



## Surface contamination with SARS-CoV-2: A systematic review

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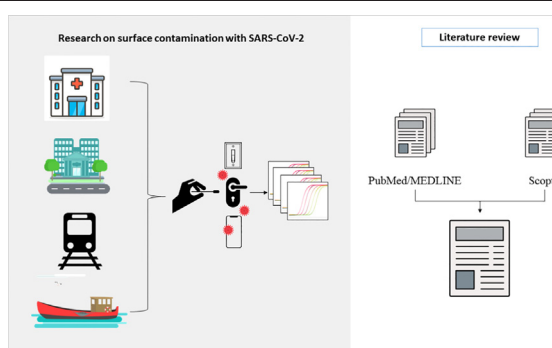
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### HIGHLIGHTS

- SARS-CoV-2 RNA has been detected in a wide range of facilities and surfaces;
- 17.7% of samples in hospital settings and 10.1% in non-hospital settings were positive for SARS-CoV-2 RNA, using various molecular methods;
- 6 out of the 37 studies have evaluated the viability/infectivity of SARS-CoV-2 from 242 positive surface samples;
- No viable virus could be isolated from the 242 samples with SARS-CoV-2 RNA detected by RT-qPCR;
- COVID-19 fomite transmission has not been demonstrated.

### GRAPHICAL ABSTRACT



### ARTICLE INFO

#### Article history:

Received 9 April 2021

Received in revised form 19 July 2021

Accepted 20 July 2021

Available online 24 July 2021

Editor: Damia Barcelo

#### Keywords:

SARS-CoV-2

COVID-19

Environmental contamination

Public health

Environmental health

### ABSTRACT

Little is known about contaminated surfaces as a route of transmission for SARS-CoV-2 and a systematic review is missing and urgently needed to provide guidelines for future research studies. As such, the aim of the present study was to review the current scientific knowledge and to summarize the existing studies in which SARS-CoV-2 has been detected in inanimate surfaces. This systematic review includes studies since the emergence of SARS-CoV-2, available in PubMed/MEDLINE and Scopus. Duplicate publications were removed, and exclusion criteria was applied to eliminate unrelated studies, resulting in 37 eligible publications. The present study provides the first overview of SARS-CoV-2 detection in surfaces. The highest detection rates occurred in hospitals and healthcare facilities with COVID-19 patients. Contamination with SARS-CoV-2 on surfaces was detected in a wide range of facilities and surfaces. There is a lack of studies performing viability testing for SARS-CoV-2 recovered from surfaces, and consequently it is not yet possible to assess the potential for transmission via surfaces.

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**1. Introduction**

On December 2019, in the city of Wuhan, China, a new coronavirus from the *Betacoronavirus* genus was isolated for the first time from a cluster of patients with an unrecognizable acute pneumonia (Wu et al., 2020). It was first reported that the only common denominator among the patients was that all of them visited the Huanan Seafood Wholesale Market in Wuhan (Peeri et al., 2020). Recent retrospective investigations concluded that not all early cases of disease had associations with the Huanan Market (WHO, 2021). The newly identified virus was named severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) (Wu et al., 2020), it spread in China and was quickly reported in nearly all countries and territories around the world (JHU, 2020; WHO, 2020a) to such an extent that it is now responsible for the ongoing global pandemic of Coronavirus Disease 2019 (COVID-19).

The *Coronaviridae* family is composed of enveloped single stranded RNA viruses with positive polarity, and members of this family are generally the causing agents of infections in the upper respiratory tract (Payne, 2017). According to the World Health Organization (WHO), the main transmission routes of SARS-CoV-2 are close contact between individuals by respiratory droplets smaller than 5 µm of diameter (Rothan and Byrareddy, 2020; WHO, 2020b). Droplet aerosols produced by infected individuals are an issue of significant importance and concern that should be considered to reduce the risk of new infections. In fact, a recent review study concluded that transmission of SARS-CoV-2 between people is mainly through viruses suspended either on droplets or aerosols (Meyerowitz et al., 2021a). According to WHO, aerosol-generating medical procedures might increase transmission of SARS-CoV-2, however air transmission outside healthcare settings has not yet been widely recognised as a transmission pathway (WHO, 2020b).

Air pollution seems to play a role on the spread of SARS-COV-2 and lethality of COVID-19, above all particulate matter (Bontempi, 2020; Coccia, 2020; Copat et al., 2020; Domingo et al., 2020; Gonçalves et al., 2021). It has been hypothesized that certain air pollutants may carry adherent SARS-CoV-2 virions, and consequently, the question of whether an interpersonal distance of 2 m is sufficient to prevent transmission between people has been raised (Adhikari and Yin, 2020; Comunian et al., 2020; Marquès et al., 2021; Setti et al., 2020a, 2020b; Yao et al., 2020; Zoran et al., 2020).

In addition to these main routes of transmission of SARS-CoV-2, a compelling body of evidence has growingly pointed contaminated surfaces as a potential route of transmission (Arav et al., 2020a; Meyerowitz et al., 2021b; Zheng et al., 2020a). Nearly a half a century ago, a review paper on the persistence of many viruses on different types of surfaces was published, highlighting for the first time the possible role of inanimate surfaces in the transmission of viruses (Mahl and Sadler, 1975). From then on, a vast amount of data has been produced on the topic and it was later applied to SARS-CoV (that emerged in 2002) (Meyerowitz et al., 2021a, 2021b). Particularly, generated data pointed to the survival of this virus on various surfaces in the environment, concluding that transmission through droplet-contaminated

cotton gowns and paper was unlikely, but yet possible to occur (Lai et al., 2005). Subsequent research supported these findings by concluding that most respiratory tract viruses can persist on surfaces for a few days and that transmission via contaminated surfaces can be a potential source of transmission if preventive surface disinfection is not performed (Kramer et al., 2006).

After more than a year since the discovery of SARS-CoV-2, and despite several studies reporting its detection on surfaces, it is still not clear to what extent SARS-CoV-2 can be transmitted via contaminated surfaces. To date, although experimental studies have demonstrated survival of the virus on certain types of surfaces, there are no reports demonstrating direct transmission via fomites. Interestingly, WHO, reports that individuals who come into contact with potentially infectious surfaces often also have close contact with an infected person, making it difficult to distinguish between respiratory droplet and fomite transmission (WHO, 2020c). Since little is known about contaminated surfaces as a route of transmission for SARS-CoV-2, a systematic review and summary is lacking and is urgently needed to provide guidelines for future research studies. Therefore, the aim of the present study was to review the current scientific knowledge and summarize the existing studies in which SARS-CoV-2 has been detected on inanimate surfaces, as well as to compile further information on fomite transmission and guidelines for infection control.

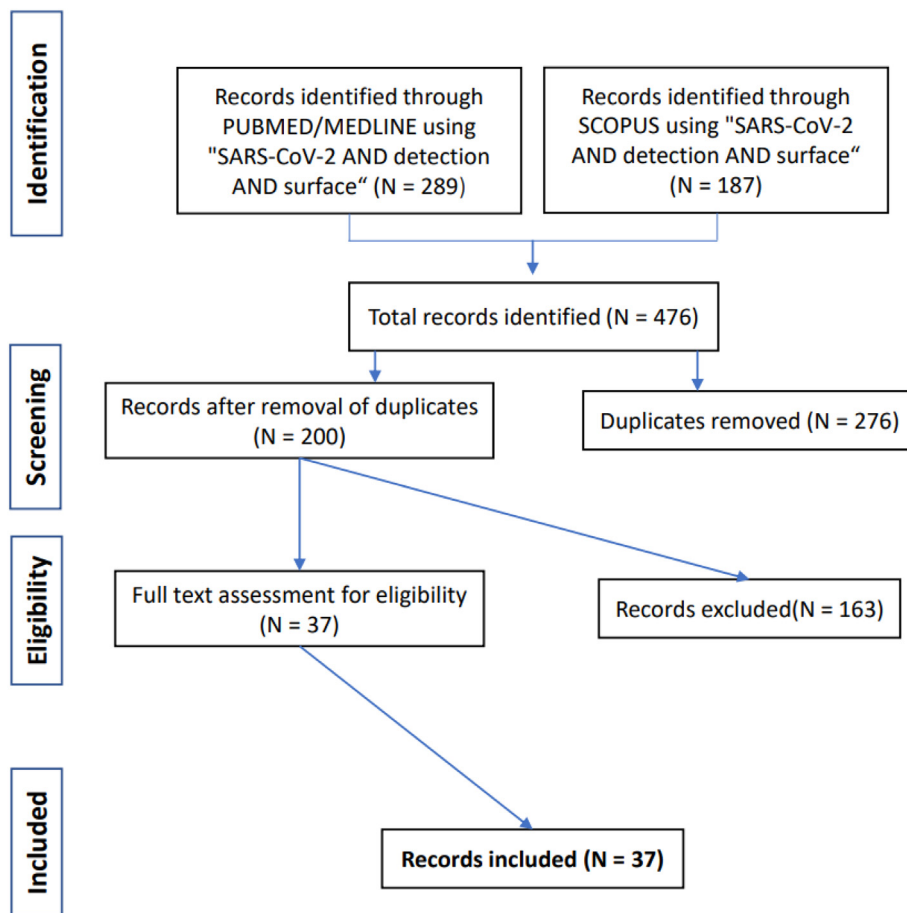
**2. Methods**

This systematic review includes studies since the emergence of SARS-CoV-2, available in the following databases: PubMed/MEDLINE and Scopus. The systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines (Shamseer et al., 2015). Language restrictions were not applied in the search. To the best of the authors' knowledge, there are no review articles on the topic presented. An extensive search was conducted, and published research articles were included.

The literature search was conducted using the terms "SARS-CoV-2 AND detection AND surface". Titles and abstracts were screened for relevance and publications up to 24 February 2021 were included if the following conditions were present: "samples were taken from surfaces and tested for SARS-CoV-2".

**3. Results**

A total of 476 articles were found during the literature search. Duplicate publications in both databases were removed, and exclusion criterion was applied to eliminate unrelated studies, resulting in 37 eligible publications (Fig. 1). The 37 publications were included in this review after being assessed and the results and findings of each publication are summarized in the Supplementary Table. This table includes the date of sampling, location and site of sampling, total number of samples collected, method used for sampling and detection of SARS-CoV-2, molecular targets, viability, number and percentage of positive samples, and surfaces on which SARS-CoV-2 RNA was detected.



**Fig. 1.** PRISMA flow diagram for inclusion of studies. PRISMA. PRISMA, Preferred Reporting of Systematic Reviews and Meta-analysis; LILACS, Latin American and Caribbean Health Sciences Literature.

**3.1. Methods used for the collection and detection of SARS-CoV-2 from surface samples**

As summarized in Table 1, most studies used swabs as a collection method for surface samples (n = 33). The exceptions were studies using a combination of swabs and wipes (Santarpia et al., 2020), gauze pads (Bloise et al., 2020) and sponges (Hu et al., 2021).

All 37 studies used RT-qPCR to detect SARS-CoV-2 RNA from surface samples. In one study, droplet digital RT-PCR (RT-ddPCR) was

additionally used (Lv et al., 2020). In this study, all 61 surface samples were negative by RT-qPCR, but 13 were positive using RT-ddPCR. Sanger sequencing was used to confirm and characterize the positive samples in one study (Wong et al., 2020).

**3.2. Sampling locations**

The studies were divided into two main categories based on where the sampling was conducted, namely hospital settings and non-hospital settings. In two studies (Ben-Shmuel et al., 2020; Mouchtouri et al., 2020), samples were taken in both hospital and non-hospital settings. Thus, the studies were included in both sample groups and the number of samples were separated according to the two categories. The details of these studies are summarized in Table 2. Studies (n = 26) conducted in hospital settings represented 70.3% and included isolation wards for COVID-19 patients (n = 14), intensive care units for COVID-19 patients (n = 3), and other hospital areas (n = 9) (e.g., cross-section of the entire hospital, diagnostic laboratories within the hospital, and others). The 26 studies conducted in hospital settings yielded 64.1% of all the surface sampling (n = 3077), with 17.3% positive samples (n = 533) for SARS-CoV-2 RNA. COVID-19 isolation wards were the sites with the highest number of samples collected (n = 1558) and the highest percentage of positive samples (24.2%). Ten out of the fourteen studies where samples were collected in isolation wards reported the number of positive COVID-19 patients hospitalized at the time of sampling. The number of COVID-19 patients in the isolation wards ranged from 1 to 21 (Cheng et al., 2021; Declementi et al., 2020; Ding et al., 2021; Kim et al., 2020; Pasquarella et al., 2020; Razzini et al., 2020; Santarpia et al., 2020; Wang et al., 2020; Wei

**Table 1**  
Summary of the methods used for sampling and detection of SARS-CoV-2 in the 37 reviewed studies.

	No. studies	No. samples	Viral viability <sup>a</sup>
<b>Sampling method</b>			
Swab	33	4574	Viral viability attempted in 5 studies but not confirmed.
Swabs and wipes	1	102	Not tested
Gauze pads	1	163	Viral viability attempted in 1 study but not confirmed.
Sponges	1	57	Not tested
Not specified	1	7	Not tested
<b>Detection method</b>			
RT-qPCR	37	4801	Viral viability attempted in 6 studies but not confirmed.
ddPCR	1	61	Not tested

<sup>a</sup> Vero E6 cells were used to culture virus from environmental samples.

**Table 2**

Number of studies, number of collected samples, number of positive samples and percentage of positive samples in the reviewed studies per sampling location. The sampling locations were divided into two main groups: hospital setting and non-hospital setting.

Sampling location	No. studies	No. collected samples	No. Positive samples (% positive samples)
<b>Hospital setting</b>			
Total	26	3077	533 (17.3)
COVID-19 isolation ward	14	1558	377 (24.2)
ICU ward	3	273	13 (4.8)
Other hospital areas (e.g. cross section)	9	1246	143 (11.5)
<b>Non-hospital setting</b>			
Total	13	1724	174 (10.1)
Transport (train, bus ferryboat, ship)	4	655	82 (12.5)
Quarantine hotel rooms	4	531	39 (7.3)
Public spaces	3	406	37 (9.1)
Long-term care facilities (e.g. nursing homes)	2	110	12 (10.9)
Diagnostic laboratory	1	22	4 (18.2)

et al., 2020a, 2020b), and no significant differences in the positivity rates among studies with different number of COVID-19 patients was found.

In 35.1% of the studies ( $n = 13$ ) samples were collected in non-hospital settings, which included transportation systems ( $n = 3$ ), quarantine hotel rooms ( $n = 4$ ), public city spaces ( $n = 3$ ), long-term care facilities ( $n = 2$ ) and a diagnostic laboratory ( $n = 1$ ). The combination of these studies yielded 35.9% of all the surface sampling ( $n = 1724$ ) with 10.1% of positive samples ( $n = 174$ ) for SARS-CoV-2. The study performed in the diagnostic laboratory reported the highest percentage of positive samples (18.2%), with SARS-CoV-2 RNA being detected on computer mice (2/4), keyboards (1/4) and on a mobile phone (1/9) (Bloise et al., 2020). Studies performed in transportation systems have the highest number of samples ( $n = 655$ ) with 12.5% ( $n = 82$ ) of them reported to be positive for SARS-CoV-2 RNA.

### 3.3. Viability of SARS-CoV-2 collected in surfaces

Six out of the 37 studies have evaluated the viability/infectivity of SARS-CoV-2 from positive surface samples (Ben-Shmuel et al., 2020; Colaneri et al., 2020; Lednický et al., 2021; Moreno et al., 2021; Santarpia et al., 2020; Yamagishi et al., 2020). A total of 242 positive samples were tested but no virus could be isolated from these samples and thus not proving the viability/infectivity of SARS-CoV-2.

## 4. Discussion

The present work is aimed at reviewing the scientific information that is currently available in PubMed/MEDLINE and Scopus databases on the detection of SARS-CoV-2 on surfaces. To the best of our knowledge, it is the first review on this topic.

One of the most important measures immediately recommended to contain the ongoing COVID-19 pandemic was recurrent cleaning and disinfection of frequently touched surfaces due to the potential contamination and stability of SARS-CoV-2 in the environment (CDC, 2020; WHO, 2020b). Studies have shown that RNA of human coronaviruses HCoV (OC43, 229E, HKU1, NL63), as well as MERS-CoV and SARS-CoV RNA may be detected on inanimate surfaces from just a few hours to a few days (Kampf et al., 2020). Recent reports indicate that SARS-CoV-2 RNA can be detected in the air for up to 3 h after aerosolization (Wißmann et al., 2021). Additional experimental efforts on surface stability of SARS-CoV-2 made in laboratory conditions show that SARS-CoV-2 is able to remain infectious for up to 24 h on cardboard surfaces, and for up to three days on plastic and stainless steel surfaces (van Doremalen et al., 2020). These findings lead to the possibility of

transmission via contaminated surfaces and there has been a rapid literature growth on the detection of SARS-CoV-2 on surfaces.

The present review shows that SARS-CoV-2 RNA contamination on surfaces has been detected in a wide range of facilities and surfaces using molecular methods. 17.7% of samples in hospital settings were positive and 10.2% in non-hospital settings. However, to date, there is a limited amount of data regarding the viability of SARS-CoV-2 on surfaces and the evaluation of its persistence in the environment has been constructed by results of studies made in laboratory settings, as recently reviewed (Aboubakr et al., 2021). Reported results from environmental contamination should be evaluated and interpreted with caution because the level of contamination in the environment with SARS-CoV-2 RNA is influenced by several factors that include the status of COVID-19 patients in the vicinity of the sampling area, cleaning and disinfection, sampling procedures, detection methods, and contamination rates.

In this review, the highest detection rate was found in COVID-19 isolation wards, followed by a single study in a diagnostic laboratory, public transport systems, and long-term care facilities. The ongoing COVID-19 pandemic has created an enormous burden on public health and diagnostic laboratories worldwide due to the demand for mass laboratory testing for SARS-CoV-2. Consequently, a higher level of contamination is a possibility and can lead to an increase number of false positive results (Borst et al., 2004). This is due to the high sensitivity of nucleic acid amplification on RT-qPCR assays where RNA derived from nucleic acid extractions or DNA fragments from the previous experiments may be (re)amplified, causing the false positive results of the next detection (Braunstein et al., 2021).

All studies selected a real time RT-PCR cycle threshold (Ct) value of  $\leq 40$  to consider a sample positive, with the exception of five studies that selected smaller threshold values (Cheng et al., 2021; D'Accolti et al., 2020; Declementi et al., 2020; Wei et al., 2020a; Ye et al., 2020). As seen in Supplementary Table, different molecular techniques and different RT-qPCR targets were used with different levels of sensitivity and specificity. In the majority of the studies, the Ct values of positive samples were very close to this value. The studies that sampled surfaces in COVID-19 isolation wards (and reported the number of patients) had from 1 to 21 positive patients at the time of sampling. There are no significant differences in the positivity rates among studies with different numbers of COVID-19 patients. Nevertheless, a study showed that the positivity rate in surface samples decreases with the increasing distance to the positive patients (Razzini et al., 2020).

Thirty-three studies used swabs to sample surfaces, which corresponds to 95.3% of the samples taken ( $n = 4574$ ). However, studies have shown that other sampling tools such as bio wipes and cell scraper-aspiration methods could be more efficient than swabs to recover viruses from surfaces due to higher moisture retention (De Keuckelaere et al., 2014; Taku et al., 2002). A review study concluded that more techniques and tools of recovery of viruses from environmental surfaces need to be evaluated and these evaluations should include a variety of human viruses (Turnage and Gibson, 2017). Most studies reported results as either positive or negative or with Ct values, while some gave the viral concentrations. Cheng et al., 2021 reported a range from  $1.1 \times 10^2$  to  $9.4 \times 10^4$  copies/mL. Lv et al., 2020 reports that the areas with highest density of SARS-CoV-2 nucleic acid were outer gloves (37.4 copies/cm<sup>2</sup>), followed by a door handle (26.25 copies/cm<sup>2</sup>), goggles (22.16 copies/cm<sup>2</sup>), an outer cover of a high speed centrifuge (19.95 copies/cm<sup>2</sup>) and an inner wall of a high speed centrifuge (14.70 copies/cm<sup>2</sup>). In the study Burton et al., 2021 the genomic copies ranged from 59 to  $2.2 \times 10^5$  genomic copies/swab. Santarpia et al., 2020 shows viral gene copy concentrations from 0 to 1.75 copies/ $\mu$ L.

Noteworthy, an expressive number of COVID-19 infections were reported to occur in hospitals and confined spaces (Arav et al., 2020b, p. 19; Azuma et al., 2020; Bhagat et al., 2020; Zheng et al., 2020b). Contamination of surfaces either by infected patients or by persons who

have been in contact with infected patients usually does not occur in isolation but by several persons touching different surfaces between entering a room where an infected person is present and leaving it (Choi et al., 2021). This in turn leads to the creation of contaminated surfaces (also known as fomites). In healthcare settings, there are so-called high-touch surfaces, namely bed rails, bed frames, movable lamps, tray tables, bedside tables, handles IV poles and blood pressure cuffs (CDC, 2020b). In the present review, environmental surfaces were contaminated with SARS-CoV-2 RNA mainly in COVID-19 patient wards, commonly used objects, high-touch surfaces, medical equipment, and PPE. The contamination is likely the result of viral shedding in respiratory droplets or aerosols from infected patients and/or indirect contact by healthcare workers, patients, and visitors. These findings emphasize the need to ensure adequate environmental cleaning, strengthen infection prevention training, and improve infection prevention precautions within healthcare premises. A study from 2017 on the potential disease transmission opportunities in healthcare environment reported that most touched items during patient care were bedrail, bed-surface and bed side table. Three of the top ten most common consequences included touching personal medical equipment (PME) and the patient, namely: computer on wheels-patient, patient-computer on wheels, and patient-IV pump. The network plots revealed large interconnectedness among objects in the room, the patient, PME, and healthcare workers (Jinadatha et al., 2017). These results demonstrate that it might be possible that a virus could be transferred between patients, surfaces and healthcare workers. If the fomite is a portable medical equipment (PME), fomite transmission could occur (Choi et al., 2021).

Despite the increasing number of studies reporting the detection of SARS-CoV-2 RNA on a variety of inanimate surfaces, few mentioned the material of the surfaces, so predictions of how long SARS-CoV-2 may persist, based on surface type, are hindered. Nosocomial transmission of SARS-CoV-2 has been extensively studied (Rickman et al., 2021), with most studies focusing on surfaces and air sampling to detect the presence of environmental contamination (Rickman et al., 2021). Temperature, relative humidity and UV radiation in indoor environments are also considered to be factors that play a key role on transmission, as infected droplets expelled by patients that could settle on surfaces or remain airborne for long periods of time are sensitive to changes in these parameters (Kanamori et al., 2020; Tang et al., 2006; Wei and Li, 2016). Biryukov et al. (2020) observed that SARS-CoV-2 decayed more rapidly when either humidity or temperature increased, but the droplet volume (1–50  $\mu$ l) and surface type (stainless steel, plastic or nitrile glove) did not show significant impacts on the decay rate. A potential fomite transmission could persist for hours to days in indoor environments, thus having important implications to assess the risks of surface contamination, especially in healthcare environments where surface contamination can be higher due to the constant presence of COVID-19 patients and frequent contact between healthcare workers and these patients (Biryukov et al., 2020). Simulated sunlight can also rapidly inactivate SARS-CoV-2 on surfaces, which suggests that persistence and exposure risk in indoor environments might be higher than in outdoor (Ratnesar-Shumate et al., 2020). A recent study has shown that SARS-CoV-2 was isolated from the surface of an imported frozen cod outer package, which highlights a potential transboundary route of SARS-CoV-2 transmission and the need to further investigate the role of fomite transmission in food packaging (Liu et al., 2020).

In spite of the wide detection of SARS-CoV-2 RNA on surfaces by RT-qPCR and ddRT-qPCR, viable viruses were not yet confirmed. Most studies do not include viral infectivity assays because this requires SARS-CoV-2 propagation in cell culture that is only allowed in biosafety level 3 facilities (not widely available) (Kaufer et al., 2020). Laboratory experiments with spiked samples have shown SARS-CoV-2 is stable in certain environmental conditions. In one study it was shown that infectious viruses could not be recovered from printing and tissue papers after only 3 h of incubation and from treated wood and cloth after two days (Chin et al., 2020a, 2020b). SARS-CoV-2 was more stable on

smooth surfaces. On the other hand, infectious virus was detected on the outer layer of a surgical mask seven days after incubation. SARS-CoV-2 was extremely stable in a wide range of pH at room temperature and highly stable at 4 °C, but very sensitive to heat (Chin et al., 2020a, 2020b). Another study conducted with spiked samples has shown that SARS-CoV-2 can be isolated in appropriate cell cultures (Wurtz et al., 2021). Nevertheless, the few studies that reported SARS-CoV-2 RNA detection from surface samples and that attempted virus isolation, either failed to induce cytopathic effect or found only weak signals for the presence of replication-competent viruses due to the very low amounts of detected RNA (Colaneri et al., 2020; Santarpia et al., 2020).

All studies that have conducted pre- and post- clean-up sampling have shown that routine cleaning interventions are highly effective. SARS-CoV and MERS-CoV are extremely sensitive to detergents and disinfectants (Aboubakr et al., 2021), and there is no evidence to date that SARS-CoV-2 has a higher resistance, so it seems adequate to continue the current periodic cleaning of surfaces (WHO, 2020b). The likelihood of surface contamination is higher in healthcare settings, especially where aerosol-generating medical procedures are performed. SARS-CoV-2 is an enveloped virus with a fragile outer lipid layer that makes it very sensitive to disinfectants (Chin et al., 2020a, 2020b). Studies have shown that surfaces can be rapidly sanitized with a variety of widely used chemicals, including povidone-iodine solution (Bidra et al., 2020; De et al., 2020), ethanol (Behzadinasab et al., 2020; Fischer et al., 2020; Kratzel et al., 2020), sodium hypochlorite (Chan et al., 2020) and benzalkonium chlorite (Chin et al., 2020b). A recent study concluded that environmental contamination with the potential for SARS-CoV-2 transmission is unlikely, provided standard cleaning procedures and precautions are followed (Mondelli et al., 2021).

WHO considers that there is not yet enough scientific evidence to suggest environmental surveillance as a standard approach for COVID-19 monitoring (WHO, 2020a, 2020b, 2020c). WHO also states that research on the detection of SARS-CoV-2 in the environment should continue with the goal to advance knowledge about COVID-19 transmission and thus aid the development of public health strategies. This review shows that many studies have demonstrated the presence of SARS-CoV-2 RNA in environmental surfaces. These studies are an important contribution to the understanding of the spread of the virus in the environment, but to date there is no evidence of viable virus on surfaces. Routine cleaning of environmental surfaces is highly effective, as is ongoing regular hand disinfection, and therefore disinfection recommendations from WHO must also continue to be followed. Although studies on the viability of SARS-CoV-2 in surfaces are scarce, surface transmission may be possible (WHO, 2020b) and consequently disinfection measures should be continued and extended to the interiors of public facilities and high-risk sites. More research is needed on the possible transmission of SARS-CoV-2 via contaminated surfaces with focus on virus viability testing and reporting the material of the tested surfaces. Viability testing is particularly important in non-hospital environments where frequent disinfection cannot occur as regularly as in hospital environments. In all settings, including those where frequent cleaning and disinfection is not possible due to resource constraints, recurrent hand washing and avoidance of touching the face must be the primary prevention approaches to decrease possible transmission associated with surface contamination.

The current data highlight the importance of environmental RNA surveillance and viral viability testing, which could contribute to improved spatial and temporal assessment of COVID-19 risk by monitoring suspicious and high-touch environmental surfaces in high-risk settings, such as hospitals, health centres, public transportation, and long-term care facilities. However, extrapolating SARS-CoV-2 RNA detection data into decision-making may exaggerate the risk of fomite transmission because there is no evidence of viable and infectious SARS-CoV-2 on surfaces. Although SARS-CoV-2 can be transmitted by direct or indirect contact, by touching contaminated surfaces and objects followed by touching the mouth, nose, or eyes, it remains

unknown whether transmission is due to a fomite because making the distinction between respiratory droplet and fomite transmission is difficult.

## 5. Conclusion

The present study provides the first overview of the detection of SARS-CoV-2 on surfaces. As expected, the highest detection rates occurred in hospitals and healthcare facilities with COVID-19 patients. Contamination with SARS-CoV-2 on surfaces was detected in a wide range of facilities and surfaces. COVID-19 fomite transmission has not been demonstrated. Until the risk of COVID-19 fomite transmission is understood and further studies of virus survival and clinical evidence of fomite transmission are available, continued efforts to frequently clean and disinfect environmental surfaces are needed. Due to the lack of BSL 3 facilities, viability testing for SARS-CoV-2 recovered from surfaces remain scarce, and consequently it is not yet possible to assess the potential for transmission via surfaces. More studies need to be conducted and the inclusion of metadata, such as surface material, temperature and relative humidity, are of paramount importance.

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.scitotenv.2021.149231>.

## CRedit authorship contribution statement

**Study conception and design:** José Gonçalves, Priscilla Gomes da Silva, João R. Mesquita.

**Acquisition of data:** José Gonçalves, Tom Koritnik.

**Analysis and interpretation of data:** José Gonçalves.

**Drafting of manuscript:** José Gonçalves.

**Critical revision:** José Gonçalves, Priscilla Gomes da Silva, Luís Reis, Maria São José Nascimento, Tom Koritnik, Metka Paragi, João R. Mesquita.

All the authors have read and approved the submitted manuscript.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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