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## Original Article

## Routes of SARS-CoV-2 transmission in the intensive care unit: A multicentric prospective study



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## ABSTRACT

**Background:** The risk of SARS-CoV-2 transmission to health care workers in intensive care units (ICU) and the contribution of airborne and fomites to SARS-CoV-2 transmission remain unclear. To assess the rate of air and surface contamination and identify risk factors associated with this contamination in patients admitted to the ICU for acute respiratory failure due to SARS-CoV-2 pneumonia.

**Methods:** Prospective multicentric non-interventional study conducted from June 2020 to November 2020 in 3 French ICUs. For each enrolled patient, 3 predefined surfaces were swabbed, 2 air samples at 1 m and 3 m from the patient's mouth and face masks of 3 health care workers (HCW) were collected within the first 48 h of SARS-CoV-2 positive PCR in a respiratory sample. Droplet digital PCR and quantitative PCR were performed on different samples, respectively.

**Results:** Among 150 included patients, 5 (3.6%, 95%CI: 1.2% to 8.2%) had positive ddPCR on air samples at 1 m or 3 m. Seventy-one patients (53.3%, CI95%: 44.5% to 62.0%) had at least one surface positive. Face masks worn by HCW were positive in 6 patients (4.4%, CI: 1.6% to 9.4%). The threshold of RT-qPCR of the respiratory sample performed at inclusion (odds ratio, OR= 0.88, 95%CI: 0.83 to 0.93,  $p < 0.0001$ ) and the presence of diarrhea (OR= 3.28, 95%CI: 1.09 to 9.88,  $p = 0.037$ ) were significantly associated with the number of contaminated surfaces.

**Conclusion:** In this study, including patients admitted to the ICU for acute respiratory failure " contact route " of transmission, i.e. through fomites, seems dominant. While presence of SARS-CoV-2 in the air is rare in this specific population, the presence of diarrhea is associated to surface contamination around Covid patients.

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## Introduction

Three years into the pandemic, there is conflicting debate about the contribution of different routes of transmission [1] of SARS-CoV-2. Like other respiratory viruses, SARS-CoV-2 can be transmitted by

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air or by hand contact. Several authors have attempted to answer this question by trying to optimize preventive measures, but as far as we know, we still do not have a clear answer to this question. There is no doubt that SARS-CoV-2 can infect humans by a “respiratory route” or by a “contact route” after being carried by hand. However, the proportion of each route of transmission remain unclear. Some authors argue that the “respiratory route” is predominant [2], while others suggest that the “contact” route is predominant.

During the various waves of the pandemic, several authors have demonstrated the presence of viral RNA on surfaces [3–5], more rarely in air samples [6,7]. However, a viable virus has rarely been identified by culture [8–10]. One of the difficulties is that many confounding factors make the literature difficult to interpret. Indeed, several factors could contribute to air or surface contamination [11]. The delay between contact and onset of symptoms, the intensity of symptoms [12], the type of care and the duration of exposure appear to be among several factors associated with a higher risk of contamination.

Understanding the different routes of transmission is the first step to help healthcare workers (HCWs) better adapt protective measures to reduce the risk of secondary infection. During the pandemic, HCWs in intensive care units were particularly exposed to SARS-CoV-2 infection because they not only cared for a large number of patients, but were also exposed to many situations considered to be aerosol-generating procedures [13]. Despite these facts, authors have suggested a lower risk of SARS-CoV-2 acquisition in this specific population citing better protection [14] or lower risk due to delayed treatment after symptom onset [15]. The discrepancy in SARS-CoV-2 samples from ICU patients is important: on the one hand, some studies do not find any virus in the air [16–19] while on the other hand, other authors were able to isolate viable virus from air and surface samples of hospitalized ICU patients [20]. Thus, the role of contaminated surfaces and air in the spread of SARS-CoV-2 in ICU environments remains unclear.

Our study aimed to assess the air and surface contamination rate and identify risk factors associated with this contamination in infected patients requiring ICU care for acute respiratory failure.

## Materials and methods

This prospective multicentric non-interventional study was conducted from June 2020 to November 2020 in 3 intensive care units (ICU) of academic hospitals of the Assistance Publique – Hôpitaux de Paris, France. Consecutive adult patients, admitted to one of the participating units for acute respiratory failure due to COVID-19 were enrolled in the study.

To meet the inclusion criteria, patients admitted to the ICU for acute respiratory failure due to Covid-19 should have positive RT-qPCR on a respiratory tract secretion (nasopharyngeal or tracheal aspirate, sputum, or broncho-alveolar lavage) within the last 48 h prior to enrollment. The following data were collected: age, gender, vaccination status against SARS-CoV-2;  $C_t$  (cycle threshold) for SARS-CoV-2 on respiratory samples within the last 48 h, and duration of symptoms prior to environmental sampling. On the day of sampling: respiratory rate, fever, respiratory symptoms such as cough, sneezing, sputum, diarrhea (defined as more than 3 episodes of loose stools or one episode of liquid stools). Comorbidities were also collected such as: Diabetes mellitus; Arterial hypertension; COPD. Immunocompromised status was defined as: neutropenia < 1 G/L, or administration of any of the following drugs: cytotoxic chemotherapy in the last year, Rituximab in the last year, more than 10 mg of steroids/day for more than 14 days in the last 3 months, any immunosuppressive agents in the last 3 months.

Various modes of respiratory support were duly recorded such as: Non-invasive Ventilation; Invasive Mechanical Ventilation; High

Flow Nasal Cannula Oxygenation; Conventional face mask oxygenation and Nebulization if administered.

To assess viral spread around Covid-19 patients, we systematically swabbed 3 predefined surfaces and collected 2 air and face mask samples from healthcare workers (HCW) for each enrolled patient as described below:

### Surface samples

Surface samples were collected at three specific points (External surface of the oxygen device used by the patient, intravenous infusion line, table or computer at least 2 m from the patient's head) using a pre-impregnated e-swab (reference ESWABR1, COPAN). The e-swab was rolled on the external surface of the oxygenation device used by the patient (the tube delivering oxygen of the high flow nasal cannula, the tube used during invasive mechanical ventilation, the mask of oxygen or non-invasive ventilation). A 100 cm<sup>2</sup> area was swabbed for each sample. The swabs were soaked in Viral Transport Medium (VTM) and rubbed over their entire surface against the various objects described above before being immersed in VTM tubes and taken to the laboratory. Transport medium samples were divided equally into two sterile tubes, one for SARS-CoV-2 RT-qPCR and one stored at – 80 °C for later in vitro viral isolation.

### Air samples

Air samples were collected using the Coriolis® system and placed at the same height as the patient's head, at a distance of 1 and 3 m from the patient's head. Aspiration was continuous at 100 L/min for 6mn to obtain 600 L of air. Air was vortexed in 15 mL phosphate buffered saline (PBS). PBS was immediately frozen at – 80 °C until SARS-CoV-2 was detected by digital droplet PCR (ddPCR) on defrosted PBS.

### Face masks samples

The outer surface of a face mask worn by different healthcare providers for a single use was analyzed. The outer surface for the HCW's mask was processed according to the protocol defined above to obtain 3 mL of sample, equally divided into two aliquots. 1) Cut 25 cm<sup>2</sup> of the inner surface (for the patient's mask) or the outer surface (for the caregiver's mask) of the mask with a scalpel. 2) Place it in a 50 mL Falcon® containing 3.0 mL of 1X PBS (Phosphate-Buffered Saline) if it is a FFP2 mask or in 3.5 mL of 1X PBS if it is a surgical mask, as this type of mask is more absorbent (average loss of 0.5 mL of PBS). 3) Mix by suction and backflow with the pipet for 5 s 4) Vortex for 10 s

5) Finally, remove the 1X PBS and aliquot into 2 tubes (one for RT-qPCR and one for viral isolation test).

Digital droplet PCR was performed on air samples (description below) while quantitative PCR was performed other samples.

### PCR methods

For ddPCR, 10 µL of extracted RNA were amplified using a one-step RT-ddPCR kit (Bio-Rad). Two target genes, nucleocapsid (N), and RNA-polymerase (RdRP-nsp12) were searched. Primers have been published elsewhere [21] while optimal primer and probe concentrations for each ddPCR assay have been previously described [22]. Probes were labeled with either FAM (N) or with HEX (RdRP-nsp12) fluorescent dyes, and 3'-modified by Iowa Black Quencher (IBQ, Integrated DNA technologies, Coralville, Iowa, USA), which produces less background noise. Droplets were generated and read on the QX200 system (Bio-Rad). RT and PCR amplification were performed in an ICycler PCR instrument (Bio-Rad) with the following steps: 1 cycle [25 °C/3mn, 50 °C/60 min, 95 °C/10 min], and 40 cycles

[95°/30 s, 55 °C/1mn] and a termination step of 98 °C/10 min. All cycles were performed at a ramp rate of 2 °C/sec. The determination of the limit of detection (LoD) was based on the calculation of the limit of blank (LoB). LoB is defined as the maximal number of positive droplets obtained from pre-pandemic RNA samples negative for SARS-CoV-2, calculated according to a modified version of the procedure described by Armbruster and Pry[23]. The LoB defined for RdRP-IP4 (n = 3), and N (n = 4) were derived from the analysis of 110 ddPCR replicates from 65 different negative RNA samples with a mean droplet count of 16188 ± 1317 performed on 12 SARS-CoV-2-negative human nasopharyngeal specimens collected during the pre-COVID-19 era. The LoD was established for each SARS-CoV-2 target gene analyzed following the same guidelines and was set at 5 droplets for both tests.

#### Ethics:

Our study is classified as standard care and was approved by the Ethics Committee CPP Sud-Méditerranée 2027 under ID 2020-A00897–32. No additional human samples were collected for the study. The patients were informed and consent was obtained orally.

#### Statistical analysis

The sample size was determined to provide a more accurate estimation of the proportion. The expected incidence of air samples containing a positive viral load at one meter from the patient is 5%. We wanted a confidence interval greater than or equal to 1%, i.e. a precision of the order of ± 4% around this incidence. Thus, for an alpha risk of 5%, i.e. a confidence interval of 95%, 150 patients must be included according to the exact Clopper-Pearson method.

The data collected were described using the number and percentage (%) for the qualitative variables. The median and interquartile range (IQR) were used for the quantitative variables.

The proportions of patients with positive ddPCR on air samples (1 or 3 m) or positive qPCR on surface samples were estimated with 95% confidence intervals (CI) (Clopper–Pearson exact method). Associations between environmental contamination and patient characteristics were analyzed using the Chi-squared test or Fisher's exact test for categorical variables, and the Mann–Whitney test for quantitative variables. Surface contamination was defined by at least one positive RT-qPCR result. In a second analysis, the number of contaminated surfaces was considered as an ordinal variable with 0, 1 and 2 or 3 surfaces. All factors with  $P < 0.10$  in the univariate analysis of surface contamination were included in a multivariate ordinal Logistic Regression. To account for missing data, the multivariate model was conducted using multiple imputations through chained equations with 10 imputations obtained after 10 iterations. The variables considered in the imputation models were all included in the univariate analyses. Results were aggregated by pooling the estimates obtained on each imputed dataset according to Rubin's rules. All tests were two-sided, with  $P < 0.05$  considered significant. Analyses were performed using R Version 4.0.3.

## Results

A total of 150 patients were enrolled in the study during the defined period. Of these, 26% were female, with a median age of 65 [54–73] years old. The median time between the first symptoms and inclusion was 10 [7–13] days. Fifty-three patients (35%) had diabetes mellitus, 70 (46%) had arterial hypertension, only 7 (5%) had chronic obstructive pulmonary disease, and 11 (7%) were immunocompromised. The mean respiratory rate at inclusion was 26 [23–30] per minute, 65 patients had cough (44%), 15 (10%) had sputum, 13 (9%) had diarrhea and 63 (43%) were febrile. The median cycle threshold ( $C_t$ ) of the RT-qPCR performed on respiratory

**Table 1**  
Patient's characteristics.

Demographic data	
Women	40 (26%)
Age (years)	65 [54–73]
<b>Covid-19 data</b>	
Vaccination against SARS-CoV-2	0
Ct of SARS-CoV-2 PCR on respiratory sample	26 [22–30]
Symptoms duration before environmental sampling	10 [7–13]
Respiratory Rate	26 [23–30]
Fever	63 (42%)
Cough	65 (43%)
Sneezing	1 (1%)
Sputum	15 (10%)
Diarrhea	13 (9%)
<b>Comorbidities</b>	
Diabetes mellitus	53 (35%)
Arterial hypertension	70 (46%)
COPD	7 (5%)
Immunosuppression	6 (4%)
<b>Respiratory support</b>	
Non invasive Ventilation	9 (6%)
Invasive Mechanical Ventilation	45 (30%)
High Flow Nasal Cannula Oxygenation	60 (40%)
Conventional face mask oxygenation	36 (24%)
Nebulization	5 (3%)
<b>Air Stream determinant in patient's room</b>	
Active ventilation system	0
Open window	81 (74%)
Closed door	150 (100%)

samples at inclusion was 26 [22–30]. Patients received different types of respiratory support at inclusion: high-flow nasal cannula oxygenation (n = 60, 41%), non-invasive ventilation (n = 19, 13%), conventional oxygen (n = 36, 24%), invasive mechanical ventilation (n = 45, 30%).

Only 2 patients (1.4%, 95%CI: 0.2% to 5.0%) had positive ddPCR on air samples taken at 1 m from the mouth. Five patients (3.6%, 95%CI: 1.2% to 8.2%) had positive ddPCR on air samples at 1 m or 3 m from their mouth. Seventy-one patients (53.3%, CI95%: 44.5% to 62.0%) had at least one surface positive using a qPCR. The qPCR performed on the external part of the face mask of HCW was positive for anyone of the HCW (nurse, assistant-nurse or physician) in only 6 patients (4.4%, CI: 1.6% to 9.4%). This corresponded to 2 masks worn during clinical examination (physician), 1 during nursing care and 2 during personal hygiene care. Risk factor analysis could not be performed due to the low level of air contamination.

We highlight a significant association in univariate analysis between, the threshold of RT-qPCR performed in the patient's respiratory sample in the last 48 h before inclusion and at least one contaminated surface ( $p < 0.001$ ). Also, the threshold of RT-qPCR ( $p < 0.0001$ ) and diarrhea ( $p = 0.027$ ) were associated with the number of contaminated surfaces in univariate analysis (Table 3). The effects of the RT-qPCR threshold (odds-ratio, OR= 0.87, 95%CI: 0.81 to 0.93,  $p < 0.0001$ ) and diarrhea (OR= 3.28, 95%CI: 1.09 to 9.88,  $p = 0.037$ ) were confirmed in the multivariate model adjusted for cough (Table 4).

## Discussion

In this multicenter prospective study conducted in ICUs during the first wave and including patients admitted for ARF, we found a higher frequency of positive surface samples than air samples. In our work, 2 factors were associated with the risk of surface contamination, the threshold of RT-PCR in the respiratory sample performed in the 48 h before environmental sampling and the presence of diarrhea. In our study, the small number of events did not allow us to investigate risk factors associated with air contamination.

**Table 2**  
Results of SARS-CoV-2 positive PCR in environmental sampling around Covid-19 patients admitted to the ICU.

Environmental sampling	n/N	% (95%CI)
<b>Air Sampling:</b> 600 L, 100 L/m, during 6 min, at the top of the patient's head		
Air sample at 3 m	3/139	2.1% (4.5 to 6.2)
Air sample at 1 m	2/141	1.4% (0.2 to 5.0)
At least one of the two air samples positive	5/139	3.6% (1.2 to 8.2)
<b>Surface sampling:</b> at least 8 h after biocleaning, eSwab		
External face of oxygen device used by patient	31/132	23.5% (16.5 to 31.6)
Line of intravenous infusion	44/131	33.6% (25.6 to 42.4)
Table or computer at least 2 m from the patient's head	17/132	12.9% (7.8 to 19.8)
At least one of the three surface positive	71/133	53.3% (44.5 to 62.2)
<b>External surface of HCW face mask</b>		
Doctor	2/119	1.7% (2.0 to 5.9)
Nurse	2/132	1.5% (1.8 to 5.4)
Care assistant	2/121	1.7% (2.0 to 5.8)
At least one of the three masks positive	6/135	4.4% (1.6 to 9.4)

Our results contribute to the ongoing and crucial debate on the attributable proportion of airborne or contact transmission for SARS-CoV-2. The presence of viruses on the surfaces can be perceived as the accumulation over time of viruses present in the air and eventually ending up on the ground due to gravity. Our study suggests the importance of the contact route in intensive care patients due to fomites. However, it is difficult to know whether this contamination occurs directly or indirectly through the hands of healthcare workers.

Our multivariate analysis suggested that surface contamination was also significantly associated with diarrhea. From a meta-analysis, the authors suggested that the pooled prevalence of all gastrointestinal symptoms was 17.6% and the pooled prevalence of stool samples positive for viral RNA was 48.1%[24]. The authors also suggested that stool excretion persisted while the respiratory

**Table 4**  
Results of multivariate analysis focusing on surface contamination with SARS-CoV-2 around Covid patients admitted to the ICU for acute respiratory failure.

Parameter	OR [IC95%]	p
Ct of SARS-CoV-2 PCR on respiratory sample	0.87 [0.81-0.93]	< 0.0001
Diarrhea	3.28 [1.09-9.88]	0.037
Cough	0.58 [0.28-1.21]	0.15

samples were negative.[24] This well-documented shedding suggests direct or indirect dissemination around the patient, which may explain the frequency of positive specimens. This result is interesting because diarrhea is a symptom that has often been overlooked in the literature, with the most common preventive measures focusing on the risk of respiratory contamination.

**Table 3**  
Results of univariate analysis focusing on surface contamination with SARS-CoV-2 around Covid patients admitted to the ICU for acute respiratory failure.

Parameter	OR [IC95%]	p
Women	1.17 [0.56-2.45]	0.68
Age	1.02 [0.99-1.04]	0.22
<b>Evolution of Covid before ICU admission</b>		
Symptoms duration before environmental sampling	0.96 [0.9-1.03]	0.24
Ct of SARS-CoV-2 PCR on respiratory sample	0.87 [0.81-0.93]	< 0.0001
<b>Comorbidities</b>		
Arterial hypertension	1.22 [0.63-2.35]	0.56
Diabetes mellitus	1.26 [0.66-2.42]	0.49
COPD	1.78 [0.88-3.58]	0.11
Immunosuppression	0.97 [0.2-4.77]	0.97
Ongoing treatment against cancer	0.72 [0.05-9.56]	0.80
Any ongoing treatment before Covid onset	1.16 [0.16-8.62]	0.88
Oral Steroids before Covid onset	0.93 [0.42-2.09]	0.86
Renin-Angiotensin System Blockers drugs before Covid onset	0.5 [0.14-1.77]	0.28
	1.72 [0.66-4.5]	0.27
<b>Clinical presentation</b>		
Respiratory Rate	1.00 [0.97-1.03]	0.89
Cough	0.57 [0.29-1.1]	0.095
Sputum	1.31 [0.43-4.04]	0.63
Fever	0.74 [0.38-1.43]	0.37
Diarrhea,	3.46 [1.15-10.39]	0.027
Other associated infection	0.38 [0.09-1.53]	0.17
<b>Respiratory management in the ICU</b>		
Non invasive ventilation	1	0.30
High Flow Nasal Cannula	1.00 [0.40-2.52]	0.99
Invasive Mechanical Ventilation	1.43 [0.67-3.06]	0.35
Enclosed suction system	1.59 [0.72-3.54]	0.26
Heated humidifier	1.80 [0.75-4.32]	0.19
Heat and moisture exchange filter	0.4 [0.1-1.62]	0.20
Spontaneous Ventilation	0.69 [0.36-1.35]	0.28
Oxygenotherapy	0.73 [0.38-1.41]	0.35
Nebulisation	0.68 [0.11-4.37]	0.69
<b>Room management</b>		
Open window	0.57 [0.22-1.43]	0.23
Negative pressure in patient's room	2.32 [0.11-51.35]	0.59
Air renewal device	2.35 [0.11-50.44]	0.58



Similarly, our work suggests less frequent contamination of air samples, despite the use of digital droplet PCR to improve SARS-CoV-2 detection. These results confirm low contamination and are consistent with most studies published to date [25,26]. Although used as a surrogate marker, mask contamination was rare in our study, reaching less than 5% of sampled masks. This finding is consistent with our results on air samples and increases our confidence in our data because two different detection techniques were used for air and mask sampling. Numerous studies conducted during the pandemic have attempted to answer the question of airborne contamination [27,28], with surprisingly inconsistent results. For instance, a review of the literature suggested that only 10% of the samples collected were positive [29] and in rare cases this corresponded to the presence of a viable virus [30], whereas a recent study conducted in the ICU and involving only 20 patients detected viral RNA in 67% of the air samples, of which 28% had a viable virus [31].

In fact, the results of studies conducted in the ICU are contradictory, suggesting percentages of positive air samples ranging from 0 to 67%. These discrepancies should prompt us to discuss the numerous confounding factors that complicate the interpretation of the results [32]. Indeed, airborne dissemination seems to differ depending on the circulating variants [33]. It is also possible that the frequency of positive air samples may vary according to the time period of each study. Recent studies have also suggested a correlation between the precocity of symptoms [34] and air contamination [31]. Indeed, in a recent study, 67% of air samples were positive. However, the median delay between symptom onset and air sampling in this study was 3 days, which was 3 times shorter than in our study. Several authors have also suggested that negative air sampling in the ICU may be explained by the fact that patients are often admitted late in the course of the disease [43]. Another confounding factor, often neglected in the literature, is related to the sampling technique and the volume of air sampled. We sampled air volumes that are relevant to the volume of air inspired by a healthcare worker in the event of prolonged care of one hour. In addition, our sampling technique is quite different from the techniques used in other works, as several authors with frequent positive air samples used an impaction sampling method [35]. We believe that airborne contamination should not be discussed as a binary outcome since it is now known that SARS-CoV-2 can spread by the respiratory route. In our opinion, the question should focus on the risk of exposure. Since no HCW could breathe all the air in a patient's room, we chose to sample 600 L of air, which is one hour of human tidal volume (500 mL, 20/mn, for 1 h). In our work, the ventilation technique did not seem to be associated with a risk of environmental contamination. This fundamental question is still very much debated in the literature, with some suggesting [36] that there is no correlation between the ventilation technique used and others suggesting that contamination is more frequent when high flow nasal oxygen is used. [32]. Indeed, closed-circuit ventilation of a certain number of patients seems to completely reduce the risk of air contamination, except in the case of accidental circuit leakage. Several authors have argued that the probability of airborne detection probably depends on the percentage of nonventilated patients included in the study [37]. Finally, other confounding factors [38] could alter the results of airborne specimens, such as: factors related to external conditions (humidity, temperature, wind speed, chemical composition of the air) and others related to sampling methods (type of impactors, type of culture media, sampling conditions). In fact, like all viruses, SARS-CoV-2 is sensitive to humidity, heat and UV [39], characteristics that change daily and are rarely taken into account when interpreting the results of clinical studies. Similarly, the influence of ancillary treatments, such as air renewal or ventilation systems, modify airborne viral concentrations and introduce additional confounding factors.

Our study had both strengths and limitations. One of the main strengths is the standardized sampling strategy, which has been

approved in many previous works [40] and gives us a clinical experience that helps to avoid bias. Secondly, sampling was performed without any air treatment, which could have caused turbulence and altered the results. Third, surfaces were used as a surrogate for cumulative airborne contamination because airborne virus particles eventually settle on surfaces after a variable amount of time in the air. Our work found that diarrhea and HCW manipulation due to patient diarrhea were associated with surface contamination. This highlights that surface contamination is not only a surrogate for cumulative airborne virus particles, but also takes into account the "contact route" of virus shedding. Finally, there was no opportunity to reduce the patient's viral load, as the study was conducted at a time when antiviral medication was not available. Our results can be considered as the "natural history of SARS-CoV-2 shedding during Covid-19" in patients requiring ICU admission. However, there are several limitations. First, despite a large number of samples (1200 qPCR) our study is limited to 150 patients in the pandemic context. Second, this work was done during the first waves and does not consider the latest variants of interest. We included patients infected with the wild strain, the alpha variant and, in rare cases, the delta variant. However, this does not allow us to draw conclusions about the risks of airborne contamination at this stage of the pandemic. Third, we included only patients admitted to the ICU and did not evaluate patients admitted to other wards. In fact, the risk and airborne contamination could differ depending on the time elapsed between the first symptoms and sampling [34]. Fourth, we collected only 3 surface samples on a given day, which limits the possibility of detecting contamination. In addition, sampling was performed at a single time point during the illness, which did not allow us to look for longitudinal contamination. Fifth, even if we analyzed more than 1000 samples for viral detection, data from 150 patients should be taken with caution in a pandemic reaching near to one billion contaminations. Sixth, a major limitation lies in the absence of viral culture performed to assess the viability of positive samples by RT-PCR. Indeed, in the absence of viral culture, we cannot confirm the infectious nature of our samples. However, based on the literature data on viability of SARS-CoV-2 on surfaces [10] and the high  $C_t$  of our samples, the hypothesis of a very low contamination by "respiratory route" in this specific ICU population seems plausible. Moreover, during the first waves, all ventilation systems were turned off to reduce the risk of nosocomial contamination, and windows were left open in most of the bedrooms of Covid-19 patients to improve air renewal and reduce the risk of HCW contamination. We recently learned that this decision has had an impact on viral spread in patient rooms due to uncontrolled airflow, such as an outside breeze or airflow from an open door [38]. Finally, because no vaccine was available during the study period, we have no data on the risk of environmental contamination around SARS-CoV-2-infected patients with prior SARS-CoV-2 vaccination.

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## Take home messages

In Covid patients admitted to the ICU for acute respiratory failure, viral dispersion around patients reach more than 50% of the surface while less than 5% of air samples were positive arguing for a important contribution of the "contact route" of transmission, i.e. through fomites. Two factors are associated with surface contamination: the viral load in respiratory samples and the presence of diarrhea.

## CRedit authorship contribution statement

YTL and JRZ drafted the manuscript, designed the protocol and were responsible for the research. AE, GV, SB, DR, AL, YTL and JRZ collected air and surface samples. PP and AM performed the digital droplet PCR. CA and HD performed the qPCR. GV and YC provided intellectual support.

## Declaration of Competing Interest

there is no conflict of interest.

## Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.jiph.2024.05.042](https://doi.org/10.1016/j.jiph.2024.05.042).

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