

Contamination of personal protective equipment and environmental surfaces in Fangcang shelter hospitals

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## Highlights

- Fangcang shelter hospital HCWs are under risk of hospital infection
- SARS-CoV-2 contamination is extensive on PPE and environmental surfaces
- Viral RNA positivity is most extensive in patient occupied areas
- Potentially contaminated areas and surfaces after cleaning are all negative

Journal Pre-proof

Contamination of personal protective equipment and environmental surfaces in Fangcang  
shelter hospitals

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The authors have no conflicts of interest to declare.

**Abstract**

**Background:** Fangcang shelter hospitals emerged as a new public health concept after

COVID-19. Data regarding contamination of Fangcang shelter environments remains scarce.

This study aims to investigate the extent of SARS-CoV-2 contamination on personal protective equipment and surfaces in Fangcang hospitals.

**Methods:** Between March and May 2022, during wave of omicron variant, a prospective study was conducted in two Fangcang hospitals in Shanghai, China. Swabs of personal protective equipment worn and environmental surfaces of contaminated areas, doffing rooms, and potentially contaminated areas were collected. SARS-CoV-2 RNA was detected by reverse transcription quantitative polymerase chain reaction. If viral RNA was detected, sampling was repeated after cleaning and disinfection.

**Results:** A total of 602 samples were collected. 13.3% of the personal protective equipment were contaminated. Positive rate was higher in the contaminated areas (48.4%) than in the doffing rooms (11.7%) and the potentially contaminated areas (0;  $P < 0.05$ ). Contamination was highest in patient occupied areas 67.5%. After cleaning, samples taken at previously contaminated surfaces are all negative.

**Conclusions:** SARS-CoV-2 RNA contamination is prevalent in Fangcang hospitals and healthcare workers are under risk of infection. Potentially contaminated areas and surfaces after cleaning and disinfection are negative, underlying the importance of infection control policy.

**Key words:** SARS-CoV-2; Omicron variant; environmental contamination; personal protective equipment; Fangcang shelter hospital

## Background

The severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) is mainly transmitted by directly inhaling virus carrying droplets or aerosols(1-3). Contact of respiratory secretions or contaminated surfaces by hand and then touching mucous membranes such as eyes, mouth and nose may also lead to infection. Viruses can be detected from non-respiratory specimens such as feces as well(4). There were reports of viral spread through sewage systems in the form of aerosols, resulting in outbreaks in buildings with poor sanitary conditions and in densely populated communities(5, 6). SARS-CoV-2 may remain viable on skin for up to 96 hours at room temperature and lower temperature further enhances its stability(7). At 20 °C, viable viruses can be isolated from surfaces of common objects such as glass, steel, and banknotes for up to 28 days. However, infectious viruses survive for less than 24 hours on some materials at 40 °C (8). Research showed that viral RNA may be detected from various personal protective equipment (PPE) materials for up to 5-30 days, and contaminated PPE remain infectious in 5-7 days(9). Another study continuous investigated viable viruses on different PPE materials, including medical examination gloves, N-95 and N-100 respirators, plastics, cotton, and stainless steel, and argues that SARS-CoV-2 could be recovered for up to 21 days in the presence of fomite(10).

On November 26, 2021, WHO designated the B.1.1.529 variant as a variant of concern (VOC) (11). The variant, named Omicron, is a highly divergent strain with large number of mutations, including 26-32 mutations in the spike protein, some of which are related to the humoral immunity escape potential and enhanced transmission. Survival time of the variant on plastic and on skin is about twice that of the Wuhan strain(12). Although risk of severe illness

and death after infection is lower than the previous variants, the extremely high transmissibility leads to a significant increase in the number of inpatients, and may continue to pose great pressure on health systems(11, 13). In March 2022, the Omicron wave of the pandemic broke out in Shanghai and reached 56948 by May 31, 2022(14). To minimize severe cases in the vulnerable groups such as unvaccinated elderly, the city started building quarantine centers and Fangcang shelter hospitals in March 2022(15). Fangcang hospital is a new public health concept generated after the emergence of COVID-19 since 2020. The core value is to isolate non severe cases at an early stage to reduce transmission in households and communities and proves to be a powerful response to the COVID-19 pandemic in China (16, 17).

Understanding transmission mechanism and occupational exposure assessment can help with risk stratification, which is essential for determining appropriate infection prevention and control measures and ensuring safety of healthcare workers (HCW). A study found that during the autopsies of confirmed COVID-19 cases, 82% of PPE worn was contaminated by viral RNA, and 27% was contaminated by infectious virus, representing potential risk for autopsy staff at work(18). Several studies proved that SARS-CoV-2 may transmit in hospital settings through a variety of routes, and contamination is extensive on surfaces and in air (19-23). However, researches were conducted mostly in acute care hospitals and designated wards for COVID-19 patients. Data regarding Fangcang shelter hospitals remains scarce. In order to fill this gap, this current cross-sectional study prospectively investigated the SAR-CoV-2 contamination of PPE worn by staff and various environmental surfaces of two Fangcang hospitals in Shanghai, China. We present the following article in accordance with the STROBE reporting checklist.

## Material and Methods

### Research design

Between March and May 2022, during the Omicron wave of the pandemic, a prospective, observational, cross-sectional study was conducted in two Fangcang shelter hospitals in Shanghai, China. The hospitals were converted from an empty campus site and an art exhibition center, which could contain a maximum of 500 and 1500 patients, respectively. Audio and video monitoring of the donning and doffing rooms were routinely practiced. During the study period, HCWs worked and lived “closed looped” according to policy with minimal cross infection possibility. The “closed looped” strategies are administrative measures bundles adopted in higher risk settings. For Fangcang hospitals, they included: Only specified personnel are allowed to enter designated areas. During their service period, HCWs are under medical observations. Staff mobility is restricted and recorded.

Sampling of PPE, skin, and environmental surfaces of various areas were taken by swabs after shifts/ ward rounds. Healthcare workers included staff members who worked shifts inside contaminated areas of Fangcang hospitals. Their identity and time spent inside were recorded. Surfaces sampled included patient occupied areas, public areas inside the contaminated areas, doffing rooms, and potentially contaminated office and living areas. Sampling of environmental surfaces took place about 5hours after the previous round of cleaning/disinfection.

One swab covering 100cm<sup>2</sup> surface area was taken for each sample site, or adjusted according to shape. Each swab was contained in one sampling tube. After the initial sampling and PCR tests, swabs of contaminated surfaces were recollected for testing after routine

cleaning and disinfection. Only results of the first samplings were counted in the calculation of contamination rates.

### **Sampling objects**

#### PPE and skin surfaces

Two individuals from each work group, including administrations, clinicians, nurses, cleaners, and securities that worked shifts inside the contaminated areas were investigated. Eleven samples from various PPE surfaces and 1 sample of human skin surface were taken from each person. At the entrance of the first doffing rooms (DR1), swabs of face shield, bilateral coverall sleeves, coverall chest area, coverall cap (head and neck), outer layer of gloves, and outer shoe covers were taken. In the second doffing rooms (DR2), swabs of N-95 respirators, inner gloves, inner shoe covers, scrub suit tops, scrub suit trousers, and skin of face, neck and hands of the workers were taken.

#### Environmental surfaces

Contaminated areas: Samples of frequently touched objects including bedside tables, bed rails, beddings, chairs, and floors were taken in patient occupied areas. In public areas, nurse station desks, nurse station computers, hospital admission desks, water dispensers, waste bins, and toilets were sampled. Doffing rooms: Door handles, desktops, walls, mirrors, waste bins, and floors of the first and second doffing rooms were sampled respectively. Potentially contaminated areas: Frequently touched surfaces of the HCW's office and living areas outside the contaminated areas are sampled. They included office spaces, dining rooms, public spaces, living areas, storages, hotel rooms, and shuttle buses.

### **Sample transfer and laboratory methods**

After collection of swabs, the samples are immediately transferred to a reference BSL-3 laboratory and processed. Samples were tested with Polymerase Chain Reaction (PCR) - Fluorescence Probing methods using Novel Coronavirus Nucleic Acid Detection Kit (BioGerm, Shanghai, China), targeting the ORF1ab and N genes to detect SARS-CoV-2 in the samples. Quantification of the viral load were estimated by the cycle threshold (Ct) value. Ct values are inversely correlated to viral loads. In this study, a sample was defined as positive if CT value for both ORF1ab and N genes are  $\leq 38$ .

### **Surface cleaning and disinfection regimen**

Tasks were executed by trained cleaning teams. When no visible fomite is present, frequently touched surfaces inside the contaminated and potentially contaminated areas were cleaned twice daily using 1000mg/L available chlorine containing disinfectant, or wiped using 3% hydrogen peroxide disinfection wipes. When large amount of fomite is present, the fomite is first covered by dry paper towel and soaked in 5000mg/L chlorine disinfectant, removed carefully, and then cleaned as usual. Doffing rooms are cleaned after every 6-hour shift using 1000mg/L chlorine containing disinfectant, or 3% hydrogen peroxide disinfection wipes, and then ultraviolet lamps were turned on for 30 minutes.

### **Statistics**

Descriptive statistics was used to represent data as numbers and percentages. Differences in the contamination rates between the areas were compared by Pearson's chi squared test. SPSS version 25 (IBM, SPSS Inc., Chicago, Illinois, USA) and GraphPad Prism 8.0 (GraphPad software company, San Diego, USA) were used for statistical analysis.  $P < 0.05$  was considered statistically significant.

## Results

### PPE and skin contamination

A total of 120 PPE and skin samples were collected. Except for administrative staff and clinicians, regular shifts inside the contaminated areas were 6-hour long. Before swabbing the surfaces, the average time spent in the cabin was 290 (240-350) mins (Table 1). The overall viral RNA positive rate was 13.3% (16/120), with 13.6% (15/110) and 10.0% (1/10) for PPE surfaces and human skin, respectively. Among them, detection rate was highest for outer shoe cover (7, 70.0%), face shield (2, 20.0%), and coverall (2, 20.0%). None of the outer layer of gloves, N-95 respirators, scrub suit tops or trousers were positive (Figure 1). The overall contamination rate was 21.7% (13/60) on PPE surfaces before entering the first doffing room and 5.0% (3/60) on PPE or skin when inside the second doffing room. Average Ct values of PPE and skin surfaces positive was  $37.84 \pm 2.02$  (Figure 2). Except for 1 pair of outer shoe cover and 1 coverall cap, Ct values were all  $>35$ .

Figure 1. Contamination rate of SARS-CoV-2 on PPE surfaces and human skin.

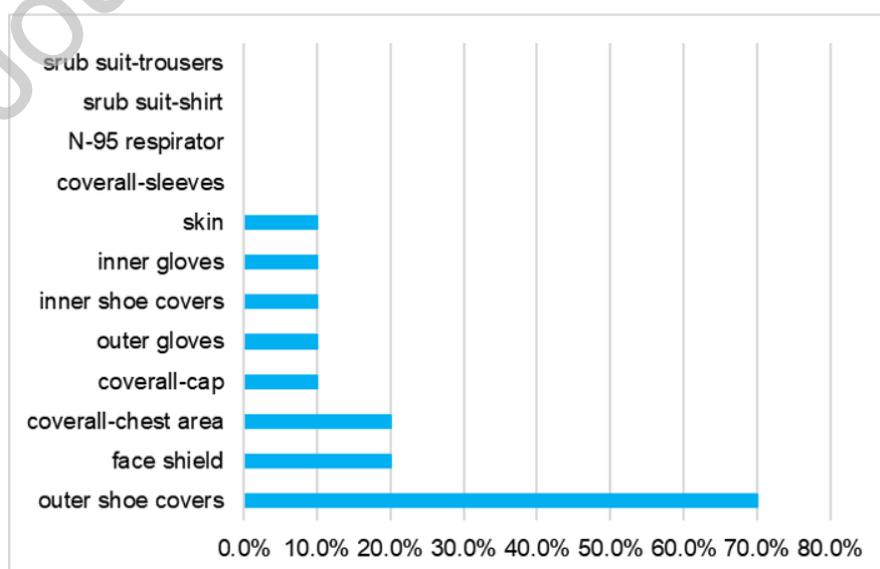


Figure 2. CT values of SARS-CoV-2 RNA on PPE, contaminated areas, and doffing rooms.

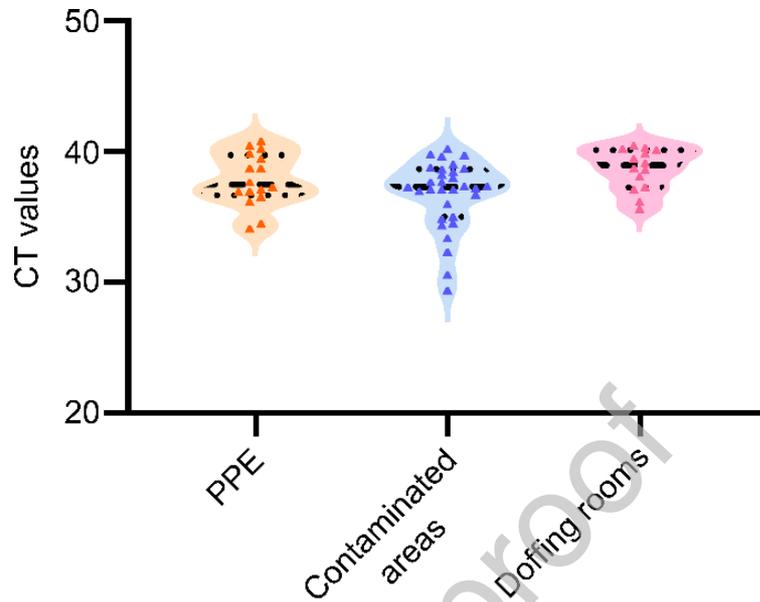


Table 1. Healthcare workers investigated, average time spent in the contaminated areas, and PPE contamination rate.

Healthcare worker	Time (min)	Sample (N)	Positive sample (N)	Positive rate (%)
administration	235	24	1	4.2
clinician	240	24	1	4.2
nurse	350	24	2	8.3
cleaner	340	24	3	12.5
security	345	24	9	37.5

Except for one administrative staff and one clinician, 80% of the HCWs sampled had at least one surface tested positive for virus RNA. The HCW with the most contamination tested positive for 41.7% (5/12) of the samples. Among different HCWs, PPE worn by security guards

(9/24, 37.5%) and cleaners (3/24, 12.5%) were most contaminated, while those worn by clinicians and administrators (both 1/24, 4.2%) were least contaminated.

### **Environmental surfaces**

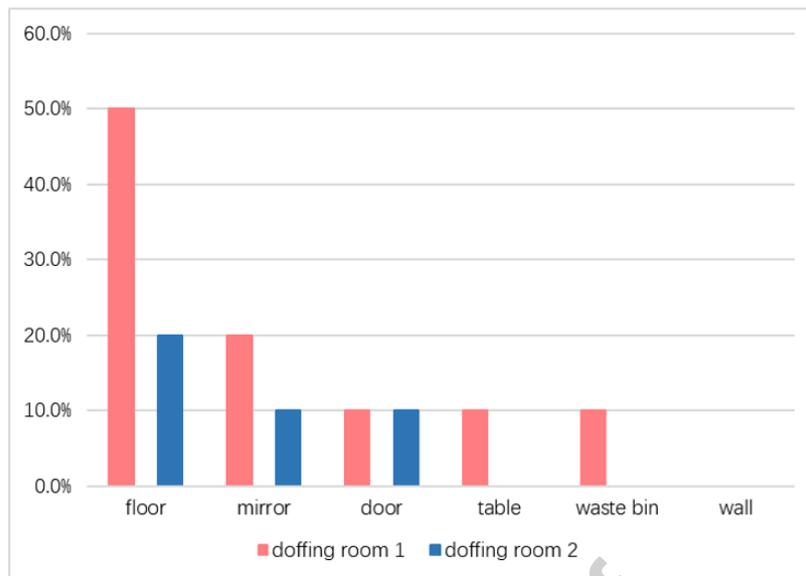
#### Contaminated areas

64 samples were collected inside the contaminated areas, overall contamination rate was 48.4%. Positive rates were 67.5% (27/40) in the patient occupied areas and 16.7% (4/24) in the public areas. Surfaces with the highest rate of contamination were bedrails (100.0%, 8/8), bedside floor (87.5%, 7/8), and chairs (75.0%, 6/8). The average CT value of was  $36.75 \pm 2.62$  (Figure 2). 22.6% (7/31) of the samples had Ct values  $<35$ . After cleaning and disinfection, resampling at the previously positive sites were all negative.

#### Doffing rooms

120 environmental samples were collected from doffing rooms with an overall positive rate of 11.7%. Contamination rate of the first and second doffing rooms were 16.7% (10/60) and 6.7% (4/60) respectively (Figure 3). The highest percentage of viral RNA was found on the DR1 floor (50.0%, 5/10), the DR1 mirror (20.0%, 2/10), and the door handle entering DR2 (20.0%, 2/10). The average CT value of SARS-CoV-2 was  $38.65 \pm 1.59$  (Figure 2). All the Ct values were  $>35$ . After cleaning and disinfection, resampling at the previously positive sites were all negative.

Figure 3. Contamination rate of SARS-CoV-2 on doffing room environmental surfaces.



#### Potentially contaminated areas

302 samples were collected, including 117 from office rooms, 103 from public spaces, 26 from rest areas, 26 from shuttle buses, and 30 from hotels. All samples were negative for viral RNA.

#### Discussion

This current study analyzed contamination of SARS-CoV-2 on PPE and Fangcang hospital environmental surfaces, which has rarely been investigated. Results show that SARS-CoV-2 contaminates PPE as well as the surfaces of contamination and doffing areas. Contaminated areas where confirmed cases were staying have higher detection rates than doffing rooms (48.4% vs 11.7%,  $P < 0.05$ ). None of the surfaces in the potentially contaminated area was positive. After routine cleaning and disinfection, no viral RNA was detected in the repeat test.

Healthcare workers are at the frontline in the fight against pandemics, hence bearing higher burden of infection. A meta-analysis showed that based on RT-PCR, the prevalence of

COVID-19 in HCW was 11.0%. Severe complications occurred in 5% of HCWs infected and 0.5% died. Inpatient/ non-emergency ward staff and nurses are the most affected(24). Another analysis showed that, in the first six months of the pandemic, 15.1% of HCW with COVID-19 required hospitalization and mortality rate was 1.5%(25). According to an investigation among Wuhan HCW who were infected early in the pandemic, the perceived route of infection and influencing factors were lack of PPE, close contact with patients, and inadequate protection during those contacts(26). Meta analysis showed that working in high-risk settings, contact with infected patients, lacking in awareness, and inadequate protective measures are all risk factors for HCW hospital infections(25). Different from a previous study(27) done in a non-ICU ward for patients with prolonged PCR positive status, where no PPE contamination was found, the overall PPE contamination in this current study was 13.3%, and up to 80% of the HCW had at least one PPE contamination. Furthermore, after taking off the PPE, up to 90% of the doffing rooms were at least contaminated in one surface. Our findings underline the potential for hospital infection in Fangcang HCW and highlights the importance of appropriate infection control measures.

The presence and concentration of SARS-CoV-2 in air and frequently touched surfaces correlate with date of onset and nasopharyngeal viral load of COVID-19 patients, and viral contamination is highest where infected cases are located and frequently touched(19, 28). Different healthcare settings and different places in the same institution have different contamination rates. During the pandemic in 2020, Zhou *et al.* sampled the environment of a large teaching hospital in London and found that 52.3% of the surfaces tested were positive for viral RNA, with >80% of the computer keyboard/ mouse, alcohol rub dispenser, and chairs

contaminated(19). Razzini *et al.* Investigated SARS-CoV-2 RNA contamination in different parts of a hospital in Milan, Italy(19). 100% of the air sampled in ICU were positive, while air in the doffing room or clean areas were all negative; The positive rate in contaminated area (35.0%) and doffing room (50.0%) was higher than that in the clean area (0.0%). A study conducted in Hunan, China detected SARS-CoV-2 in 82.6% and 7.7% of the ICUs and wards in designated hospitals, respectively(29). Positive rate of SARS-CoV-2 on the environmental surface of Wuhan Leishenshan hospital, an Fangcang hospital, was only 3.03%(30), far lower than that of other hospitals. Interestingly, when a concept of directly-observed environmental decontamination was adopted, there was zero environmental contamination in Hong Kong's community treatment facility(31). The current study employed similar surface sampling methods as most studies(32), and results show that contamination is highest in patient occupied areas, and followed by public areas inside the Fangcang and doffing rooms, while potentially contaminated areas are not contaminated. Our findings are consistent with the trends reported in the literature. Although contamination of inanimate surfaces around the patients was high, the overall positive rates of PPE was not as high. It may be because patients admitted into Fangcang shelter hospitals do not require any invasive aerosol generating procedures, and that HCW shift duration was strictly limited to no more than 6 hours.

SARS-CoV-2 can spread through aerosol and multiple routes in hospitals(33)(34). Chia *et al.* Sampled the air of three air borne infection isolation room (AIIRs) in the national center for infectious diseases in Singapore. Results show that although these rooms had 12 air changes per hour, viral particles with sizes  $>4\mu\text{m}$  and  $1\sim 4\mu\text{m}$  were still detected in two of the rooms(21).

In our study, since none of the N95 respirator, scrub suit, or environmental surface in the potentially contaminated areas tested positive for viral RNA, the explanation for the only one positive skin sample was likely due to contamination during the worker's doffing process inside the second doffing room. However, it is worth noting that detection of viral RNA from surfaces does not represent infectivity, and infection through contact with the contaminated surfaces or fomite is not as widespread as previously thought. Colaneri *et al.* sampled 26 high-risk objects in the emergency room and sub-intensive care unit of a hospital in Italy. 2 of the samples detected low-level viral RNA from positive pressure helmets, but no virus was grown after 7 days of culture(35). Another study with a much larger size, which collected 218 air and surface samples, showed that although viral RNA was detected in 52.3% of the surfaces and 38.7% of the air samples, CT values of all samples were  $>30$ , and viral cultures were all negative(19). Zhang *et al.* analyzed the SAR-CoV-2 load in a university's buildings and buses in the United States and risk of infection among the exposed population. It was suggested that for non-medical settings, inhalation is the main route of transmission when compared with contacting surfaces. According to its risk modeling, infection probability is estimated to be 1 in 100 exposures to virus carrying aerosol and as high as 1 in 100000 exposures by contacting contaminated surfaces(36).

Due to its increased transmissibility, the emergence of Omicron variant caused widespread concern. Research show that the median survival time of Omicron BA.1 and BA.2 on plastic and skin exceeded 190 hours and 21 hours respectively, the longest when compared with Wuhan strain, the Alpha, Beta, Gamma, and Delta variant(12).However, different from speculated, Glinert *et al.* didn't detect infectious virus of any variant from

surfaces of isolation wards and hotels in Israel, and propose that the Omicron variant doesn't have higher airborne infectivity, environmental contamination rate or stronger survival ability on inanimate surfaces when compared with the other variants(37). Speculations are that the strong transmissibility of the variant may be related to spike protein mutations, causing higher affinity to angiotensin converting enzyme 2 (ACE2) receptor and lower immune recognition. In addition, it may be easier to cause more community transmission when it takes longer for individuals with no or mild symptoms to be diagnosed. Compared with a previous study conducted in a Wuhan Fangcang hospital (30), results of this current study show a higher contamination rate of environmental surfaces. Although most CT values are over 35, indicating that the overall risk of infection is not high.

Summary of the past evidence suggest that ventilation, open space, particle filtration and air disinfection, as well as proper use of key spaces, such as toilets, can effectively limit the concentration of SARS-CoV-2 RNA in aerosols(33, 34, 38), and implementation of cleaning and disinfection standards are effective(27)(28)(30). Currently, scientists are interested in development of anti-viral materials to reduce contact transmission of infectious viruses in clinical and public environments(39). In our study, all the samples taken at the previously contaminated surfaces after cleaning and disinfection were negative, and no surface in the potentially contaminated areas were positive, proving the effectiveness and importance of infection prevention and control policies. Proper architectural layouts, hand hygiene, adequate personal protective equipment, cleaning and disinfection of the environments will continue to be valuable for the ongoing pandemic.

The current study is not without limitations. First, only viral RNA was tested and no viral

culture was done. Due to the high Ct values of the virus in positive samples, infectivity of contaminated surfaces could not be determined. Second, viral load in air samples was not detected. Second, the environmental temperatures and humidity, which may influence viral stability, were not recorded when swabs were taken. Finally, the Fangcang shelter hospitals included are reconstructed from existing venues, hence building layouts and structures are different. Experiences of these two hospitals may not directly apply to other Fangcang sites. Nevertheless, this study contributes to the understanding of PPE and environmental surface contamination in Fangcang hospitals during the Omicron wave of the pandemic.

### **Conclusions**

In conclusion, SARS-CoV-2 contamination is widespread in Fangcang shelter hospital environmental surfaces, with the highest rate in patient occupied areas. PPE and doffing rooms are contaminated to different extent. Healthcare workers are at risk of hospital infection. Contaminated area samples, as well as samples of previously positive surfaces after cleaning and disinfection, are negative. This further illustrates the importance of implementing infection control policy.

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**Footnote:**

The authors have completed the STROBE reporting checklist.

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form. The authors have no conflicts of interest to declare.

The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. Ethical approval was not necessary due to the absence of patient involvement in this study.

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Abbreviations:

COVID-19: coronavirus disease 2019

SARS-CoV-2: severe acute respiratory syndrome coronavirus 2/ novel coronavirus

PPE: personal protective equipment

HCW: healthcare worker

DR: doffing room

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