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Review

SARS-CoV-2 Detection Rates from Surface Samples Do Not Implicate Public Surfaces as Relevant Sources for Transmission

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Abstract: Contaminated surfaces have been discussed as a possible source of severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2). Under experimental conditions, SARS-CoV-2 can remain infectious on surfaces for several days. However, the frequency of SARS-CoV-2 detection on surfaces in healthcare settings and the public is currently not known. A systematic literature review was performed. On surfaces around COVID-19 cases in healthcare settings (42 studies), the SARS-CoV-2 RNA detection rates mostly were between 0% and 27% (Ct values mostly > 30). Detection of infectious SARS-CoV-2 was only successful in one of seven studies in 9.2% of 76 samples. Most of the positive samples were obtained next to a patient with frequent sputum spitting during sampling. Eight studies were found with data from public surfaces and RNA detection rates between 0% and 22.1% (Ct values mostly > 30). Detection of infectious virus was not attempted. Similar results were found in samples from surfaces around confirmed COVID-19 cases in non-healthcare settings (7 studies) and from personal protective equipment (10 studies). Therefore, it seems plausible to assume that inanimate surfaces are not a relevant source for transmission of SARS-CoV-2. In public settings, the associated risks of regular surface disinfection probably outweigh the expectable health benefits.

Keywords: SARS-CoV-2; surface; contamination; RNA; infectious virus

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1. Introduction

The global spread of SARS-CoV-2 in 2020 has resulted in a variety of strategies for transmission control. Early laboratory data obtained after an artificial contamination of carrier surfaces with a high viral load suggested that coronaviruses in general may remain infectious on inanimate surfaces at room temperature for up to 9 days [1] and in the dark and in the presence of bovine serum albumin for even up to 28 days [2]. Similar results, though with much shorter stability times, were obtained with SARS-CoV-2 under laboratory settings [3]. The relevance of the rather long persistence on surfaces remains controversial because viruses from respiratory secretions are embedded in mucus and saliva, which probably contain specific antibodies against the virus, high numbers of leukocytes, and intrinsic antiviral activity because of their polyanionic charge which binds to viruses as well as bacteria and fungi, which may influence the environment around the virus [4]. The applicability of the findings to real life has also been questioned because in the studies, a high load of infectious virus was applied to a small surface area, which is much higher than those in droplets in real-life situations. As a result, the amount of virus actually deposited on surfaces could be several orders of magnitude smaller [5]. Nevertheless, these findings obtained under laboratory conditions raised the concern that viral shedders in the public may contaminate frequent touch surfaces, finally resulting in

viral transmission via uncontrolled hand-face-contacts. As a result, many public surfaces were subjected to disinfection, e.g., in shops, museums, restaurants, public transportation, or sports facilities.

Recent data suggest that infectious SARS-CoV-2 is rarely found on surfaces around confirmed COVID-19 cases in healthcare settings despite variable detection rates of viral RNA [6,7]. Laboratory data with SARS-CoV-2 show that Ct (cycle threshold) values of 29.3 (steel surface) or 29.5 (plastic surface) correlate with detection of culturable virus, whereas Ct values of 32.5 (steel surface) or 32.7 (plastic surface) correlate with the detection of non-culturable virus [6]. It was implicated that a Ct value > 30 obtained from a surface sample has probably no epidemiological relevance [6]. In contrast, dried inocula with Ct values < 30 (corresponding to an E gene copy number of $\geq 10^5$ per mL) yielded SARS-CoV-2 that could be cultured [6]. A simple binary approach to the interpretation of PCR results obtained from surface samples and not validated against viral culture will probably result in unnecessary, regular disinfection of surfaces [8]. The frequency of SARS-CoV-2 detection by PCR on surfaces in healthcare settings and the public is currently not known. In addition, the corresponding Ct values have not been comprehensively evaluated. The aim of this review is to summarize published data on this aspect.

2. Materials and Methods

A Medline search was done on 13 October 2020 and updated on 1 April 2021 using the following terms: SARS-CoV-2 surface contamination (261 hits) and SARS-CoV-2 PPE contamination (79 hits). All studies were screened for original data of surface contamination with SARS-CoV-2 (RNA, including Ct values and infectious virus). Data were extracted from studies that described the presence of SARS-CoV-2, both RNA and infectious virus, on surfaces. Reviews were not included but were screened for any information relevant to the scope of this review.

3. Results

3.1. Areas Surrounding Confirmed COVID-19 Cases in Healthcare Settings

Overall, 42 studies were found with data on the presence of SARS-CoV-2 RNA in the areas surrounding confirmed COVID-19 patients in healthcare settings. In 27 of the studies, no specific information was available when the last cleaning or disinfection was done prior to sampling [6,7,9–33]. In two studies, sampling was performed prior to cleaning with 1000 ppm sodium hypochlorite [34,35], and in five studies it was done before the next scheduled surface cleaning [36–40]. Other investigators performed surface sampling at least four hours after the last cleaning procedure [41,42], within four to seven hours after the first daily cleaning [43], seven hours after cleaning and disinfection [44], at least eight hours after any cleaning procedure [45], before and after decontamination [46,47], or after terminal disinfection [48].

For none of the confirmed COVID-19 patients was it attempted to detect infectious SARS-CoV-2 from respiratory tract samples at the time of diagnosis or at the time of surface sampling. In 14 studies, there was evidence that COVID-19 patients were SARS-CoV-2-RNA-positive. Five studies reported the corresponding Ct values, which were between 13.7 and 39.0. The detection rate of SARS-CoV-2 RNA on surfaces was mostly between 0% and 27% of all samples. Most of the corresponding Ct values were > 30. Detection of infectious virus was attempted in 7 of the 42 studies. Only one study provided evidence for infectious SARS-CoV-2 in 10.5% of 76 samples. Seven of the eight positive samples were obtained in the area surrounding one patient with persistent cough and frequent sputum spitting during sampling. All samples from the other six studies were culture negative (Table 1).

Table 1. Frequency of detection of SARS-CoV-2 on inanimate surfaces in healthcare settings in the area surroundings of confirmed COVID-19 patients sampled for RNA or infectious virus.

Setting (Country)	Types of Sampled Surfaces (n)	Evidence for Infectious Virus in Samples from Cases (Ct Values of Clinical Samples)	Targets on SARS-CoV-2 Genome	Sample Considered Positive with Ct Value of	Proportion of Viral RNA Detection	Ct Values	Reference
Hospital with COVID-19 patients (USA)	Surfaces in the patient surrounding (734)	No * (no Ct values)	E and N genes	<40	13.1%	Not specified; 10^2–10^5 viral copies detected in positive samples	[9]
Different wards in grade III hospital (China)	Surfaces on different wards (626)	No	ORF1ab and N genes	<40	13.6%	Not described	[10]
Dedicated general ward for COVID-19 cases (Singapore)	Various high-touch surfaces in the patient surroundings and toilet area (445)	No * (no Ct values)	E and ORF1b-nsp14 genes	Not described	2.2%	Not described	[34]
Various healthcare settings (Brazil)	Various surfaces (403)	No	N1 and N2 genes	<40	5.0%	23.3–37.7 (N1) and 22.2–39.4 (N2)	[11]
COVID-19 isolation rooms (China)	Surfaces in patient rooms (377)	No	RdRp gene	Not described	5.0%	1.1×10^2–9.4×10^4 RNA copies per ml	[35]
Treatment rooms for COVID-19 patients (England)	High contact surfaces in patient rooms (336)	No * (17.7 and 21.4; 2 of 44 Ct values)	RdRp, N, ORF1ab, and E genes	<40	8.9% **	28.8–39.1	[12]
Rooms of COVID-19 patients in four hospitals (Republic of Korea)	Various surfaces (330)	No	RdRp and E genes	<35	27.0%	25–39; values < 30 only on bedside rail (2 samples), sink internal bowel (1 sample), floor (1 sample), and bathroom door handle (1 sample)	[36]
Four hospitals with COVID-19 patients (China)	Various surfaces (318)	No	ORFab and N genes	<40	3.1%	3–8 RNA copies per cm^2	[13]
Surfaces in 27 hospital rooms of COVID-19 patients (Singapore)	Various surfaces (245)	No * (20.4–35.7)	ORF1ab and E genes	≤45	22.9%	Not described	[14]
Designated COVID-19 hospital (China)	Various surfaces in isolation wards and ICUs (244)	No	ORF1ab gene	Not specified	4.1%	Not specified	[37]
Teaching hospital with COVID-19 patients (UK)	Various surfaces in different parts of the hospital (218)	No	E gene	<40.4	10.6% **	Not specified; 10^1–10^4 genome copies detected in positive samples	[6]
COVID-19 hospital (China)	Surfaces frequently touched by patients or healthcare workers (200)	No	RdRp, N, and E genes	≤43	19.0%	Not described	[15]
COVID-19 ICU (Singapore)	Various surfaces in 20 patient rooms (200)	No * (23.1–39.0)	ORF1ab and E genes	<45	14.0%	Not described	[16]
Emergency department (France)	Different surfaces from the patient care area (102) and the non-patient care area (74)	No	ORF1ab and E genes	Not described	5.1% ***	35.7–39.7	[46]
ICU with COVID-19 patients (Switzerland)	Different surfaces in patient rooms after terminal disinfection (176)	No	Not described	Not described	0%	-	[48]

Table 1. *Cont.*

Setting (Country)	Types of Sampled Surfaces (n)	Evidence for Infectious Virus in Samples from Cases (Ct Values of Clinical Samples)	Targets on SARS-CoV-2 Genome	Sample Considered Positive with Ct Value of	Proportion of Viral RNA Detection	Ct Values	Reference
COVID-19 treatment centre for patients after tracheostomy (China)	Various surfaces (152)	No	ORF1ab and NP genes	<40	1.3%	36.8–37.5	[17]
Intensive care unit and ordinary ward with COVID-19 cases (Taiwan)	Samples from 16 different surfaces (144)	No	RdRp, N, and E genes	<45	1.4%	30.4, 31.8	[38]
Designated COVID-19 hospital (China)	Various surfaces on isolation ward (144)	No	ORF1 and N genes	<40 <45	0.7% 2.8% 17.0% (7.5% ****)	38.6 41.0–44.8	[18]
Contaminated, semi-contaminated, and clean areas of an ICU with COVID-19 patients (China)	Floor (53) Doorknob (34) Air outlet filter (18) Sickbed handrail (14) Computer mouse (8) Trash can (5)	No	ORF1ab and N genes	Not described	0% 44.4% (22.2% ****) 43% (29% ****) 75% (25% ****) 60% (60% ****)	No Ct values described; average RNA concentration between 2.9×10^3 and 1.5×10^5	[19]
ICU with COVID-19 patients (France)	Various frequently touched surfaces (117)	No * (no Ct values)	E gene	Not described	24.8%	29.0–39.0 (median: 36)	[45]
COVID-19 isolation ward (China)	Surfaces in patient rooms and the toilet area (112)	No * (no Ct values)	ORF1ab and N genes	Not described	39.3%	Not described	[43]
Intensive care unit, isolation ward, and general ward (Republic of Korea)	Surfaces in patient rooms, the ante room, the floor of an adjacent common corridor, and the nursing station (105)	No	RdRp, N, and E genes	Not described	3.8%	Not described	[20]
			Only two of the genes positive		4.8%		
			Only one of the genes positive		3.8%		
COVID-19 isolation ward (China)	Various surfaces (84)	No	ORF1ab and N genes	<37	7.1%	Not described	[21]

Table 1. *Cont.*

Setting (Country)	Types of Sampled Surfaces (n)	Evidence for Infectious Virus in Samples from Cases (Ct Values of Clinical Samples)	Targets on SARS-CoV-2 Genome	Sample Considered Positive with Ct Value of	Proportion of Viral RNA Detection	Ct Values	Reference
Isolation rooms for COVID-19 patients (Ireland)	Various surfaces in isolation rooms and the nurses' station (81)	No	N2 and E genes	Not described	16%	Not described	[41]
Hospital, rehabilitation centre, and apartment building complex with COVID-19 patients (Republic of Korea)	Surfaces frequently touched by the patients (80)	No	RdRp gene E gene	<35	2.5%	27.8, 32.9 31.5, 34.8	[22]
Dedicated SARS-CoV-2 outbreak centre (Singapore)	Patient rooms A and B: various surfaces after routine cleaning (52) Patient room C: various surfaces before routine cleaning (28)	No * (23.2–35.3)	RdRp and E genes	≤45	0% 60.7%	- 30.6–38.2 (mostly > 34)	[47]
Severe COVID-19 cases in isolation rooms (Republic of Korea)	Surroundings of three patients (76)	No * (15.3–26.2)	RdRp and E genes	≤35	19.7% *****	28.9–33.0 (mostly > 30)	[7]
COVID-19 ICU (Singapore)	Various surfaces in common areas and staff pantry (75)	No * (23.1–39.0)	ORF1ab and E genes	<45	10.7% **	36.2–38.1	[16]
COVID-19 ICU (Spain)	Various surfaces in 3 risk areas (72)	No	ORF1ab and N genes	Not described	0%	-	[23]
COVID-19 isolation unit (Israel)	Various surfaces (55)	No * (no Ct values)	E gene	<45	52.7% **	30.0–39.8	[24]
COVID-19 isolation ward (China)	Various surfaces (50)	No	E gene	≤40	8.0% **	29.4–33.6	[25]
COVID-19 isolation ward (Iran)	Various surfaces (50)	No	ORF1ab and N genes	≤40	18.0% **	30.9–38.2	[26]
COVID-19 reference hospitals (Italy)	Various surfaces (49)	No	RdRp, N, and E genes	< 40	6.1% ***	Not described	[27]
Quarantine room of three COVID-19 patients (China)	Various surfaces (41)	No * (20–39)	ORF1ab gene	<37	34.1%	26–38 (median: 35)	[28]

Table 1. *Cont.*

Setting (Country)	Types of Sampled Surfaces (n)	Evidence for Infectious Virus in Samples from Cases (Ct Values of Clinical Samples)	Targets on SARS-CoV-2 Genome	Sample Considered Positive with Ct Value of	Proportion of Viral RNA Detection	Ct Values	Reference
Inpatient and outpatient oncology clinics (USA)	Various surfaces around COVID-19 patients (38)	No	ORF1ab gene	Not described	2.6%	Not described	[39]
Wards for COVID-19 patients (Spain)	Various surfaces that could not be touched (36)	No * (21.6–37.7)	RdRp, N, and E genes	Not described	5.6%	31.9–37.4	[29]
COVID-19 cases in hospitals (Italy)	Various surfaces (26)	No	RdRp gene and E genes	Not described	7.7% **	"very low RNA levels"	[42]
COVID-19 isolation wards (Greece)	Various surfaces (26)	No	Not described	Not described	15.4%	32–36	[40]
COVID-19 ward (Italy)	Various surfaces (22)	No	RdRp, ORF1ab, S, and N genes	<40	13.6%	29.5–33.0 (1 sample); > 35 (two samples)	[44]
COVID-19 isolation rooms (Saudi Arabia)	Various surfaces (20)	No	Not described	≤45	15%	Not described	[30]
COVID-19 ward (Italy)	Surfaces with high risk of contamination (16)	No	RdRp gene and E genes	Not described	0%	-	[31]
COVID-19 isolation room (Singapore)	Environmental samples (3)	No * (13.7–15.6)	RdRp gene E gene	<36	100% 100%	28.7, 29.7, and 33.3 32.8, 33.5, and 37.8	[32]
COVID-19 patient room (China)	Bench, bedside rail, locker, bed table, alcohol dispenser, and window bench (unknown)	No	E gene	<45	1 positive sample on window bench	6.5×10^2 RNA copies per ml	[33]

* PCR test results positive; ** no infectious SARS-CoV-2 detected; *** all positive samples in patient care area; **** only weak positive (one of the two genes positive); ***** infectious SARS-CoV-2 in 10.5% of samples detected, 7 of 8 positive samples obtained in the surroundings of one patient with persistent cough and frequent sputum spitting during sampling.

3.2. Areas Surrounding Confirmed COVID-19 Cases in Non-Healthcare Settings

A total of seven studies provide data on SARS-CoV-2 detection on surfaces around confirmed COVID-19 cases in non-healthcare settings. The epidemiological situation during the study period was described in three of the seven studies. It was during an ongoing COVID-19 outbreak investigation on a ferry boat [40], during a COVID-19 outbreak on a cruise ship [49], during a COVID-19 outbreak in a nursing home [40], and during a local COVID-19 outbreak [50]. No specific information regarding the local or national epidemiological situation during the study period was found in four of the studies [51–54].

In three studies, samples were taken before any cleaning or disinfection procedure was carried out [40,49,54]. In one study, 50% of the 428 samples were taken before the cleaning and disinfection, and the other half was taken after the disinfection procedure [51]. No specific information regarding any prior treatment of surfaces was found in three studies [50,52,53]. The public availability of hand sanitizers was not described in any of the studies [40,49–54].

For none of the confirmed COVID-19 patients was it attempted to detect infectious SARS-CoV-2 from respiratory tract samples at the time of diagnosis or at the time of surface sampling. Six studies confirm the presence of SARS-CoV-2 RNA in respiratory samples, with Ct values in one study between 25.7 and 33.1. The detection rate of SARS-CoV-2 RNA on surfaces was mostly between 0% and 20% of all samples with corresponding Ct values mostly > 30. In two of the four studies, detection of infectious SARS-CoV-2 was attempted. All samples, however, were culture negative (Table 2).

3.3. Public Surfaces

Eight studies were found with data on the contamination of public surfaces with SARS-CoV-2. The epidemiological situation during the study period was described in four studies. In Brazil, the study took place in one of the regions with the highest number of notified COVID-19 cases [11]. In the U.S., sampling was done during a regional COVID-19 outbreak [55]. In Iran, sampling was performed during the early stage of a local outbreak [56]. In Italy, surfaces were samples 2–3 months after the national epidemic peak [27]. No information was found in the other studies [30,57–59].

The RNA detection rates were low, at 0% to 22.1%; the corresponding Ct values were mostly > 30. There were no attempts to detect infectious virus (Table 3). In seven of eight studies, it was not described if any of the sampled surfaces was cleaned or disinfected before the sampling took place [11,27,30,55–57,59]. In one study, however, samples were taken four hours after surface disinfection with 1000 ppm sodium hypochlorite [58]. In addition, in one study, it was described that surface disinfection was initiated in a public building after the positive results were communicated, suggesting that surface disinfection was not done routinely [11]. The public availability of hand sanitizers was not described in any of the studies [11,27,30,55–59].

3.4. Personal Protective Equipment

Ten studies were found with data on the contamination of surfaces of PPE. In none of the studies was it confirmed that the COVID-19 patients harboured infectious SARS-CoV-2. In four studies, there was evidence that the COVID-19 patients were SARS-CoV-2-RNA-positive with corresponding Ct values between 13.7 and 37.9. SARS-CoV-2 RNA was detected on 0% to 33.3% of all samples with either a low RNA concentration or high corresponding Ct values > 38. None of the studies attempted to detect infectious SARS-CoV-2 (Table 4).

Table 2. Frequency of detection of SARS-CoV-2 on inanimate surfaces in the surroundings of confirmed COVID-19 patients in non-healthcare settings or in a diagnostic laboratory sampled for RNA or infectious virus.

Setting (Country)	Types of Sampled Surfaces (n)	Evidence for Infectious Virus in Samples from Cases (Ct Values of Clinical Samples)	Targets on SARS-CoV-2 Genome	Sample Considered Positive with Ct Value of	Proportion of Viral RNA Detection	Ct Values	Reference
Diamond Princess cruise ship during COVID-19 outbreak (Japan)	Surfaces in cabins of confirmed cases (330) Surfaces in cabins of non-cases (160) Surfaces in shared areas (97)	No * (no Ct values)	Not specified	Not specified	17.3% ** 0% ** 1.0% **	26.2–39.0; values < 31.0 only on floors	[49]
Rooms of COVID-19 patients (Singapore)	High-touch surfaces in accommodation rooms (428)	No * (no Ct values)	RdRp gene	<35	0.5%	Not described	[51]
COVID-19 quarantine hotel (China)	Various surfaces (271)	No * (no Ct values)	ORF1ab and N genes	<40	6.6%	35 (median)	[52]
COVID-19 cases in isolation at home (Germany)	Surfaces in 21 households (119)	No * (no Ct values)	RdRp and E genes	Not described	3.4% **	>30	[50]
Clinical microbiology laboratory (France)	Various surfaces (23)	Not applicable	ORF1ab, N, and S genes ORF1ab gene N gene S gene	Not described	0% 4.3% 0% 17.4%	- 39.0 - 30.3, 37.6, 38.3, 38.8	[53]
Centralized quarantine hotel (China)	Various surfaces (22)	No * (25.7–33.1)	ORF1ab and N genes	<40	36.4%	28.8–37.6 (median: 35.6)	[54]
Nursing home during a COVID-19 outbreak (Greece)	Various surfaces (20)	No * (no Ct values)	Not described	Not described	20%	32–34 (median: 32)	[40]
Long-term care facility with 30 asymptomatic COVID-19 cases (Greece)	Various surfaces (10)	No * (no Ct values)	Not described	Not described	0%	-	[40]
Ferryboat during an ongoing COVID-19 outbreak investigation (Greece)	Various surfaces (9)	No * (no Ct values)	Not described	Not described	55.6%	26–37 (median: 34)	[40]

* PCR test results positive; ** no infectious SARS-CoV-2 detected.

Table 3. Frequency and detection rates of SARS-CoV-2 on public surfaces.

Setting (Country)	Types of Sampled Surfaces (n)	Targets on SARS-CoV-2 Genome	Sample Considered Positive with Ct Value of	Proportion of Viral RNA Detection	Ct Values	Detection Rate of Infectious SARS-CoV-2	Reference
Various public settings (Brazil)	17 public squares, 10 universities/schools, 6 bus terminals, 2 public parks, 1 public market, 1 shopping mall, and 21 other public places (530)	N1 and N2 genes	<40	5.5% *	29.0–38.1 (N1) and 30.5–39.6 (N2)	Not described	[11]
Bank notes (Bangladesh)	Various bank notes (425)	N and ORF1b genes	≤36	7.3%	Not described	Not described	[57]
Various public settings (USA)	Various surfaces (348)	N1 or E gene	<40	8.3%	28.7–40.2 (N1) ** 26.6–39.0 (E) ***	Not described	[55]
Various public settings (Iran)	Various high-touch surfaces (104)	N and ORF1ab genes	≤45	22.1%	Not described	Not described	[56]
Public setting next to COVID-19 hospitalization units (Spain)	Various public high-touch surfaces (46)	RdRp gene	Not described	0%	-	Not described	[58]
Playgrounds (Israel)	Various surfaces (43)	RdRp, N, and S genes	Not described	4.7%	Not described	Not described	[59]
Various public settings (Italy)	Surfaces in public buildings and outdoors (41)	RdRp, N, and E genes	<40	0%	-	Not described	[27]
Water fountains (Israel)	Various surfaces (25)	RdRp, N, and S genes	Not described	4.0%	Not described	Not described	[59]
High-touch public surfaces (Saudi Arabia)	Various surfaces (22)	Not described	≤45	4.5%	Not described	Not described	[30]

* all 7 positive samples on the 6 bus terminals were at entrance handrails, no positive samples at universities, schools, public parks, and shopping mall; ** only one Ct value < 32.2; *** only one Ct value < 32.9.

Table 4. Frequency of detection of SARS-CoV-2 RNA on personal protective equipment in the surrounding of COVID-19 patients.

Setting (Country)	Types of Sampled PPEs (n)	Evidence for Infectious Virus in Samples from Cases (Ct Values of Clinical Samples)	Targets on SARS-CoV-2 Genome	Sample Considered Positive with Ct Value of	Proportion of Viral RNA Detection	Ct Values	Reference
Different wards in grade III hospital (China)	Hand sanitizer dispenser (59), glove (78), eye protection, or face shield (58)	No	ORF1ab and N genes	<40	20.3% 15.4% 1.7%	Not described	[10]
COVID-19 negative-pressure isolation room (Republic of Korea)	Different surfaces from PPEs (133)	No	S and N genes	<45	11.3% *	Not described; average RNA concentration between 4.3×10^2 and 2.2×10^4	[60]
COVID-19 isolation room (Singapore)	Different surfaces from PPEs (90)	No ** (28.8–30.9)	RdRp and E genes	Not described	0%	-	[61]
Rooms with non-severe COVID-19 patients (China)	Different surfaces of PPE (55)	No ** (20.8–37.9)	ORF1ab and N genes	<40	0%	-	[62]
University hospital during COVID-19 pandemic (England)	Surfaces of powered air purifying respirators (40)	No	ORF1ab and E genes	Not described	0%	-	[63]
ICU and general ward with COVID-19 patients (China)	Shoe sole (9), glove (7), sleeve cuff (9), and face shield (9)	No	ORF1ab and N genes	Not described	33.3% 14.3% *** 11.1% 0%	Not described; average RNA concentration between 2.9×10^3 and 3.2×10^4	[19]
COVID-19 treatment centre for patients after tracheostomy (China)	Powered air-purifying respirators (8), glove (8), gowns (8), and shoes (8)	No	ORF1ab and NP genes	<40	0%	-	[17]
Emergency department (France)	Different surfaces from PPEs (16)	No	ORF1ab and E genes	Not described	6.3%	38.4	[46]
COVID-19 isolation room (Singapore)	Different surfaces from PPEs (10)	No ** (23.2–35.3)	RdRp and E genes	≤45	10% (front of shoes)	39.0	[47]
COVID-19 isolation room (Singapore)	Face shield (1), N95 mask (1), and waterproof gown (1)	No ** (13.7–15.6)	RdRp and E genes	<36	0% 0% 0%	-	[32]

* mainly on the top of the head and the foot dorsum; ** PCR test results positive; *** only weakly positive (one of the two genes positive).

4. Discussion

This literature review shows that infectious SARS-CoV-2 is rarely detected on surfaces in the areas surrounding confirmed COVID-19 patients, mainly when a patient is coughing during sampling. In addition, viral RNA can be detected in variable proportions but mostly with Ct values > 30 suggesting a low viral RNA load. It is therefore assumed that surfaces in hospitals have probably no relevance as a potential source for transmission, especially when regular disinfection and cleaning is done as recommended by the WHO [64]. Similar findings were described for SARS-CoV-2 from public surfaces and PPE surfaces. The results are in line with very low detection rates of infectious influenza virus in 90 households (0%) or on 671 frequently touched surfaces in hospital rooms with confirmed influenza infection (0.3%) [65,66].

The CDC has recently published a science brief on the possible transmission of SARS-CoV-2 from surfaces and concluded that it is possible for people to be infected through contact with contaminated surfaces or objects (fomites), but the risk is generally considered to be low [67]. Based on different quantitative microbial risk assessments, it was considered to be generally less than 1 in 10,000 [55,68]. Under low viral bioburden conditions (<1 genome copy per cm^2), it was described to be below 1:1,000,000 [69].

The major limitation of the currently available studies is the lack of evidence that COVID-19 patients in healthcare settings were still shedding infectious SARS-CoV-2, as only viral RNA was detected for confirmation of the diagnosis. It has been described that infectious SARS-CoV-2 is typically detected for 7 days in respiratory tract samples, whereas viral RNA may be found for up to 28 days after beginning of the symptoms [70,71]. If patients do not shed infectious SARS-CoV-2 anymore but only viral RNA, it would be plausible to detect mainly viral RNA on surfaces and only rarely infectious virus. Future research on surface contamination need to also address the question of whether the patient carries infectious SARS-CoV-2 at the time of surface sampling. Another limitation is that the incidence of COVID-19 in the various public settings described in the studies is variable and often not known.

Whereas regular and targeted disinfection of surfaces in the areas surrounding critically ill patients in healthcare settings remains an important measure to control the spread not only of viruses but also bacteria and fungi [72], there is currently no evidence that suggest an important role of fomite transmission in the public setting. The available data do not support the necessity of regular disinfection procedures of public surfaces as currently observed in many countries. WHO still recommends reducing potential for COVID-19 virus contamination in non-healthcare settings, such as in the home, office, schools, gyms, or restaurants [73]. High-touch surfaces in these non-health care settings should be identified for priority disinfection. These include door and window handles, kitchen and food preparation areas, counter tops, bathroom surfaces, toilets and taps, touchscreen personal devices, personal computer keyboards, and work surfaces [73]. CDC advocates the cleaning and disinfection of surfaces in community facilities only after persons with suspected or confirmed COVID-19 have been in the facility [74]. The Robert Koch Institute in Germany describes cleaning of surfaces as the preferred option because it is still unknown if a surface disinfection outside healthcare facilities is overall necessary. A routine disinfection at home or in public places, including surfaces with frequent hand contacts, is currently not recommended [75]. In public settings, the contamination with high-titre infectious virus is even less likely compared to the immediate surrounding of confirmed COVID-19 cases in healthcare settings or at home. Viral contamination can possibly occur in the unlikely event of a symptomatic or an asymptomatic COVID-19 case near the surface. However, unlike in patient rooms or the domestic setting, it is not expected that there is a permanent presence of a potential virus source next to the surface.

A possible transmission from surfaces could occur via transiently contaminated hands after contact with a virus-contaminated surface followed by a hand-nose or hand-mouth contact. Several studies have analysed the likelihood of fomite transmission for respiratory viruses. One study highlighted the importance of aerosols for rhinovirus transmission

in contrast to a neglectable role for surfaces. In this study, two groups of men played poker, one group sick with the common cold and the other group healthy. The healthy group was exposed to infectious virus aerosols simply by being in the same room with the sick group; however, they were restrained so that participants could not touch their faces. Cards and chips used in the poker game were transferred to a group of healthy men to play with, and they were instructed to touch their faces frequently. Interestingly, the aerosol-exposed group got sick, while the surfaces-exposed group did not [76]. Another study could show that, on hands, only a small fraction of infectious virus is usually found after contact with artificially contaminated surfaces, such as 1.5% with parainfluenza virus and 0.7% with rhinovirus [77]. In addition, only a small fraction of the viral load can be transferred from contaminated hands to a surface (0% with parainfluenza virus and 0.9% with rhinovirus) [77]. Importantly, the risk of disease transmission by hand contact with a contaminated surface followed by a single hand-nose-contact is for rhinovirus low (0.0486%) and for influenza virus very low (0.0000000256%) [78]. Of note, seasonality of virus transmission should be considered when interpreting these results as some factors including humidity can directly influence aerosol stability. Under tropic conditions (warm and humid climates), aerosols or droplets evaporate less water and therefore readily settle on surfaces, which could favour fomite transmission as hypothesized for influenza viruses [79]. In addition, it was shown under experimental laboratory conditions at 24 °C that the half-life of SARS-CoV-2 infectivity is 15 h at 20% relative humidity, 12 h at 40% humidity, and 9 h at 60% humidity, suggesting a longer persistence of SARS-CoV-2 in dry air [80]. In addition, viral half-life was shorter at 35 °C compared to 24 °C [81]. Comparative data at 10 °C and 22 °C at different relative humidities show a longer persistence of SARS-CoV-2 at the lower temperature [81]. Nevertheless, hand washing is recommended for the public especially when returning home because the hands may also get contaminated from other people who are coughing or sneezing [82].

Especially in the public setting, as exemplified by a study analysing bus terminals in Brazil, it was interesting to see that all seven positive samples (RNA detection) were found at entrance handrails of the bus terminals. This may be explained by droplets coming from viral carriers close to the handrails. It may also be explained by SARS-CoV-2-positive passengers wearing face masks during coughing, sneezing, or talking because SARS-CoV-2 RNA may be found on the outer surface of a face mask. By touching the face mask, the hands may get contaminated, which may finally result in a handrail contamination. The corresponding Ct values, however, were so high that the RNA-positive handrails are probably not a relevant source of transmission because only a fraction of the virus remains on the hands after a hand-surface contact.

Cleaning of surfaces by a single, two second wipe has been described to reduce infectious coronavirus by 2.4 $\log_{10}$ [83]. Similar results (2.5 $\log_{10}$) were obtained with a five second single wipe against ebolavirus [84]. These results suggest that in most settings, a simple cleaning procedure with a moist wipe will be sufficient to control the very low risk attributed to public surfaces.

A health benefit of regular disinfection of public surfaces is unlikely, given the currently assumed low transmission risk via this route. Furthermore, it is important to note that regular disinfection of surfaces also carries costs, such as reducing the diversity of the microbiome and increasing the diversity of bacterial resistance genes [85]. Microbiome diversity on surfaces is especially important for babies to ensure a balanced and healthy gut microflora [86]. An increased diversity of resistance genes enhances the occurrence of multi-resistant bacteria, which is a major burden for healthcare in Europe [87] and elsewhere. Permanent exposure of bacteria to subinhibitory concentrations of some biocidal agents used for surface disinfection can cause a strong, adaptive cellular response resulting in a stable tolerance to the biocidal agents and rarely, in a few species, in a new antibiotic resistance [88]. The daily number of calls to U.S. poison centres has substantially increased in 2020, mainly for bleach (+62.1%) and other disinfectants (+36.7%). Inhalation represented the largest percentage increase among all exposure routes (+35.3% for cleaners like bleach;

+108.8% for all other disinfectants) [89]. The non-targeted, regular surface disinfection in many public places will probably have no health benefit but may have some negative side effects, similar to the broad non-targeted use of triclosan in the past [90].

A relevant question, however, remains open in this context and will hopefully be addressed in future research. To our knowledge, it has not been described how long SARS-CoV-2 remains infectious on surfaces when left in the respiratory tract secretions of confirmed COVID-19 patients. All experiments were so far done with laboratory-based, cultured SARS-CoV-2. It may well be that SARS-CoV-2 in body fluids is inactivated much faster than SARS-CoV-2 in stock solutions, as suggested by experiments with faeces [91].

5. Conclusions

Currently, available data do not support surfaces as a relevant source of SARS-CoV-2 transmission. In healthcare settings with confirmed COVID-19 cases, regular surface disinfection remains a precautionary element of infection control. In public settings, however, the associated risks and harms of regular surface disinfection probably outweigh the expected health benefits. Future studies should focus on sampling surfaces for infectious SARS-CoV-2 and better combining epidemiological and environmental data to evaluate the relevance of surfaces as a possible source for SARS-CoV-2 transmission.

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