses with a fragile outer lipid envelope and are more susceptible to germicides, compared with non-enveloped viruses [7]. The EPA-registered hospital-grade disinfectants with an efficacy claim against at least a small or large non-enveloped virus are used against an enveloped emerging viral pathogen, including SARS-CoV-2, since disinfectants inactivating harder to inactivate microorganisms (e.g., non-enveloped viruses, mycobacteria) than coronaviruses are expected to inactivate SARS-CoV-2 [57]. The EPA's List N of disinfectants for use against SARS-CoV-2 are available and has over 450 entries and 30 different active ingredients [58]. Hand sanitizers are regulated by the Food and Drug Administration (FDA), and information on alcohol-based hand sanitizers during the COVID-19 public health emergency are available [59].

The combined approach of practice and product can lead to effective surface cleaning/disinfection as well as removal and inactivation of SARS-CoV-2 on environmental surfaces and medical devices, thereby reducing the risk of nosocomial transmission in hospitalized patients with COVID-19 and healthcare personnel. After air change time required to remove potentially infectious particles has elapsed (e.g., 23 minutes for 99% removal with 12 air changes), terminal cleaning/disinfection of environmental surfaces and shared equipment can be implemented [60]. Non-dedicated and non-disposable medical devices used for COVID-19 patients should be cleaned/disinfected per healthcare facility policies and manufacturer's instructions [53]. The WHO interim guidance recommends that medical and housekeeping staff should follow standard operating procedures regarding responsibility and frequency of cleaning/disinfection by type of environmental surfaces based on COVID-19 patient areas (e.g., at least twice daily cleaning with a focus on high-touch surfaces), and monitor cleaning practices and cleanliness, and be vigilant for environmental cleaning/disinfection of touchable surfaces and patient care items [7].

No-touch methods such as ultraviolet light (UV) devices and hydrogen peroxide (HP) systems have been applied to supplement environmental cleaning and disinfection in healthcare facilities [54]. Multiple experimental and clinical studies have demonstrated germicidal activities of these systems against healthcare-associated pathogens on environmental surfaces and reduction of healthcare-associated infections [61]. Given that the manual cleaning/disinfection is often inadequate, supplemental use of no-touch methods should be considered when patients with coronavirus infection are discharged [9]. The UV-C light disinfection technologies inactivates SARS-CoV and MERS-CoV under controlled laboratory conditions [62]. The upper limit for UV-C radiation median log-reduction dose necessary to inactivate coronavirus, including SARS-CoV and MERS-CoV, but not SARS-CoV-2, as a 90% reduction in low-absorbance media, was 10.6 $mJ/cm^2$ with more precise

estimation of 3.7 mJ/cm$^2$ [63]. An *in vitro* study by Heilingloh et al. demonstrated that the emitted UV-C dose required to completely inactivate SARS-CoV-2 at a concentration of 5 x $10^6$ $TCID_{50}$/ml was 1,048 mJ/cm$^2$ after 9 minutes of exposure [64]. Simmons et al. examined the efficacy of pulsed xenon UV disinfection against SARS-CoV-2 on hard surfaces with viral titer of $10^7$ plaque forming units/ml and achieved 3.5, >4.5, and >4.1 log reductions in viral load for 1, 2, and 5 minutes, respectively [65]. Jerry et al. reported that the contamination level of SARS-CoV-2 RNA in the patient room environment was reduced after terminal clean using chlorine dioxide followed by UV-C disinfection [20].

The UV devices and HP systems are currently available for terminal room cleaning/disinfection but cannot be used when HCP or patients are in the room. As the environmental surfaces can be frequently and repeatedly contaminated with epidemiologically-important pathogens, including SARS-CoV-2, continuous room disinfection would be promising in terms of environmental infection prevention. The continuous disinfection technologies include visible light (400-470 nm), far UV-C (207-222 nm), dilute hydrogen peroxide, self-disinfecting surfaces (e.g., copper, silver), and surface chemical disinfectants with persistence (e.g., organosilane compounds, quaternary ammonium compound-based agents) [66]. However, scientific and clinical evidence of adequate surface disinfection of SARS-CoV-2 and other pathogens (e.g., MRSA) has not been established.

**Conclusions**

The healthcare environment was frequently contaminated with SARS-CoV-2 RNA in most environmental studies of COVID-19 but no evidence of viable virus. Although direct exposure to respiratory droplets (and possibly microdroplets) is a main transmission route of SARS-CoV-2, the healthcare environment contaminated with SARS-CoV-2 likely can result

in transmission of SARS-CoV-2 as described in other coronaviruses such as SARS-CoV and MERS-CoV. To reduce the risk of healthcare-associated transmission of SARS-CoV-2 via the healthcare environment as a fomite, it is essential to improve thoroughness of cleaning/disinfection practice in healthcare facilities and select effective disinfectants to decontaminate environmental inanimate surfaces and shared items used in patients with COVID-19.

## Notes

*Potential conflicts of interest.* Drs. Rutala and Weber are consultants for PDI (Professional Disposable International). Dr. Rutala reports stock/stock options from Kinnos, outside the submitted work.

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Table 1. Contamination of the healthcare environment with SARS-CoV-2.

| Author, Country | COVID-19 patients status | Hospital areas sampled | Cleaning and disinfection practice | Environmental sampling situation | Environmental sampling and SARS-CoV-2 detection method(s) | Type of healthcare environment positive for SARS-CoV-2 | Contamination rate |
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| Chia, Singapore [16] | Symptomatic and asymptomatic cases | Airborne infection isolation rooms in ICU and general ward. | High-touch surfaces were disinfected twice daily with 5000 ppm sodium of dichloroisocyanurate. | In the morning before cleaning, samples collected from various surfaces, including high-touch surfaces. Concentration of virus highest in week of illness. | Premoistened macrofoam sterile swab, RT-PCR | Floor, air exhaust vent, bed rail, bedside locker, cardiac table, electric switch, chair, toilet seat, automatic toilet flush button | Contamination rate highest for floor 65%, followed by air exhaust vent 60%, bed rail 59% and bedside locker handle 47% |
| Colaneri, Italy [17] | Patients with respiratory symptoms receiving CPAP | Infectious disease emergency unit, infectious disease sub-intensive care ward that allows advanced respiratory care | Twice-daily cleaning (morning and afternoon) was conducted using sodium hypochlorite at a concentration of 1000 ppm on a daily basis and 5000 ppm after discharge | Approximately 4 hours after cleaning, samples collected from various surfaces in potentially contaminated areas | Flocked swabs premoistened with universal transport medium, RT-PCR and viral culture | Plastic of CPAP helmet close to the patient's airways | Contamination rate7.7% (2/26). No virus cultured. |
| Colaneri, Italy [18 | Pneumonia patients treated with CPAP or high flux oxygen | National SARS-CoV-2 referral center, Infectious Diseases ward | Cleaning was conducted using sodium hypochlorite at a concentration of 1000 ppm on a daily basis and 5000 ppm after discharge | Samples collected from inanimate surfaces at high risk of contamination inside the ID wards | Nylon flocked premoistened swabs and universal | No SARS-CoV-2 RNA detected from inanimate surfaces tested | Contamination rate 0% (0/16) |

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| ] | | | | | transport medium, RT-PCR | | |
| Guo, China [19] | Severe cases in ICU and mild cases in general ward | ICU and general ward of COVID-19 | NA | Samples collected in a hospital operating at full capacity in an outbreak region | Sterile premoistened swab, RT-PCR | Objects (floors, computer mice, trash cans, sickbed handrails), indoor air and the air outlets | Contamination rate 26.5% (63/238): ICU 43.5% (54/124), general ward 7.9% (9/114). Objects: floors (ICU 70%, 7/10), computer mice (ICU 75%, 6/8; general ward 20%, 1/5), trashcans (ICU, 60%, 3/5); sickbed handrails (ICU 42.9%, 6/14; general wards 0%, 0/12). |
| Jerry, Ireland [20] | Symptomatic cases | Clinical areas of COVID-19, including emergency department and ICU | Patient rooms were cleaned once per day and nurses' station areas twice. Room surfaces were cleaned using a chlorine dioxide agent once daily and after discharge followed by UVC disinfection. | Before and after terminal cleaning/disinfection, samples collected from a confirmed COVID-19 patient room, an empty patient room following terminal cleaning and UVC disinfection, and nurses' station of wards with COVID-19 patients | Flocked swabs and universal viral transport medium, RT-PCR | Bed remote controller, bed rail and side table, call bell, patient chair arm, and telephone | Contamination rate 42.3% (11/26) in COVID-19 patient area, 3.3% (1/30) in nurse stations, and 4% (1/25) in patient room after terminal cleaning |
| Jiang, China [21] | NA | Nurse stations | NA | Samples collected from surfaces of nurse stations and belongings of confirmed COVID-19 patients | Swabs, RT-PCR | All tested surfaces of nurse stations, nurse rolling carts and the water cups were negative except one from a mobile phone of patient. | Contamination rate 0% (0/5) |
| Lei, China [22] | Severe and critical cases | ICU and isolation ward | ICU floor was disinfected with chlorine-containing disinfectant twice a day at 11am and 3pm. Furniture and equipment were disinfected with chlorine-containing disinfectant once a day at 11am. | Samples collected between 8am and 11am from common areas and surrounding areas of patients who were hospitalized for weeks after initial diagnosis and clinically improved | Sterile flocked swabs and viral transport medium, RT-PCR | In ICU, floor close to patient head, bed rail, patient's clothing, bed sheet, control panel of ventilator, and ventilator outlet valve. In isolation ward, floor, bed rail, bedside table, patient's mobile phone, bed sheet, patient's facemask, and TV remote control in patient rooms; toilet, bathroom door handle, and faucet handles on sink in | Contamination rate 0.5% (1/218) in ICU; 4.9% (9/182) in isolation ward (both environmental and air samples) |

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| | | | | | | bathrooms. | |
| Li, China [23] | Severe ill and critical cases | A designated hospital, including ICU | Twice-daily cleaning of surfaces with 500 mg/L sodium dichloroisocyanurate and floors with 1000 mg/L sodium dichloroisocyanurate | 1 hour after routine cleaning on three separate days, samples collected from inside and outside isolation ward, including high-risk, medium-risk, and low-risk areas | Swabs moistened by saline, RT-PCR | All environmental surfaces tested except two samples from a COVID-19 patient's mask were negative. | Contamination rate 0% (0/69) on environmental surfaces |
| Liang En Ian, Singapore [24] | Symptomatic mild-severe cases. The majority of cases had pneumonia, including patients who required supplemental oxygen and mechanical ventilation. | Cohorted respiratory surveillance wards | Cleaning/disinfection were conducted using 1000 ppm sodium hypochlorite with wards and toilets being cleaned 3 times a day. | Before and after terminal cleaning, samples collected from high-touch areas in patient's vicinity and toilet facilities | Sterile premoistened swab, RT-PCR | Patient's call bell, foot and cot side of bed, bedside table, toilet bowl, bathroom drain | Contamination rate 2.2% (10/445) from high-touch areas in immediate vicinity of the patients (mainly requiring supplemental oxygen) before terminal cleaning. Contamination rate 0% after terminal cleaning. |
| Ong, Singapore [25] | Mildly symptomatic cases | Airborne isolation room | Twice daily cleaning with 5000 ppm sodium dichloroisocyanuarte | Before and after cleaning/disinfection, samples collected on 5 days over a 2-week period | Sterile premoistened swab, RT-PCR | Patient room sites (cardiac table, bed rail, locker with hand slot, chair, light switches, stethoscope, sink, floor, glass window and door, PPE storage area over sink, air outlet fans), toilet sites (toilet bowl, sink, door handle) | 87% (13/15) of room samples and environmental samples positive before routine disinfection 61% (17/28). Samples negative after routine disinfection. |
| Razzini, Italy [26] | Patients intubated and supported by a respirator and a patient not intubated and without CPAP nasal mask | COVID-19 ward, including an intensive care unit | Surface and objects were wiped daily using active chlorine (5–10%) disinfectant. | Before disinfection operations, samples collected from contaminated, semi-contaminated, and clean areas | Sterile premoistened swabs and virus preservation solution, | Bedrails, benches, computer keyboards, door handles, glove boxes, hand sanitizer dispensers, medical equipment, touch screens, shelves for medical equipment, staff lockers, walls, waste containers, water taps, and windows | Overall contamination rate 24.3% (9/37); contaminated (35%, 7/20); ICU 41.7% (5/12), semi-contaminated areas 50% (2/4), and clean area 0% (0/13). Medical equipment 66.7% (2/3), touch screens 50% (1/2), shelves 40% (2/5), door handles 33.3% (1/3), |

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| | support | | | | RT-PCR | | bedrails 33.3% (1/3). |
| Ryu, Korea [27] | Asymptomatic to severely symptomatic cases in well-equipped isolation rooms, asymptomatic cases in common hospital rooms | Well-equipped isolation rooms, common hospital rooms | Disinfection with 0.1% hypochlorite was not performed daily | 1-184 hours from the last room cleaning/disinfection, samples collected at different single time points in hospitals receiving patients with various severities | Dacron swab premoistened and viral transport medium, RT-PCR | Ambu bag, infusion pump, pillow, patient monitor, ceiling air exhaust damper, fluid stand, head of the bed, TV; floor center, toilet seat, side rail of bed | Contamination rate 16.5% (13/79): hospital A 17.5% (10/57); hospital B was 13.6% (3/22) |
| Santarpia, USA [28] | Mildly ill cases | Nebraska Biocontainment Unit hospital and National Quarantine Unit residential isolation rooms | Frequent environmental cleaning performed | Samples collected in quarantine rooms on days 5-10 | Sterile gauze pads moistened with phosphate buffered saline, RT-PCR and viral culture | Room surfaces (ventilation grates, window ledges, bed rails, bedside tables, floors under bed), personal items (cellular phones, exercise equipment, television remotes, medical equipment), and toilets (rim of the bowl) | Contamination rate 75% on room surfaces and 70.6% on personal items. No virus cultured, but presence of replication competent virus confirmed from a windowsill sample. |
| Shin, Korea [29] | Asymptomatic cases with persistently high viral loads | Isolation room | Patient room and bathroom were cleaned weekly | Samples collected from surfaces of surrounding environment 41 days after initial diagnosis, cleaning conducted 4 days before environmental sampling | Sterile swabs moistened with distilled water and viral transport medium, RT-PCR | No SARS-CoV-2 RNA detected from environmental surfaces tested; mobile phones, tablet, bedside tables, bed rail, bed call bell, wall panel/door handle, floor, and sink/toilet bowl | Contamination rate 0% (0/12) |
| Su, Taiwan | Moderate-severe cases | Negative pressure isolation room in ICU or ordinary | Disinfected daily with 1:10 dilution of 5% sodium hypochlorite. | Before routine cleaning on the same dates as patient sampling, samples collected | Sterile throat swabs and viral | Ventilator tubing before heat and moisture exchange filter | Contamination rate 1.4% (2/144) |

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| [30] | | ward | | from various surfaces | transport medium, RT-PCR | | |
| Wang, China [31] | Severely ill cases | Isolation ICU ward and Isolation wards | Surfaces of objects were routinely wiped using 1000 mg/L chlorine containing disinfectant every 4 h in ICU ward and every 8 h in general wards. | About 4 hours after cleaning/disinfection, samples collected from surfaces in clean area, semi-contaminated area, and contaminated area | Swab and universal transport medium, RT-PCR and viral culture | No SARS-CoV-2 RNA detected from environmental surfaces tested | Contamination rate 0% (0/36). No virus cultured. |
| Wei, China [32] | Asymptomatic and mild symptomatic cases | Negative-pressure rooms with toilets in a dedicated non-ICU isolation ward | Patient rooms and toilets were cleaned and disinfected twice daily using a 2000 mg/L chlorine solution | 4 to 7 hours after the first daily cleaning, samples collected from high-touch surfaces and floor in patient rooms | Sterile swabs premoistened with viral transportation solution, RT-PCR | Bedrails, room and toilet door handles, light switches, foot flush buttons, sink rims, sink and toilet bowls and drains, bedside tables, bedsheets, pillows, equipment belts on walls, floors, and air exhaust outlets. | Contamination rate 39.3% (44/112); bedrails 53.9%, pillows 50%, bedsheets 50%, air exhaust outlets 50%, and light switches 40% |
| Wu, China [33] | NA | In designated COVID-19 hospitals, medical area with moderate and high-risk regions (patient's room, nurse station, buffer room for taking off PPE) and living quarters | Chlorine-based disinfectants twice daily | Before routine cleaning and disinfection, samples collected from environmental surfaces frequently touched by patients or healthcare personnel | Premoistened flocked swab and viral transport medium, RT-PCR | In medical areas, keyboards, computer mice, beepers, bedside tables, bedrails, medical equipment (ventilators, monitors), water machine buttons, elevator buttons. In living quarters, telephones and desktop | Contamination rate 24.8% (36/145) in medical areas and 3.4% in living quarters. In medical areas, keyboards 33%, computer mice 40%, beepers 50%, bedside tables 14%, bedrails 14%, medical equipment (ventilators, monitors monitors, and X-ray devices) 31%, water machine buttons 50%, elevator buttons 43%. |
| Ye, China [34] | Multiple symptoms and severity | Hospital function zones (ICU, obstetric isolation ward, isolation ward, emergency | Environmental cleaning protocols were extensive | Samples collected while the outbreak was ongoing | Dacron swabs premoistened with cell preservati | Common hospital items (self-service printers, desktops, keyboards, telephones), surfaces (doorknobs, walls, floors), hospital equipment (pulse oximetry, electrocardiogram monitors, oxygen cylinders, oxygen regulators, | Environmental samples positive 13.6% (85/626); highest rate in ICU 31.9% (22/69). Contamination rate for hospital objects 13.9% (60/431). |

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| | | department) | | | on solution, RT-PCR | oxygen masks, CT scanner, centrifuge, biosafety cabinet, ventilator, hand sanitizer dispensers) | |
| Yung, Singapore [35] | Asymptomatic cases | Isolation room | NA | Samples collected on day 2 of admission when the COVID-19 patient had a high viral load | Synthetic fiber flocked swabs and universal transport medium, RT-PCR | Infant's bed, cot rail, table | All 3 environmental samples (bed, cot rail, table) positive. |
| Zhou, China [36] | NA | Isolation wards of COVID-19 patients | Surfaces of objects were wiped with 1000 mg/L chlorine-containing disinfectants or tissues containing peroxyacetic acid and hydrogen peroxide. Surfaces contaminated by secretions were wiped with disposable absorbent material (gauze, dishcloth) with 5000 mg/L chlorine-containing disinfectants. | Before and after disinfection, samples collected from 28th day after discharge of COVID-19 patients | RT-PCR | Surfaces of pagers and drawers before disinfection. All surfaces and objects tested negative after disinfection. | Contamination rate 52.3% (114/218) of surfaces. |
| Zhou, UK [37] | Severe cases | Clinical areas of emergency department, admissions ward, cohort wards, theatres, ICU, negative pressure area, and public area of hospital | All surface areas were disinfected daily with twice daily disinfection of high-touch surfaces using a combined chlorine-based detergent/disinfectant | Samples collected during three tracheostomy procedures in the peak of COVID-19 pandemic | Flocked swabs and Dulbeccos's minimal essential medium, RT-PCR and viral culture | High-touch surfaces, including bed rails, clinical monitoring devices (blood pressure monitors), telephones, computer keyboards, clinical equipment (syringe pumps, urinary catheters), hand-cleaning facilities (hand washing basins, alcohol gel dispensers). | Contamination rate 10.6% (23/218). No virus cultured. |

Abbreviations: COVID-19, coronavirus disease 2019; CPAP, continuous positive airway pressure; ICU, intensive care unit; NA, not applicable; PPE, personal protective equipment; RT-PCR, reverse transcription polymerase chain reaction; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2; UVC, ultraviolet C.

Table 2. Recommendation for cleaning and disinfection of noncritical environmental surfaces and medical devices in rooms occupied by known or suspected COVID-19 patients.

- Standardize cleaning/disinfection of environmental surfaces and medical devices in rooms occupied by COVID-19 patients.
- Follow CDC recommendation for letting room remain empty regardless of PPE after discharge for the specified time period.
- Provide education and training for cleaning/disinfecting staff on proper donning and doffing of PPE as recommended by CDC.
- Use an EPA-registered disinfectant on the List N that has qualified under emerging viral pathogens program for use against SARS-CoV-2.
- All noncritical touchable surfaces and medical devices should be cleaned/disinfected at least once daily and when visibly soiled.
- Assess cleaning thoroughness with a validation method (e.g., fluorescent dye markers).
- Provide regular feedback to environmental services personnel on the thoroughness of cleaning.
- Comply with the manufacturer's treatment time/contact time/kill time for wipes and liquid disinfectants.
- Consider no-touch methods (e.g., ultraviolet devices) when available as an adjunct to chemical disinfection for terminal disinfection as data demonstrate reduction of microbial contamination and colonization/infection due to epidemiologically-important pathogens despite less clinical evidence on inactivation of SARS-CoV-2.
- No recommendation for using a method of continuous room disinfection as there is insufficient evidence of effectiveness.

Abbreviation: CDC, Centers for Disease Control and Prevention; COVID-19, coronavirus disease 2019; EPA, Environmental Protection Agency; PPE, personal protective equipment; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2.