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Environmental contamination and evaluation of healthcare-associated SARS-CoV-2 transmission risk in temporary isolation wards during the COVID-19 pandemic

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ABSTRACT

Background: Temporary isolation wards have been introduced to meet demands for airborne-infection-isolation-rooms (AIIRs) during the COVID-19 pandemic. Environmental sampling and outbreak investigation was conducted in temporary isolation wards converted from general wards and/or prefabricated containers, in order to evaluate the ability of such temporary isolation wards to safely manage COVID-19 cases over a period of sustained use.

Methods: Environmental sampling for SARS-CoV-2 RNA was conducted in temporary isolation ward rooms constructed from pre-fabricated containers (N = 20) or converted from normal-pressure general wards (N = 47). Whole genome sequencing (WGS) was utilized to ascertain health care-associated transmission when clusters were reported amongst HCWs working in isolation areas from July 2020 to December 2021.

Results: A total of 355 environmental swabs were collected; 22.4% (15/67) of patients had at least one positive environmental sample. Patients housed in temporary isolation ward rooms constructed from pre-fabricated containers (adjusted-odds-ratio, aOR = 10.46, 95% CI = 3.89-58.91, \(P = .008\)) had greater odds of detectable environmental contamination, with positive environmental samples obtained from the toilet area (60.0%, 12/20) and patient equipment, including electronic devices used for patient communication (8/20, 40.0%). A single HCW cluster was reported amongst staff working in the temporary isolation ward constructed from pre-fabricated containers; however, health care-associated transmission was deemed unlikely based on WGS and/or epidemiological investigations.

Conclusion: Environmental contamination with SARS-CoV-2 RNA was observed in temporary isolation wards, particularly from the toilet area and smartphones used for patient communication. However, despite intensive surveillance, no healthcare-associated transmission was detected in temporary isolation wards over 18 months of prolonged usage, demonstrating their capacity for sustained use during succeeding pandemic waves.

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Key Words:
SARS-CoV-2
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required to construct permanent structures with AIIR capabilities, vari-
ous workarounds have been proposed to create temporary isolation
wards, including conversion of pre-existing hospital wards, erection of
temporary structures, or conversion of non-medical facilities. However, evaluation of the capability of such temporary isolation
wards to safely manage COVID-19 cases is significantly lacking; largely
because these temporary isolation wards were often introduced at the
pandemic peak to provide surge-capacity and resources for detailed
evaluation were unavailable. Reports of healthcare-associated SARS-
CoV-2 transmission in such temporary isolation wards, as well as out-
breaks of varicella in COVID-19 isolation facilities, highlight the poten-
tial for breaches in infection-prevention at such temporary isolation
wards, particularly over a sustained duration of usage.

At our institution, a large tertiary hospital in Singapore, pre-pandemic a purpose-built 50-bedded isolation ward (IW) was available, comprising single-occupancy AIIRs with ≥12 air changes-per-hour, controlled direction of air flow with negative differential pressure of ≥2.5 Pascal or greater, and anterooms designed to provide an “air-lock” between the adjacent area and the AIIR. However, the substantial increase in demand for AIIRs during the COVID-19 pandemic rapidly outstripped the number of AIIRs available, and COVID-19 patients were housed in temporary isolation wards converted from general ward rooms. Our institution opened an additional 50-bedded temporary isolation ward in July 14, 2020, comprising prefabricated containers, each of which were redesigned as a single-occupancy room and met design standards for AIIRs. These temporary isolation wards, saw sustained usage throughout 2021, during a surge in community transmission driven by the SARS-CoV-2 delta-variant. We therefore sought to assess SARS-CoV-2 environmental contamination and/or transmission risk associated with such temporary isolation wards over a prolonged period of usage. Notably, our institution conducted contact-tracing for ascertainment of epidemiological exposure, together with active sur-
veillance (including rostered-routine-testing, RRT) and whole genome sequencing (WGS) for all COVID-19 cases amongst HCWs. This allowed us to evaluate if clusters of COVID-19 cases amongst HCWs working in isolation-areas, including temporary isolation wards, could potentially be attributed to healthcare-associated SARS-CoV-2 trans-
mISSION. By assessing SARS-CoV-2 environmental contamination and potential transmission risk in such temporary isolation wards, we sought to ascertain the safety of these temporary isolation wards over a period of sustained use. Such information could potentially inform hos-
pital practice during subsequent pandemics caused by novel respira-
tory pathogens.

METHODOLOGY

Institutional setting and study period

Our campus handled COVID-19 and non-COVID-19 admissions and hosts a 1785-bed acute hospital, a 545-bed community hospital, and 4 specialist centers. Environmental sampling to assess the degree of contamination within patient rooms in temporary isolation wards was conducted in August 2021. Environmental sampling was con-
ducted in the temporary isolation ward constructed from pre-fabri-
cated containers as well as temporary isolation wards converted from normal-pressure general wards. These converted general wards contained a mixture of normal-pressure single rooms and cohorted 5-bedded cubicles with en-suite toilets, which opened onto common corridors. In the conversion of these general wards, temporary full-height partitions were erected to close off cohorted cubicles from the common corridor. Each cohorted cubicle and single room had its own ventilation system, and air was not recirculated between cubicles or rooms. Prior to conversion, these general wards met the minimum of ≥6 air-
exchanges and/or hour; in line with conversion into temporary

isolation wards, air exchange rates were increased to meet the stan-
dard of ≥12 air-exchanges and/or hour. The average size of a normal-
pressure single room was 4 meters (m) by 10m, while cohorted cubi-
cles on average measured 8 m by 10 m. In contrast, in the temporary isolation ward constructed from pre-fabricated containers, single-
occupancy patient rooms (with en-suite toilets) measured 2.4 m x
6 m. Each container met design standards for AIIRs, with ≥12 air exchanges and/or hour and laminar (unidirectional) air flow with negative differential pressure of ≥2.5 Pascal or greater, and had its own ventilation system; air was not recirculated between containers or into the temporary structure containing the 50 prefabricated con-
tainers. All temporary isolation wards were air-conditioned and not open to outdoor air, given high heat and humidity in tropical Singa-
pore.

Additionally, to assess potential healthcare-associated transmis-
sion from patients to health care workers (HCWs) working in isolation
areas, cases of COVID-19 infections amongst HCWs working in isolation areas were collated over an 18 month period from July 2020 to December 2021. Surveillance was conducted for all HCWs working in isolation areas (including temporary isolation wards, purpose-built isolation ward, and isolation areas in the emergency department), given ongoing contact with COVID-19 inpatient cases as well as inter-
actions between staff during patient transfers and handovers. When clusters of COVID-19 infection were reported amongst HCWs work-
ing in isolation areas, we utilized epidemiological investigations and
whole genome sequencing (WGS) to ascertain the possibility of health care-associated transmission.

COVID-19 infection prevention measures

All HCWs in the institution donned N95 respirators as a manda-
tory minimum. HCWs in isolation wards (both purpose-built and temporary isolation wards) donned N95 respirators in patient rooms and common areas (eg, common corridors); during entry into patient rooms, single-use disposable gloves, gowns and face shields were additionally utilized as personal protective equipment (PPE). COVID-
19 vaccination uptake amongst HCWs was high, with 89.6% fully-vac-
cinatted with mRNA vaccines by end-April 2021. Pre-pandemic, all inpatient isolation areas were cleaned with 1000 ppm hypochlorite-
based disinfectant 3x-a-day; this was maintained in all temporary isolation wards during the pandemic period, with cleaners required to wear N95 respirators, eye-protection, and disposable gown and/or gloves. In the temporary isolation ward constructed from pre-fabricated containers, in-room smart-phones were also provided for remote communication with the patient via video-conferencing. For disinfection of the smart-phone after patient usage, upon patient discharge. HCWs used wipes with quaternary-ammonium-compounds (Schülke mikrozid AF) were used to wipe the screen while ethanol wipes (Schülke mikrozid AF) were used to clean the remaining parts of the smart-phone and its casing. Subsequently, cleaning staff would remove the smart-phone from its casing for decontamination with hydrogen peroxide vaporization prior to re-use.

Surveillance for COVID-19 amongst HCWs

More than 13,000 HCWs worked on-campus. All symptomatic HCWs could access free PCR-testing at our institution’s Staff Clinic. Routine-rostered-testing (RRT) was conducted for all asymptomatic HCWs from April 2021, initially with fortnightly PCR. Given surging community transmission, HCW surveillance was stepped up to twice-weekly rapid-antigen-detection (RAD) testing from September 29, 2021. HCWs working in inpatient areas (high-risk) were required to obtain confirmatory PCR-testing if they tested positive on RAD.
Definition of HCW COVID-19 clusters

Epidemiological HCW clusters were defined as ≥2 COVID-19 cases amongst HCWs in the same setting (ward/workplace), with overlap during their infective periods (defined as 2 day prior to symptom-onset if symptomatic or 7 day prior to positive-PCR if asymptomatic); ending when no cases were diagnosed for 14 days. Genomic clusters were detected based on whole-genome-similarity analysis (when sequences are≤3 SNPs different and fall in the same branch of the genome-similarity-tree).

Epidemiologic and genetic analysis

Contact-tracing was performed for all HCWs at work during their infective periods; cases with a cycle-threshold (CT)-value of <31 on PCR were sent for WGS using the ARTIC protocol on Oxford Nanopore minION sequencers. When clusters of COVID-19 were reported amongst HCWs working in inpatient isolation areas, available isolates from all inpatient cases admitted to that isolation area in the preceding 14 day were also sequenced, in order to ascertain if there was potential patient-to-HCW transmission.

Environmental sampling

Environmental sampling was done in patient rooms within temporary isolation wards to test for SARS-CoV-2 RNA. Sampling was conducted at a single timepoint per room at the point of patient discharge and/or transfer-out, prior to terminal cleaning with sodium hypochlorite 1,000 ppm, and again after terminal cleaning was completed. Per-protocol, areas that were sampled routinely included: near-patient environment (bedside, bedside table, which was replaced by a ledge in the prefabricated containers as space constraints could not accommodate a full-sized table), patient equipment (call-bell), toilet area (seat and/or flush-handle), and shower area. The phone screen of the in-room smartphones used for remote communication in the temporary isolation ward constructed from pre-fabricated containers was swabbed as well. HCWs wearing full PPE used sterile premoistened polyester-tipped swab sticks to swab high-touch areas for 2-3 minutes per surface. Air sampling for SARS-CoV-2 RNA was also conducted in the temporary isolation ward converted from normal-pressure general wards, concurrent with environmental sampling. Separately, aerosol samples were collected with the patient present, using NIOSH BC 251, 2 stage cyclone aerosol samplers connected to air sampling pumps set at a flow-rate of 3.5 L/min.

Statistical analysis

Chi-square-test (univariate analysis) and multivariate logistic regression was used to compare factors associated with detectable SARS-CoV-2 environmental contamination amongst inpatient cases for which environmental sampling was conducted. SPSS (Version 20.0. Armonk, NY, USA: IBM Corp) was used for statistical analysis and a cutoff of P < .05 was set for statistical significance.

Ethics statement

As this study was conducted as part of outbreak investigation, ethics approval was not required under our institutional review board guidelines.

RESULTS

Over the 18 month study period, a total of 4,247 inpatient COVID-19 cases were admitted, of which 35.6% (1510/4247) were initially admitted to the temporary isolation ward constructed from pre-fabricated containers, 26.4% (1125/4247) to the temporary isolation ward converted from normal-pressure general wards and the remainder to the purpose-built isolation ward. The average length-of-stay in temporary isolation wards was 3.89 days (SD = 1.32). A total of 441 COVID-19 infections were reported amongst HCWs over the corresponding period; of which 5.7% (25/441) occurred amongst HCWs working in COVID-19 isolation-areas. The majority of infections amongst HCWs working in isolation areas (60.0%, 15/25) occurred in HCWs working in converted areas of the emergency department (ED) where confirmed/suspected COVID-19 cases were managed. Three cases occurred amongst HCWs working in the purpose-built IW, and the remainder occurred amongst HCWs working in temporary isolation wards(converted from general wards, N = 5; prefabricated containers, N = 2). Around half (56.0%, 14/25) of COVID-19 cases amongst HCWs working in isolation-areas were successfully sequenced. A total of 104 HCWs were identified as having had close-contact with the index HCW-cases and placed on furlough. The majority of COVID-19 cases amongst HCWs working in isolation areas were sporadic, with the exception of a single epidemiological cluster of infections reported amongst 2 HCWs working in the temporary isolation ward constructed from pre-fabricated containers, who were diagnosed with COVID-19, 2 days apart. On epidemiological investigation, both HCWs had overlapped at work; however on WGS analysis, the two HCW sequences clustered on separate branches of the genome-similarity tree, suggesting that healthcare-associated HCW-to-HCW transmission in the temporary isolation ward constructed from pre-fabricated containers was less likely (Fig 1A). On WGS and epidemiological analysis, there was also no evidence of patient-to-HCW transmission in the temporary isolation ward constructed from pre-fabricated containers, based on dissimilarity with sequences of inpatients admitted to the temporary isolation ward constructed from pre-fabricated containers over the preceding 2 weeks and/or absence of an epidemiological link between genetically-linked sequences (Fig 1B).

Environmental sampling for SARS-CoV-2 RNA was conducted prior to terminal cleaning amongst representative inpatient cases admitted to temporary isolation wards constructed from pre-fabricated containers (N = 20) or converted from normal-pressure general wards (N = 47). A total of 355 swabs were taken prior to terminal cleaning; 12.4% (44/355) of swabs tested positive, with 22.4% (15/67) of sampled cases having had a positive environmental sample. No swabs tested positive after terminal cleaning. Comparing clinical and demographic characteristics of sampled cases in the temporary isolation ward rooms constructed from pre-fabricated containers versus cases in the converted general-ward (Supplementary Table 1), inpatient cases in the temporary isolation ward rooms constructed from pre-fabricated containers were younger (age<60 years, aOR = 12.74, 95% CI = 2.82-57.46, P = .001) and had lower odds of pneumonia (aOR = 0.04, 95% CI = 0.006-0.26); this was reflective of triage criteria utilized to assign COVID-19 cases to the container-ward. On univariate (Table 1) and multivariate analysis, being housed in temporary isolation ward rooms constructed from pre-fabricated containers (adjusted-odds-ratio, aOR = 10.46, 95% CI = 3.89-58.91, P = .008), having had an aerosol-generating procedure at any point (aOR = 6.84,
95% CI = 1.01-49.42, \(P = .049\), having ongoing diarrhea (aOR = 30.20, 95% CI = 1.66-548.05, \(P = .021\)), as well as a cycle-threshold value of <20 on SARS-CoV-2 PCR of nasopharyngeal swab specimens (aOR = 8.38, 95% CI = 1.03-67.96, \(P = .047\)) were independently associated with greater odds of detectable SARS-CoV-2 environmental contamination. Within temporary isolation ward rooms constructed from pre-fabricated containers, the majority of sampled patients had positive environmental samples from the toilet area.

### Table 1

Factors associated with PCR detection of SARS-CoV-2 in near-patient environments within temporary isolation ward rooms (N = 67)

| Covariates (index cases) | Detection of SARS-CoV-2 in near-patient environment prior to terminal cleaning, N (%) | Odds ratio, 95% CI* | \(P\)-value |
|--------------------------|-----------------------------------------------------------------|--------------------|------------|
| **Clinical characteristics** | | | |
| Age | | | |
| \(\geq 60\) years | 5/38 (13.2) | 1.00 | |
| \(< 60\) years | 10/29 (34.5) | 3.47 (1.03-11.68) | 0.074 |
| Gender | | | |
| Female | 4/22 (18.2) | 1.00 | |
| Male | 11/45 (24.4) | 1.46 (0.41-5.23) | 0.757 |
| **Clinical presentation** | | | |
| Upper respiratory symptoms alone | 10/44 (22.7) | 1.00 | |
| Pneumonia | 5/23 (21.7) | 0.94 (0.28-3.19) | 1.00 |
| Symptomatic | 12/46 (26.1) | 1.00 | |
| Asymptomatic | 3/21 (14.3) | 0.47 (0.12-1.89) | 0.356 |
| SARS-CoV-2 variant | | | |
| SARS-CoV-2 Delta variant | 10/39 (25.6) | 1.00 | |
| Other SARS-CoV-2 variants\(^{z}\) | 5/28 (17.9) | 0.84 (0.54-1.29) | 0.558 |
| **Room characteristics** | | | |
| Type of temporary isolation ward | | | |
| Converted general ward room | 5/47 (10.6) | 1.00 | |
| Prefabricated container-ward room | 10/20 (50.0) | 8.40 (2.35-30.09) | 0.001* |
| Room-occupancy (no. of beds) | | | |
| Single-occupancy room | 10/35 (28.6) | 1.00 | |
| Cohort room (5-bedded) | 5/32 (15.6) | 2.16 (0.65-7.20) | 0.250 |
| **Admission events** | | | |
| Aerosol-generating procedure | | | |
| No aerosol-generating procedure\(^{y}\) | 9/56 (16.1) | 1.00 | |
| Aerosol-generating procedure at any point during isolation ward admission | 6/11 (54.5) | 6.27 (1.57-25.02) | 0.012\(^{y}\) |
| Presence of diarrhea | | | |
| No diarrhea | 12/63 (19.0) | 1.00 | |
| Ongoing diarrhea | 3/4 (75.0) | 12.75 (1.22-133.55) | 0.033\(^{y}\) |
| SARS-CoV-2 PCR within 48h of environmental sampling\(^{x}\) | | | |
| Cycle-threshold <20 | 2/28 (7.1) | 1.00 | |
| Cycle-threshold ≥20 | 13/32 (40.6) | 1.79 (8.90-44.14) | 0.003\(^{y}\) |

*Chi-square test.

\(^{y}\)Aerosol-generating procedures defined as: supplemental oxygen, nebulizers, high flow nasal cannula, noninvasive positive pressure ventilation, intubation; at any point during isolation ward admission.

\(^{z}\)SARS-CoV-2 strains circulating in Singapore prior to emergence of the SARS-CoV-2 Delta variant in April 2021 included Alpha, Beta and Gamma variants. All patients involved in the study had received 2 doses of mRNA vaccinations prior to infection.

\(^{x}\)If SARS-CoV-2 PCR on nasopharyngeal swab specimens had not been done within 48h of environmental sampling, it was counted as missing data.

\(^{y}\)P-value < .05 on multivariate logistic regression, including the following variables: room type, aerosol-generating-procedure, diarrhea, and result of SARS-CoV-2 PCR on nasopharyngeal swab samples conducted within 48h of environmental sampling.
| Layout, ventilation, and sites of PCR detection of SARS-CoV-2 in temporary isolation wards |
|---------------------------------------------------------------|
| Temporary isolation ward constructed from pre-fabricated containers | Temporary isolation ward converted from normal-pressure general wards |

**Table 2**

| Site of sampling                  | Percentage of sampled patients having detectable environmental contamination with SARS-CoV-2 (N%) |
|-----------------------------------|-------------------------------------------------------------------------------------------------|
| Patient equipment (call-bell, phone) | 8/20 (40.0)                                                                                      |
| Near-patient environment (bedside ledge, bedside) | 0/20 (0.0)                                                                                      |
| Toilet area (seat and flush handle) | 12/20 (60.0)                                                                                     |
| Shower area                        | 1/20 (5.0)                                                                                       |
| Patient equipment (call-bell)      | 2/47 (4.3)                                                                                       |
| Near-patient environment (bedside table, bedside) | 5/47 (10.6)                                                                                     |
| Toilet area (seat and flush handle) | 8/47 (17.0)                                                                                      |
| Shower area                        | 2/47 (4.2)                                                                                       |

*Of the 8 patients who had positive environmental swabs from patient equipment (call-bell, phone), 2 had positive swabs from both the phone screen and call-bell, 5 had positive swabs from the phone screen alone, and 1 had positive swabs from the call-bell alone.

*Of the 5 patients who had positive environmental swabs from the near-patient environment, 4 had positive swabs from both the table and bedside, and 1 had positive swabs from the table alone.
Environmental contamination was detected more frequently in the temporary isolation ward rooms constructed from pre-fabricated containers compared to those converted from normal-pressure general wards. This might be attributable to the more compact size of patient rooms modified from pre-fabricated containers. There were also some differences in the observed pattern of contamination. In isolation wards converted from general wards, environmental contamination was detected at the bedside and/or bedside table in 10% of cases sampled, whereas no SARS-CoV-2 RNA was detected on the bedside ledge that replaced a full-sized bedside table in prefabricated containers due to a lack of space. This could potentially reflect different patterns of usage; perhaps in isolation rooms converted from general wards, with more space at the bedside and a proper-sized bedside table for use, patients utilized this more often, resulting in more detectable environmental contamination around the bedside.

Contamination of the toilet area was reported in both types of temporary isolation wards. Significant environmental contamination of the toilet area with SARS-CoV-2 RNA in contrast to other patient areas has been reported previously, given that the toilet is usually a smaller area with SARS-CoV-2 RNA in air samples taken at a distance of 1 meter from the patient bed, from 1 normal-pressure single room and 1 cohorted 5 bedded cubicle, respectively. No air samples at 2 meter distance or from the common corridor tested positive for SARS-CoV-2 RNA.

DISCUSSION

Environmental contamination was detected more frequently in the temporary isolation ward rooms constructed from pre-fabricated containers compared to those converted from normal-pressure general wards. This might be attributable to the more compact size of patient rooms modified from pre-fabricated containers. There were also some differences in the observed pattern of contamination. In isolation wards converted from general wards, environmental contamination was detected at the bedside and/or bedside table in 10% of cases sampled, whereas no SARS-CoV-2 RNA was detected on the bedside ledge that replaced a full-sized bedside table in prefabricated containers due to a lack of space. This could potentially reflect different patterns of usage; perhaps in isolation rooms converted from general wards, with more space at the bedside and a proper-sized bedside table for use, patients utilized this more often, resulting in more detectable environmental contamination around the bedside.

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SUPPLEMENTARY MATERIALS

Supplementary material associated with this article can be found in the online version at https://doi.org/10.1016/j.ajic.2022.09.004.

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