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SARS-CoV-2 surface and air contamination in an acute healthcare setting during the first and second pandemic waves

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SUMMARY

Background: Surfaces and air in healthcare facilities can be contaminated with severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2). Previously, the authors identified SARS-CoV-2 RNA on surfaces and air in their hospital during the first wave of the coronavirus disease 2019 pandemic (April 2020).

Aim: To explore whether the profile of SARS-CoV-2 surface and air contamination had changed between April 2020 and January 2021.

Methods: This was a prospective, cross-sectional, observational study in a multi-site London hospital. In January 2021, surface and air samples were collected from comparable areas to those sampled in April 2020, comprising six clinical areas and a public area. SARS-CoV-2 was detected using reverse transcription polymerase chain reaction and viral culture. Sampling was also undertaken in two wards with natural ventilation alone. The ability of the prevalent variants at the time of the study to survive on dry surfaces was evaluated.

Findings: No viable virus was recovered from surfaces or air. Five percent (N=14) of 270 surface samples and 4% (N=1) of 27 air samples were positive for SARS-CoV-2, which was significantly lower than in April 2020 [52% (N=114) of 218 surface samples and 48% (N=13) of 27 air samples (P<0.001, Fisher’s exact test)]. There was no clear difference in the proportion of surface and air samples positive for SARS-CoV-2 RNA based on the type of ventilation in the ward. All variants tested survived on dry surfaces for >72 h, with a <3-log10 reduction in viable count.

Conclusion: This study suggests that enhanced infection prevention measures have reduced the burden of SARS-CoV-2 RNA on surfaces and air in healthcare facilities.

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Introduction

The coronavirus disease 2019 (COVID-19) pandemic continues, with epidemic waves affecting various parts of the world [1]. Several epidemic waves have occurred in the UK, resulting in a peak of hospitalizations in April 2020, and a second, larger peak of hospitalizations in January/February 2021 [2,3]. The second wave of hospitalizations in early 2021 was associated with increased community prevalence of COVID-19 infection and a second wave of COVID-19 in healthcare workers [4].

Respiratory viruses, such as influenza, severe acute respiratory syndrome coronavirus-1 (SARS-CoV-1), SARS-CoV-2 and others, are able to transmit via the air and via contact under some circumstances [5,6]. There is considerable controversy around the relative importance of different routes of transmission involving air as a vector, with some arguing that transmission over short and long ranges via small aerosolized particles is the predominant route of transmission [7,8]. The SARS-CoV-2 virus has been shown to survive on surfaces and in air for days to weeks [9,10]. SARS-CoV-2 RNA has been identified in hospital air, and viable SARS-CoV-2 has been cultured from a small number of samples in these studies [11–13]. SARS-CoV-2 RNA has also been identified on surfaces in hospitals, although viable SARS-CoV-2 that can be cultured has not been identified [12,14]. The role of contaminated surfaces and air in the spread of SARS-CoV-2 within healthcare environments is unclear [14].

An important feature of the epidemiology of SARS-CoV-2 is the emergence and international spread of several different variants, which vary in their transmissibility, virulence and vaccine response [15]. During the second wave of hospitalizations, the Alpha variant (B.1.1.7) emerged as the predominant cause of COVID-19 in the UK [15]. This variant has been found to be more transmissible than other SARS-CoV-2 variants circulating at the time [15,16]. The reasons for increased transmissibility of the Alpha variant and other variants are unclear, but do not appear to be as a result of fundamental differences in the route of transmission [15]. The Alpha variant also has a characteristic ‘S gene’ knockout mutation, which has proven to be a useful way to rapidly identify it presumptively from other types of SARS-CoV-2 [15].

During the first wave of COVID-19, environmental sampling of air and surfaces at the study hospitals in London was undertaken in seven clinical areas and a public entrance [12]. This work identified extensive SARS-CoV-2 RNA contamination of surfaces and air in patient care and non-patient care areas, but found that viable virus could not be cultured from any samples. In order to re-evaluate surface and air contamination in the study hospitals during the second wave, and in the context of the emergence of SARS-CoV-2 variants, the same sampling methods were used to test for SARS-CoV-2 surface and air contamination in comparable areas to those sampled during the first wave. In addition, the authors aimed to understand patterns of surface and air contamination with SARS-CoV-2 variants, so the genotype of SARS-CoV-2 was inferred in patients on the day of sampling, and in SARS-CoV-2 detected from surface and air samples. Renal dialysis represents a particular and complex risk and challenge at the interface of community and health care in the context of COVID-19 [17]. Therefore, additional sampling was performed in a renal dialysis setting. Given the role of ventilation in preventing the spread of SARS-CoV-2 [18], air and surfaces were sampled for SARS-CoV-2 in wards with a range of ventilation approaches, including some with natural ventilation alone. Finally, given limited data on the capacity for SARS-CoV-2 variants to survive on surfaces, a laboratory experiment was performed to evaluate the ability of the Alpha variant to survive on dry surfaces compared with other variants.

| Table I |
| --- |
| Summary of areas sampled |

| Ward type | Ward details | Patient group | Ventilation type |
| --- | --- | --- | --- |
| Cohort ward A (patient bays and single rooms) | April 2020 (Ward 1) | COVID-19 cohort ward | Mechanical supply and extract |
| Cohort ward B (‘Nightingale’ design) | April 2020 (Ward 3) | COVID-19 cohort ward | Mechanical supply and extract |
| Adult acute admission unit | January 2021 (Ward 4) | COVID-19 cohort ward | Mechanical supply and extract |
| Adult emergency department | | Mixed cohort of patients with COVID-19 and other patients | Mechanical supply and extract |
| Hospital public areas | | Mixed cohort of patients with COVID-19 and other patients | Mechanical supply and extract |
| CPAP/NIV suite | April 2020 (Ward 5) | CPAP/NIV for patients with COVID-19 | Mechanical supply and extract |
| Adult ICU | January 2021 (Ward 2) | CPAP/NIV for patients with COVID-19 | Mechanical supply and extract |
| Inpatient dialysis unit | | Mixed cohort of patients with COVID-19 and other patients | Mechanical supply and extract |
| Cohort wards with natural ventilation | Ward 6 | COVID-19 cohort ward | Natural ventilation |
| | Ward 7 | COVID-19 cohort ward | Natural ventilation |

CPAP, continuous positive airway pressure; NIV, non-invasive ventilation; ICU, intensive care unit; COVID-19, coronavirus disease 2019.
| Table II | Polymerase chain reaction results from surface and air samples |
|---------|---------------------------------------------------------------|

| Cohort ward A (Ward 1 April 2020; Ward 2 January 2021) | Staff room | Surfaces sampled | Surfaces positive | % positive | Air positive | Jan-21 Surfaces sampled | Surfaces positive | % positive | Air positive |
|-------------------------------------------------------|------------|------------------|------------------|------------|-------------|--------------------------|------------------|------------|-------------|
| Nurse station | 6 | 2 | 33.3 | Negative | Doctors’ office | 10 | 0 | 0.0 | Negative |
| Patients’ shared bathroom | 6 | 2 | 33.3 | Negative | Nurse station | 10 | 0 | 0.0 | Negative |
| Patient bay | 6 | 5 | 83.3 | Positive | Patient bay | 10 | 4 | 40.0 | Negative |
| Staff room | 4 | 0 | 0.0 | Negative | Staff room | 10 | 0 | 0.0 | Negative |

| Cohort ward B (Ward 3 April 2020; Ward 4 January 2021) | Nurse station | Surfaces sampled | Surfaces positive | % positive | Air positive | Jan-21 Surfaces sampled | Surfaces positive | % positive | Air positive |
|-------------------------------------------------------|------------|------------------|------------------|------------|-------------|--------------------------|------------------|------------|-------------|
| Patients’ toilet (in the ward) | 7 | 1 | 14.3 | Positive | Nurse station | 10 | 0 | 0.0 | Negative |
| Male bay | 12 | 5 | 41.7 | Positive | Male bay | 10 | 0 | 0.0 | Negative |
| Single room | 8 | 7 | 87.5 | Positive | Single room | 10 | 3 | 30.0 | Negative |
| Ward manager’s office | 5 | 3 | 60.0 | Negative | Staff room | 10 | 0 | 0.0 | Negative |
| Patient bay 1 | 8 | 2 | 25.0 | Negative | Patient bay | 10 | 1 | 10.0 | Negative |
| Patient bay 2 | 10 | 8 | 80.0 | Negative | Patients’ shared bathroom | 10 | 1 | 10.0 | Negative |

| Adult acute admission unit | Nurse station | Surfaces sampled | Surfaces positive | % positive | Air positive | Jan-21 Surfaces sampled | Surfaces positive | % positive | Air positive |
|----------------------------|------------|------------------|------------------|------------|-------------|--------------------------|------------------|------------|-------------|
| Patient assessment cubicles | 3 | 1 | 33.3 | | | | | | |
| Male toilet (next to the nurse station) | 2 | 1 | 50.0 | | | | | | |
| Resus bay (last patient > 2 h) | 10 | 4 | 40.0 | Positive | Cubicle with patient undergoing non-invasive ventilation | 10 | 0 | 0.0 | Negative |

| Adult emergency department | Nurse station | Surfaces sampled | Surfaces positive | % positive | Air positive | Jan-21 Surfaces sampled | Surfaces positive | % positive | Air positive |
|----------------------------|------------|------------------|------------------|------------|-------------|--------------------------|------------------|------------|-------------|
| ‘Green’ majors — no suspected COVID-19 | 10 | 6 | 60.0 | Negative | Majors — no suspected COVID-19 | 10 | 0 | 0.0 | Negative |
| Nurse station | 4 | 2 | 50.0 | Negative | Majors — suspected or confirmed COVID-19 | 10 | 0 | 0.0 | Negative |
| Ambulatory waiting | 3 | 3 | 100.0 | Negative | Main department — suspected or confirmed COVID-19 | 10 | 2 | 20.0 | Negative |

| Hospital public areas | Hospital building main entrance | Surfaces sampled | Surfaces positive | % positive | Air positive | Jan-21 Hospital building main entrance | Surfaces positive | % positive | Air positive |
|-----------------------|---------------------------------|------------------|------------------|------------|-------------|--------------------------------------|------------------|------------|-------------|
| Male toilet at hospital building main entrance | 7 | 5 | 71.4 | Positive | Hospital building main entrance | 10 | 1 | 10.0 | Negative |
| Female toilet at hospital building main entrance | 7 | 4 | 57.1 | Positive | Female toilet at hospital building main entrance | 10 | 0 | 0.0 | Negative |
| Lift area hospital building ground floor | 10 | 4 | 40.0 | Negative | Staff café | 10 | 0 | 0.0 | Negative |

| CPAP/NIV suite (Ward 5 April 2020; Ward 2 January 2021) | Nurse station | Surfaces sampled | Surfaces positive | % positive | Air positive | Jan-21 Nurse station | Surfaces positive | % positive | Air positive |
|-------------------------------------------------------|------------|------------------|------------------|------------|-------------|--------------------------|------------------|------------|-------------|
| Staff room | 5 | 3 | 60.0 | Positive | Nurse station | 10 | 0 | 0.0 | Negative |
| Staff room | 19 | 14 | 73.7 | Positive | | | | | |
Methods

Selecting clinical areas to sample

In order to provide a comparison of surface and air contamination in the second wave of the COVID-19 pandemic compared with the first wave, surface and air samples were collected from seven comparable areas to those sampled in the first wave [12], representing a range of clinical services provided by the hospital group. These comprised:

- adult emergency department, which included sections dedicated for suspected and confirmed cases of COVID-19 and for patients not suspected to have COVID-19;
- a COVID-19 cohorting adult acute admissions unit;
- a COVID-19 cohorting adult intensive care unit;
- two adult COVID-19 cohort wards: one with physically separated four-bedded bay areas, and one with large open bay areas;
- an adult ward area used for the management of non-invasive ventilation/continuous positive airway pressure – procedures that are thought to be high risk for the generation of infectious SARS-CoV-2 aerosol; and
- the entrance and public area of the main hospital building.

Each of these clinical areas had either mechanical ventilation, recirculated air, or natural ventilation and mechanical ventilation (Table 1). In addition, two wards cohorting patients with COVID-19 with natural ventilation alone were sampled to explore the possible role of different ventilation systems in determining surface and air contamination. Sampling was also undertaken in a renal dialysis unit at one of the study hospitals.

Sample collection

Surface samples were taken from high-touch areas, including bed rails, ward telephones, computers, clinical equipment (syringe pumps, blood pressure monitors) and hand hygiene facilities (handwashing basins, alcohol gel dispensers). Air samples were collected in parallel. Samples were collected from the lowest to highest perceived risk of SARS-CoV-2 contamination. Samples were collected between 6th and 18th January 2021.

Sampling methods

Air sampling was performed using a Coriolis Micro air sampler (Bertin Technologies, Montigny-le-Bretonneux, France), which collects air at 300 L/min. After 10 min of sampling at 300 L/min, a total of 3.0 m³ air was sampled into a conical vial containing 5 mL of Dulbecco’s minimal essential medium (DMEM). Surface samples were collected by swabbing approximately 25-cm² areas of each item using flocked swabs (Copan, Murrieta, CA, USA) moistened in DMEM. Swabs were deposited into 1 mL of DMEM.

Detection and quantification of SARS-CoV-2

Viral RNA detection and absolute quantification was performed using quantitative real-time reverse transcription polymerase chain reaction (RT-qPCR). Samples were extracted
from 200 μL of DMEM using the QIAsymphony SP (Qiagen, Hilden, Germany) instrument according to the manufacturer’s instructions. SARS-CoV-2 viral RNA was detected using AgPath-ID One-Step RT-PCR Reagents (Life Technologies, Rockville, MD, USA) with specific primers and probes targeting the envelope (E) [19] and ORF1a genes [20]. A standard curve with six serial dilutions of 1x10^5—1x10^9 copies/μL E gene was included in each run of the RT-qPCR. The number of SARS-CoV-2 virus E gene copies per m^3 air and copies per swab were calculated. Samples were considered positive for SARS-CoV-2 RNA if E or ORF1a RT-qPCR assays had a cycle threshold (Ct) value <45. Human biological material in air samples was quantified by RT-PCR targeting human ribonuclease P and 18S ribosomal RNA [20].

### Genotyping SARS-CoV-2 from air and surface samples

The proportion of air and surface samples with mutations consistent with SARS-CoV-2 variants of concern were determined by PCR. The primers (forward 5'-ACTTTCCTTTACATCATAAGTTAATTG-3' and reverse: 5'-ACTACTCTGTATTGTGTTACCCGAC-3') and probes (5' -FAM-TTTCCAACCCACTTAT-MGB-3' and 5'-VIC-CTCTTTCAACCCACCTTAT-MGB-3') were used for the assay to differentiate asparagine or tyrosine at residue 501 of spike protein. The primers (forward: 5'-ACCTTTCTTTTCCAATGGTTACTT-3' and reverse 5'-TTAAATGGTAGGACAGGTATCAAA-3') and probes (5'-FAM-CTCTTTCAATGGTTACTT-3' and 5'-VIC-GTTCCATGCTATACATGT-MGB-3') were used to differentiate between the 69/70 deletion and wild-type spike protein.

### Virus culture

Only samples with a Ct value <30 were cultured, because previous work showed that surface and air samples with a Ct value >30 are not culturable [12]. Vero E6 (African Green monkey kidney) cells were used to culture virus from air and environmental samples. The cells were maintained in DMEM supplemented with heat-inactivated fetal bovine serum (10%) and penicillin/streptomycin (10,000 IU/mL and 10,000 μg/mL). For virus isolation, 200 μL of samples was added to 24-well plates. On day 0 and after 5–7 days, cell supernatants were collected, and RT-qPCR was performed to detect SARS-CoV-2, as described above. Samples with at least one log increase in copy numbers for the E gene (reduced Ct values relative to the original samples) after 5–7 days of propagation in cells compared with the starting value were considered positive by viral culture [21].

### SARS-CoV-2 laboratory surface stability assay

A laboratory experiment was performed to examine the stability and infectivity of SARS-CoV-2 dried on plastic surfaces. Three SARS-CoV-2 representative variants: Alpha (GISAID: EPI_ISL_693401), Beta (GISAID: EPI_ISL_770441) and wild-type D614G (GISAID: EPI_ISL_660788) were diluted to 1 x 10^5 plaque-forming units/mL. Five 2-μL droplets of virus culture were pipetted on a plastic surface (cell plates). The inoculated surfaces were dried in a safety cabinet for 1 h, after which they were visibly dry. The inoculated surfaces were soaked with 1 mL of virus transport medium for 30 min to elute the virus at three time points: 1, 24 and 72 h. The samples were titred by the plaque assay as described previously [22].

### Prevalence of variants in patients on the day of sampling

S gene target failure was used routinely as a proxy to indicate infection caused by the Alpha (B.1.1.7) variant. Ward admission and discharge dates in electronic patient records were used to determine which patients were in the clinical area on the day of sampling. Patients with at least one positive SARS-CoV-2 PCR test within 14 days before the sampling day were considered to have COVID-19.

### Ethics

In 2020, Imperial National Institute for Healthcare Research (NIHR) Biomedical Research Centre developed the secure Clinical Analytics, Research and Evaluation (iCARE) high-

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**Figure 1.** Overall percentage of surface (solid bars) and air (open bars) samples positive for severe acute respiratory syndrome coronavirus-2 RNA in April 2020 vs January 2021. Two hundred and eighteen surface samples were collected in April 2020 and 270 were collected in January 2021; 27 air samples were collected in both April 2020 and January 2021.
performance analytics environment, which hosts secondary care data from Imperial College Healthcare NHS Trust (ICNT) and COVID-19 test results from North West London (NWL) Pathology. The iCARE system provides linked health records from ICNT and NWL Pathology which have been de-identified and made available for approved research. This study was approved by the Imperial Academic Health Science Centre COVID Research Committee, the COVID-19 NWL Data Prioritization Group, and the Discover Research Advisory Group, which jointly provide a governance mechanism.

Results

No viable virus was recovered from any of the surface or air samples (Table II). In the clinical areas that were selected for sampling in January 2021 as being comparable to those sampled in April 2020, the overall percentage of air and surface samples from which SARS-CoV-2 RNA was detected by PCR was significantly lower in January 2021 compared with April 2020 (Figure 1, Table II). The overall percentage of surfaces contaminated with detectable SARS-CoV-2 RNA in April 2020 was 52% (N=114) of 218 surfaces, compared with 5% (N=14) of 270 surfaces in January 2021 (P<0.001, Fisher’s exact test). The overall percentage of air samples contaminated with detectable SARS-CoV-2 RNA in April 2020 was 48% (N=13) of 27 air samples compared with 4% (N=1) of 27 air samples in January 2021 (P<0.001, Fisher’s exact test). SARS-CoV-2 RNA was detected in patient care areas, nursing stations and staff rooms in April 2020, whereas SARS-CoV-2 RNA was only detected in areas occupied by patients or patient bathrooms in January 2021 (except for the lift buttons in the lift lobby of the main hospital building) (Figure 2, Table II). At least one positive air sample was identified from every ward/area sampled in April 2020. In January 2021, the one positive air sample was detected in a bay dedicated to patients undergoing aerosol-generating procedures.

There was no clear difference in the proportion of surface and air samples positive for SARS-CoV-2 RNA based on the type of ventilation in the ward. SARS-CoV-2 RNA was identified by PCR from 6% (N=5) of 80 surface samples and 12% (N=1) of eight air samples from the two wards selected because they were naturally ventilated. The proportion of surface and air samples from naturally ventilated wards was not significantly different compared with areas with mechanical ventilation (P>0.05 for both). There was also no clear difference in the proportion of surface and air samples positive for SARS-CoV-2 in the renal dialysis unit: 2% of 40 surface samples and none of the four air samples.

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**Figure 2.** Severe acute respiratory syndrome coronavirus-2 envelope (E) gene copy number from surface swabs. The quantity of E gene copy number per swab is shown. Positive swabs and negative swabs are indicated by solid circles and open circles, respectively. All samples from the adult intensive care unit were negative, so are not shown. COVID-19, coronavirus disease 2019; PPE, personal protective equipment; CPAP, continuous positive airway pressure; NIV, non-invasive ventilation.
Fifty-one percent of 180 patients in the areas that were sampled had S gene knockouts consistent with the Alpha variant. Thirteen of 21 (62%) surface and air samples that detected SARS-CoV-2 RNA could be genotyped by PCR; eight (38%) were the Alpha variant.

In the laboratory stability assay, all three variants tested survived for at least 72 h with a $<3\log_{10}$ reduction in viable count (Figure 3).

**Discussion**

This study was undertaken to compare SARS-CoV-2 surface and air contamination in the second wave of COVID-19 in acute care hospitals in London compared with the first wave. Whilst SARS-CoV-2 RNA was detected in clinical and non-patient care areas, no viable virus was recovered. Despite similar levels of bed occupancy by patients with COVID-19, the levels of air and surface RNA contamination in a range of clinical areas chosen to be comparable with the areas sampled in the first wave were significantly lower in the second wave compared with the first wave. There was no obvious correlation between the type of ventilation in the area and the level of surface and air contamination with SARS-CoV-2 RNA. SARS-CoV-2 RNA surface and air contamination was not notably different in a renal dialysis unit compared with the general ward setting. Approximately half of SARS-CoV-2 from patients in the clinical areas at the time of sampling and SARS-CoV-2 RNA identified in surface and air samples was the Alpha variant. A laboratory study showed that the Alpha variant did not have notably different environmental survival properties compared with other variants.

The proportion of surface and air samples from which SARS-CoV-2 was detected was considerably lower in January 2021 during the second wave in the UK compared with April 2021 during the first wave. There may be several factors driving this difference, including enhanced prevention measures (summarized in Table III) implemented between the COVID-19 waves, the emergence of new variants, changes in patient mix, the introduction of patient and staff vaccination, and changes in the use of clinical areas. It seems most likely that changes in prevention measures implemented between the two waves had the greatest impact on the levels of surface and air contamination measured. Other studies have investigated surface and air contamination with SARS-CoV-2 [11–14, 23, 24]. Consistent with these findings, whilst most studies have identified at least some SARS-CoV-2 RNA on surfaces and air in patient care areas, few have been able to culture viable virus [13, 23, 24]. It is not clear why no viable virus was cultured from surfaces or air in the present study; possibilities include low viral load, methodological issues (e.g. choice of surface and air sampling technique, viral transport medium, or laboratory culture methods), or a combination of these factors. In common with the present study, one study from the USA found a reduction in the proportion of surfaces from which SARS-CoV-2 RNA was detected from 11% to 2%, which they attributed to improved environmental and patient management practices [25]. Genotyping of the environmental samples found strong evidence that they originated from patients on the ward at the time of sampling.

This laboratory study suggests that the three variants tested could survive for $>72$ h when dried on to a plastic surface with a $<3\log_{10}$ reduction. This rate of decay did not differ from the other two variants tested, suggesting that differences in environmental persistence are not a factor driving the increased transmissibility of the Alpha variant [15]. The present findings on the environmental stability of these viruses is in line with the findings of others [9,10,26]. For example, one study evaluated the capacity of a range of SARS-CoV-2 variants, including the Alpha variant, to survive on stainless steel surfaces [26]. In this study, there was no clear difference in the capacity of the variants tested to survive on the steel surface, and all survived for $>72$ h with an approximate $3\log_{10}$ reduction.

SARS-CoV-2 is able to transmit more efficiently in indoor spaces with inadequate ventilation [6–8,18]. Therefore, this study evaluated whether differences in ward ventilation impacted the level of surface and, in particular, air contamination. No differences in contamination level based on ward ventilation system were found. However, it is important to note that natural ventilation can provide efficient air changes if it is designed optimally [18], and the effectiveness of the ventilation system was not measured as part of this study. There has been much debate about the role of particle size in the transmission of SARS-CoV-2 via air [8]. As particle size was not measured in the present study, the results cannot add to this debate.

**Figure 3.** Survival of severe acute respiratory syndrome coronavirus-2 variants dried on to plastic surfaces. Mean and standard deviation of plaque-forming units (PFU) and envelope (E) gene copies are shown. Black squares, wild-type D614G variant; blue circles, Alpha variant; red triangles, Beta variant.
Patients who are dialysis dependent are at particular risk of COVID-19 [17,27]. These patients require regular visits to dialysis units with consequent contact with other dialysis-dependent patients, live outside the hospital, and require regular travel to dialysis units. The first wave of COVID-19 resulted in outbreaks in patients undergoing renal dialysis, with poor clinical outcomes [17,28]. The results of this study suggest that a high burden of surface and air contamination was not a feature of the epidemiology of COVID-19 in renal dialysis units.

Strengths of this study include the selection of a range of clinical and non-clinical areas to represent a breadth of clinical services provided by the study hospitals, including a renal dialysis unit. The selection of clinical areas enabled the comparison of contamination levels between the first and second waves. Some wards with natural ventilation alone were sampled in order to provide information on whether the ward-level ventilation system affects contamination levels. The sampling methods used included both PCR and an attempt to culture live virus from environmental specimens. This study made use of routinely collected data on the inferred genotype of SARS-CoV-2 from patients, and PCR genotyping of SARS-CoV-2-positive air and surface samples was undertaken which enabled the proportion of cases of the Alpha variant in patient and environmental samples to be examined. A laboratory evaluation of the survival properties of a range of SARS-CoV-2 variants, including the Alpha variant, was undertaken.

Limitations of this study include that each area was only sampled once; without longitudinal sampling, the findings provide a snapshot of contamination levels. Exactly the same area was sampled where possible, but, in some cases, changes in the use of clinical areas between April 2020 and January 2021 meant that comparable areas had to be used for sampling. Whilst all clinical areas sampled were fully occupied by

| April 2020 | January 2021 |
|-----------|-------------|
| Patients  | Asymptomatic testing of all elective and non-elective admissions, and serial SARS-CoV-2 testing of all inpatients in place so more rapid identification of infected patients | Surgical masks for all patients (where possible) |
|           | No recommendation for surgical masks for patients | Improved bed spacing |
|           | Standard bed spacing | Active identification and management of COVID-19 outbreaks amongst patients |
|           | No requirement for active identification and management of COVID-19 outbreaks amongst patients | |
| Staff     | No recommendation for surgical masks outside of direct patient care | Universal surgical masks for all staff in healthcare buildings, including in all clinical areas |
|           | No specific measures for office spaces | ‘COVID-secure’ measures in office spaces (including physical distancing) |
|           | No specific measures for office spaces | ‘COVID-secure’ measures in office spaces (including physical distancing) |
|           | No routine staff testing | Improved compliance with recommended PPE (reductions in both excessive use and under use) and hand hygiene |
|           | Challenges with PPE use | Initial implementation of a staff vaccination programme |
|           | No vaccination | |
|           | Normal footfall on wards | Reduced footfall on wards |
|           | No requirement for active identification and management of COVID-19 outbreaks amongst staff | Active identification and management of COVID-19 outbreaks amongst staff |
| Visitor/carer restrictions | Visiting permitted | No ward visitors (outside of exceptional circumstances) |
|           | No specific provision for enhanced hand hygiene at two hospital entrances | Welcome stations introduced to promote hand hygiene and masks at hospital entrances |
| Environmental hygiene | No specific increase in ward cleaning | Cleaning frequency increased to meet national recommendations. This included one additional clean for each clinical area, plus a further additional touchpoint clean. In addition, a new touchpoint cleaning programme began in public spaces |
| Ventilation | No specific improvements in ventilation | Exterior windows opened where safe and possible |

PPE, personal protective equipment; SARS-CoV-2, severe acute respiratory syndrome coronavirus-2.
patients with COVID-19, the role of viral load and patient vaccination status on the shedding of SARS-CoV-2 into the environment was not examined. Samples were not collected from patients, air and surfaces contemporaneously, meaning that contamination levels cannot be linked to individual patients. The methods used to provide regular reports on the inferred prevalence of the Alpha variant in patients assumed that patients were physically in the ward; this may not have been the case if patients were temporarily in different parts of the hospital, such as for a procedure. Whilst two wards with natural ventilation alone were sampled, several of the other wards included parts of the ward with natural ventilation alone. Also, air flow or other measures of air quality (e.g. CO2 levels of bacterial counts) were not used. Finally, this study was undertaken before the emergence of the Omicron variant.

These findings underline the potential risk of surface and air contamination in managing COVID-19, particularly during direct patient care. The findings suggest that COVID-19 prevention measures that have been introduced have reduced the level of surface and air contamination. The findings also suggest that enhanced ability to shed or survive on surfaces and/or in air are not the key driver for increased transmissibility of variants that have emerged recently. Based on these results, no changes in current practice are recommended. However, a continued focus on infection prevention and control activities is required to prevent the in-hospital transmission of COVID-19 [29].

Further work that would follow-on from this study includes longitudinal environmental sampling of surfaces and air in clinical and non-clinical areas to understand how patterns of contamination change over time. Further sampling should consider measurement of air flow to correlate air flow and environmental hygiene measures with contamination levels, measurement of particle size, and genotyping of isolates, and linking environmental sampling to contemporaneous patient samples would enable the evaluation of patient level risk factors for the shedding of SARS-CoV-2 such as viral load, duration of illness, and symptoms. Further work is required to understand the increased transmissibility of SARS-CoV-2 variants, and evaluating the role of patient and staff vaccination in the shedding of SARS-CoV-2 into the environment.

This study reinforces that SARS-CoV-2 RNA can contaminate surfaces and air in healthcare settings, and suggests that enhanced infection prevention measures have reduced the burden of SARS-CoV-2 RNA on surfaces and air in healthcare facilities. This study did not find evidence that enhanced environmental survival properties are linked to the Alpha variant, which was prevalent at the time of the study.

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Conflict of interest statement

JAO is a consultant to Gama Health Ltd and has given paid talks for ASP, Diversey, Ecolab and Knowlex. The other authors declare no potential conflicts of interest related to this study.

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Disclaimer

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