applied sciences

MDPI

Review

Environmental Disinfection Strategies to Prevent Indirect Transmission of SARS-CoV2 in Healthcare Settings

Dorina Lauritano [1,*,†], Giulia Moreo [1,†], Luisa Limongelli [2], Michele Nardone [3] and Francesco Carinci [4]

1 Department of Medicine and Surgery, Centre of Neuroscience of Milan, University of Milano-Bicocca, 20126 Milan, Italy; moreo.giulia@gmail.com
2 Interdisciplinary Department of Medicine, University of Bari, 70121 Bari, Italy; luisa.limogelli@gmail.com
3 ASST Melegnano e della Martesana, 20070 Melegnano, Italy; michele.nardone@asst-melegnano-martesana.it
4 Department of Morphology, Surgery and Experimental Medicine, University of Ferrara, 44121 Ferrara, Italy; crc@unife.it
* Correspondence: dorina.lauritano@unimib.it
† Co-first authorship.

Received: 28 July 2020; Accepted: 7 September 2020; Published: 10 September 2020

Abstract: (1) Introduction: The novel respiratory syndrome coronavirus 2 (SARS-CoV-2), also called coronavirus disease 2019 (COVID-19), is rapidly spreading in many countries and represents a public health emergency of international concern. The SARS-CoV-2 transmission mainly occurs from person-to-person via respiratory droplets (direct transmission route), leading to the onset of mild or severe symptoms or even causing death. Since COVID-19 is able to survive also on inanimate surfaces for extended periods, constituting an indirect transmission route, healthcare settings contaminated surfaces should be submitted to specific disinfection protocols. Our review aimed to investigate the existing disinfection measures of healthcare settings surfaces, preventing the nosocomial transmission of SARS-CoV-2. (2) Materials and Methods: We conducted electronic research on PubMed, Scopus, Science Direct, and Cochrane Library, and 120 items were screened for eligibility. Only 11 articles were included in the review and selected for data extraction. (3) Results: All the included studies proposed the use of ethanol at different concentrations (70% or 75%) as a biocidal agent against SARS-CoV-2, which has the capacity to reduce the viral activity by 3 $\log_{10}$ or more after 1 min of exposure. Other disinfection protocols involved the use of chlorine-containing disinfectant, 0.1% and 0.5% sodium hypochlorite, quaternary ammonium in combination with 75% ethanol, isopropyl alcohol 70%, glutardialdehyde 2%, ultraviolet light (UV-C) technology, and many others. Two studies suggested to use the Environmental Protection Agency (EPA)-registered disinfectants, while one article chooses to follow the WST-512-2016 Guidance of Environmental and Surfaces Cleaning, Disinfection and Infection Control in Hospitals. (4) Conclusion: Different surface disinfection methods proved to reduce the viral activity of SARS-CoV-2, preventing its indirect nosocomial transmission. However, more specific cleaning measures, ad hoc for the different settings of the healthcare sector, need to be formulated.

Keywords: Sars-Cov-2; COVID-19; disinfection; dentistry; infection

1. Introduction

The new severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) was first detected in Wuhan (Hubei province, China) at the end of December 2019, and now, it is rapidly spreading all around the world. The COVID-19 pandemic urged World Health Organization (WHO) to officially declare it as a public health emergency of international concern [1].

As well as SARS-CoV-1 and Middle East respiratory syndrome (MERS), SARS-CoV-2 is an enveloped single-stranded RNA zoonotic virus, and it belongs to the β-coronavirus genera [2–4]. The SARS-CoV-2 is transmitted from person-to-person through close contact with positively infected individuals via respiratory droplets. This virus may lead to the onset of mild or severe symptoms (after an incubation period of approximately 5.2 days) or it could even cause death, especially in middle-aged and elderly subjects with pre-existing diseases. Typical mild symptoms are reported to resolve within one week and consist in fever, cough, pneumonia, fatigue, myalgia, and dyspnoea. A poor prognosis may occur due to alveolar damage, which causes a progressive respiratory failure [5–7]. In order to combat the spread of SARS-CoV-2, general public prevention measures should be adopted: social distancing, isolation of subjects with symptoms, use of surgical face masks, frequent hand hygiene, and surfaces disinfection on those which the virus is able to survive [8–11].

According to Aitken et al. [12], viruses could be important sources of nosocomial infection and the main defence strategy against their spread in hospitals is the education of staff and strict adherence to infection control protocols. The protection of health personnel in healthcare settings is crucial, since they have the task of taking care of the infected patients; this novel pandemic demonstrated to have the capacity to damage the work carrying out of many hospitals, and for this reason, healthcare workers should protect themselves and limit the spread of the virus via patient, person, and surfaces contamination in order to ensure patient care: unprepared health systems must not become vehicles for transmission through poor infection prevention [13,14].

As well as the usage of personal protective equipment by medical and nursing staff, an important prevention measure against COVID-19 is represented by the disinfection of the healthcare facilities contaminated surfaces. Many viruses, including SARS-CoV-2, could remain alive for extended periods on dry surfaces, constituting an infection source for hands and clothing, consequently leading to the inoculation through contact with eyes, mouth, or nose (indirect transmission route) [15,16].

According to the literature, the outbreak of the infection provided by coronaviruses is in part due to nosocomial spread: SARS-CoV-1 nucleic acids on surfaces were detected thanks to conventional surface swabbing, suggesting that surfaces may represent an alternative transmission route [17–19]; Ong et al. [20] took surface environmental samples at 26 sites of isolation rooms of three patients in the dedicated SARS-CoV-2 outbreak centre in Singapore, proving that the virus has the capacity to contaminate nosocomial environment (air and surfaces). The study by van Doremalen et al. [21] demonstrated the ability of SARS-CoV-2 to survive on surfaces and aerosols, testing its stability: a three-jet Collinson nebulizer generated aerosols (<5 μm) containing $10^{5.25}$ 50% tissue-culture infectious dose per millimetre of SARS-CoV-2, which was fed it into a Goldberg drum, creating an aerosolized environment. The authors calculated the virus decay rate by using a Bayesian regression model. The half-life of the virus in aerosols reaches approximately 1.1–1.2 h, while its survivability on inanimate surfaces showed higher values: on copper and cardboard no viable SARS-CoV-2 was measured after 4 and 8 h, respectively; 5.6 h was the half-life registered on stainless steel, while the viability of the virus on plastic was recorded to be equal to 6.8 h. Contaminated surfaces could represent an undocumented infection source, facilitating the dissemination of SARS-CoV-2 and contributing to the amplification of the disease caused by this pathogen in hospitals [22].

For this reason, the introduction of specific surfaces disinfection protocols against SARS-CoV-2 is crucial, which has the objective to prevent the creation of a further virus transmission mode, and may reduce concerns over the contagion risk in healthcare settings [23–25].

Objectives

This study aimed to review literature, in order to establish the existing surfaces disinfection protocols used in the healthcare settings, preventing the nosocomial transmission of SARS-CoV-2.

2. Materials and Methods

2.1. Protocol and Registration

The protocol for systematic reviews provided by the PRISMA statement [26] was followed to select methods and inclusion criteria.

2.2. Eligibility Criteria

2.2.1. Inclusion and Exclusion Criteria

This review included all the studies that investigated possible strategies for the disinfection of healthcare settings surfaces against the spread of SARS-CoV-2. Surfaces taken into consideration were tables, door handles, floors, airflow of both medical personnel and patients' dedicated rooms, instruments, and devices used for patient care. Only articles written in English were selected.

2.2.2. Search, Study Selection, and Data Collection Process

An electronic literature search was conducted using PubMed, Scopus, Science Direct, and Cochrane Library databases with the objective of finding recent research concerning the disinfection measures for nosocomial surfaces contaminated by SARS-CoV-2. Our review included institutionally approved disinfection protocols and self-reported disinfection measures experienced in hospital areas affected by the virus. The keywords used for the research in all the above-mentioned databases were combined with the Boolean term "AND": "SARS-CoV-2", "COVID-19", "contaminated surfaces disinfection", "healthcare settings surfaces", selecting paper abstracts and titles as the search field. The eligible articles for our review were selected by two researchers (G.M. and D.L.), who independently evaluated title, abstract, and full text of the found studies. From each included items, data collection was performed by two reviewers (G.M. and D.L.). The following information was extracted from the studies: healthcare setting area subjected to disinfection, type of biocidal agents used to disinfect nosocomial surfaces from SARS-CoV-2, and when explained, the frequency with which the disinfection protocol should be repeated in order to obtain strict cleaning. Figure 1 shows the flow chart used for this review.

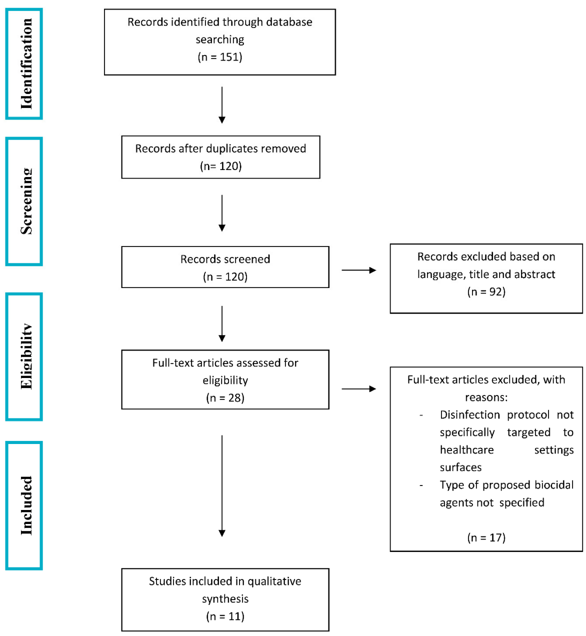

Figure 1. Flow chart of publication assessment.

3. Results

3.1. Study Selection and Characteristics

After the research on the four databases (PubMed, Science Direct, Scopus, and Cochrane Library), a total of 151 items were found. After duplication removal, 120 articles were submitted to title, abstract, and full text examination. Since this review included only English publications, 12 studies were not selected, because they were written in Chinese; fifty-five articles were excluded based on title; twenty-five based on abstract, and seventeen after a full-text evaluation. Data extraction was consequently performed for the 11 selected studies. Principal outcome measures reported in this review were: (1) type of biocidal agents used for surfaces/floor disinfection, (2) required contact time and frequency for the disinfectant to act, and (3) the area of the healthcare setting in which the disinfection protocol was implemented.

3.2. Results of Individual Studies

The included studies highlighted that different surface disinfection methods may be performed in order to prevent the indirect nosocomial transmission of SARS-CoV-2 (Table 1) by inactivating its virulence.

Kampf et al. [27] analysed different surfaces of healthcare settings, without specifying the department in which the analysis was conducted. According to this review, a significant inactivation of SARS-CoV (isolate FFM-1 and Hanoi strain) infectivity was reached in suspension tests using the following disinfectant agents: the utilization of 78–95% ethanol guaranteed a viral activity reduction of approximately 4 $\log_{10}$ or more (with a contact time of 30 s). The same result was obtained with glutardialdehyde 0.5% (contact time of 2 min) and 2.5% (contact time of 5 min) acting against Isolate FFM-1 and Hanoi Strain, respectively, while the 30 s contact of 100% concentration of 2-propanol with contaminated surfaces lead to the viral activity reduction of 3.3 $\log_{10}$ or more. More than 4.3 $\log_{10}$ viral activity reduction resulted after the application of 2-propanol 45% combined with 1-propanol 30% for 30 s. Formaldehyde 0.7–1% (contact time of 2 min) and povidone iodine 0.23–1% (contact time of 1 min) provided a viral activity reduction equal to or higher than 3$\log_{10}$. Carrier tests, reported in the same study, demonstrated that when 70% ethanol, 0.1% and 0.5% sodium hypochlorite, and 2% glutardialdehyde are allowed to act for 1 min on the contaminated surface, they brought to a viral activity reduction of 3.0 $\log_{10}$ or more. Coronavirus 2 is a new virus, and for this reason, limited research is available to date: in fact, the authors specified that the data reported in their study referred to severe acute respiratory syndrome coronaviruses for suspension tests and to human coronaviruses in general for carrier tests and that they expect similar effects against the novel SARS-CoV-2.

Dexter et al. [28] shared a surface disinfection protocol to manage the transmission of the pathogen in operating rooms (OR). This protocol requires the use of disinfection wipes (with anti-viral activity) containing a quaternary ammonium compound and alcohol, and for improved routine and terminal cleaning, it foresaw the utilization of a quaternary ammonium compound spray with a top down approach and 1–3 min of contact. This operation should be repeated twice, and at the end, a dry microfiber cloth should be used to wipe the disinfected surfaces. High-risk operating rooms should receive an additional measure, which include the use of ultraviolet light (UV-C) for 20–30 min.

According to Ti et al. [29], the disinfection of floors, surfaces, and computer screens of OR should be performed using Chlor-Clean (floor, surfaces) and Mikrozid (computer screens).

For burn wards disinfection, Li [30] et al. demonstrated that 1000 mg/L chlorine-containing disinfectant or 75% alcohol (with a contact time of 30 min) are effective on table surfaces, using a wipe or soak disinfection method and on the ground, using wipe or soak method (from the outside to indoors).

Three of the included studies provided surfaces disinfection protocols for radiology departments [31–33].

The environmental protection agency (EPA)-registered disinfectants [34] against human coronaviruses (Table 2) are cited in the study by Chandy et al. [31] and in those by Ather et al. [35], in order to clean all the SARS-CoV-2 contaminated surfaces of the interventional radiology department and dental care unit, respectively, such as hydrogen perioxide, phenolic, quaternary ammonium combined with ethanol or with isopropanol, and sodium hypochlorite.

Huang et al. [32] proposed the application on the surfaces of 1000 mg/L chlorine-containing disinfectants, wiping it twice with 75% ethanol and the use of 1000 mg/L chlorine-containing disinfectants once every 4 h for the ground cleaning.

Finally, the use of isopropyl alcohol 70% with the wipe method is foreseen for the radiology department in the study by Goh et al. [33].

Disinfection protocol for the Oral and Maxillofacial Surgery Unit proposed by Yang et al. [36] referred to the WST-512-206 Guidance of Environmental and Surfaces Cleaning Disinfection and Infection Control in Hospitals [37], which is shown in Table 3. Although the disinfection protocol reported by this study has been conceived for hospital settings, the authors suggested to apply it to dental units and maxillofacial surgery departments, which require the same need for cleaning strategies.

Wei et al. [38] described the environmental disinfection protocol against COVID-19, which is performed in the Radiation Oncology Department in of Hubei Cancer Hospital in Wuhan (China). For clean zones, authors wiped down all surfaces with disposable disinfecting wipes or 75% ethanol. All the surfaces of contaminated zones were disinfected twice daily with disposable disinfecting wipes or 75% ethanol. Ground of all the areas was disinfected twice daily with 1000 mg/L chlorine-containing disinfectants with spray method. At the end of the day, the surfaces were wiped down with 75% ethanol, the large equipment were disinfected with movable UV lights for 1 h and the ground was cleaned with 1000 mg/L chlorine-containing disinfectants.

According to Chen et al. [39], surfaces of the contaminated zone of the radiation oncology department should be cleaned using 2000 mg/L chlorine disinfectant for at least 30 min and 75% ethanol (following the manufacturer instructions).

In conclusion, some of the included studies divided the environment in different at-risk zones, each of which should be cleaned followed specific protocols. For example, Wei et al. [38] and Chen et al. [39] divided the radiation oncology unit in a contaminated, semi-contaminated, and clean zone (Table 1), while Yang et al. [35] divided the Oral and Maxillofacial Surgery Unit in a low-, medium-, and high-risk area (Table 3). The radiology department and the ward unit in the study by Goh et al. [33] and Li et al. [30], respectively, foresaw the division in a clean and dirty area. According to the Guidelines for Infection Control in Dental Health-Care Settings (2003) [40], clinical contact surfaces and housekeeping surfaces (floors, walls, sinks) should be differentiated, since these latter have a lower risk of disease transmission, and for this reason, they can be disinfected with less meticulous methods.

Table 1. Results of individual studies: biocidal agents proposed by the included articles, time of exposure/viral activity reduction of each disinfectant, and area in which the disinfection was performed.

Biocidal Agents	Time of Exposure (TE) and Viral Activity Reduction (VAR)	Disinfected Area	Study
Environmental Protection Agency (EPA)-registered disinfectants [34]	Not reported	Dental care unit	Ather et al., 2020 [35]
Environmental protection agency (EPA)-registered disinfectants [34]	Not reported	Interventional radiology department	Chandy et al., 2020 [31]
Contaminated zone: 2000 mg/L chlorine disinfectant	30 min VAR not reported	Radiation oncology facility	Chen et al., 2020 [39]
75% ethanol	Use as directed in manufacturer instructions		
Semi-contaminated zone and clean zone: Disinfection according to the regulation of disinfection techniques in the healthcare setting as issued by the country prior to COVID-19	Not reported		

Table 1. *Cont.*

Biocidal Agents	Time of Exposure (TE) and Viral Activity Reduction (VAR)	Disinfected Area	Study
Quaternary ammonium + alcohol	1–3 min VAR not reported	Operating room	Dexter et al., 2020 [28]
UV-C in high-risk anaesthesia work area	20–30 min VAR not reported		
Surfaces: Isopropyl alcohol 70%	not reported	Radiology department	Goh et al., 2020 [33]
Terminal cleaning of the scan room: Diluted bleach solution (6 mg chlorine releasing disinfectant tablet to 1000 mL water) for machine, walls, and floor.			
For delicate parts of the machine (collimators, control console, exposure buttons) isopropyl alcohol 70%			
Surfaces: 1000 mg/L chlorine-containing disinfectants, wiped twice with 75% ethanol	Not reported	Radiology department	Huang et al., 2020 [32]
Equipment: 2000 mg/L chlorine-containing disinfectant	Not reported		
DR and CT gantry wiped with 500 to 1000 mg/L chlorine containing disinfectants or alcohol-containing disposable disinfectant wipes	Twice a day		
Ground: 1000 mg/L chlorine-containing disinfectants	Once every 4 h		
Inactivation of SARS-CoV-1 (Isolate FFM-1 and Hanoi strain) in suspension tests: Ethanol 78%, 80%, 85% and 95%	30 s with a viral activity reduction of >5.0 $\log_{10}$, >4.3 $\log_{10}$, >5.5 $\log_{10}$, >5.5 $\log_{10}$, respectively	Inanimate surfaces of healthcare settings (department not specified)	Kampf et al., 2020 [27]
2-Propanol 100%	For 30 s with a viral activity reduction of ≥3.3 $\log_{10}$		
2-Propanol 45% + 1-Propanol 30%	30 s with a viral activity reduction of ≥4.3 $\log_{10}$		
Formaldehyde 0.7 and 1%	2 min with a viral activity reduction of >3.0 $\log_{10}$		
Glutardialdehyde 0.5 and 2.5%	2 and 5 min respectively with a viral activity reduction of >4.0 $\log_{10}$		
Povidone iodine 0.23–1%	1 min with a viral activity reduction of ≥3.8 $\log_{10}$		
Inactivation of SARS-CoV-1 (Strain 229E) in carrier tests: Ethanol 70%	1 min with a viral activity reduction of >3.0 $\log_{10}$		
Sodium hypochlorite 0.1 and 0.5%	1 min with a viral activity reduction of >3.0 $\log_{10}$		
Glutardialdehyde 2%	1 min with a viral activity reduction of >3.0 $\log_{10}$		
1000 mg/L chlorine-containing disinfectant or 75% alcohol for tables, using wipe or soak disinfection method	Not reported	Burn ward	Li et al., 2020 [30]
1000 mg/L chlorine-containing disinfectant for the ground, using wipe or spray method	For no less than 30 min		
Chlor-Clean for surfaces and floor	Not reported	Operating room	Ti et al., 2020 [29]
Mikrozid for computer screens			
Clean zones: Ventilation + disinfecting wipes or ethanol 75% on surfaces	Not reported	Radiation oncology department	Wei et al., 2020 [38]
Semi-contaminated zones: Terminal disinfection + good ventilation			
Contaminated zones: Disposable disinfecting wipes or 75% ethanol on surfaces			
Floor: 1000 mg/L chlorine-containing disinfectants with spray method (twice daily)			

Table 1. *Cont.*

Biocidal Agents	Time of Exposure (TE) and Viral Activity Reduction (VAR)	Disinfected Area	Study
Terminal cleaning: 75% ethanol with wipe method for surfaces			
Movable UV lights (1 h) for large equipment			
1000 mg/L chlorine-containing disinfectants for floors			
WST-512-2016 Guidance of Environmental and Surfaces Cleaning, Disinfection and Infection Control in Hospitals	Not reported	Oral and Maxillofacial Surgery unit	Yang et al., 2020 [36]

CT = computed tomography; DR = digital radiography; TE = time of exposure; UV-C = ultraviolet light; VAR = viral activity reduction.

Table 2. List of Environmental Protection Agency-registered disinfectants against human coronavirus qualified under the EPA's emerging viral pathogens program for healthcare settings [34].

Active Ingredients	Company	Contact Time	Formulation Type	Surfaces
Ethanol	- Reckitt Benckiser	0.5 min (30 s)	RTU	Hard nonporous
Hydrogen perioxide	- Diversey Inc - Virox Technologies	5 min	Dilutable or RTU	Hard nonporous
Hydrogen perioxide	- S.C. Johnson Professional	5 min	RTU	Hard nonporous
Hydrogen peroxide Ammonium carbonate Ammonium bicarbonate	- Kimberly-Clark Global Sales LLC	5 min	Pressurized liquid	Hard nonporous
Hydrogen peroxide Peroxyacetic acid	- Mason Chemical Company	- 10 min: Maguard 5626 - 1 min: Maguard 1522	Dilutable	Hard nonporous
Hydrogen peroxide Peroxyacetic acid	- Contec Inc	2 min	Dilutable	Hard nonporous
Hydrogen peroxide Peroxyacetic acid	- Contec Inc	0.5 min (30 s)	Wipe	Hard nonporous
Peroxyacetic acid	- Evonik Corporation	1 min	Dilutable	Hard nonporous
Hypochlorous acid	- Simple Science Limited	10 min	RTU	Hard nonporous
Octanoic acid	- Ecolab Inc	2 min	Dilutable	Hard nonporous
Phenolic	- Wexford Labs Inc	10 min	Dilutable	Hard nonporous
Phenolic	- Diversey Inc	10 min	Dilutable	Hard nonporous

Table 2. *Cont.*

Active Ingredients	Company	Contact Time	Formulation Type	Surfaces
Phenolic	- Contec Inc	5 min	RTU or wipe	Hard nonporous
Quaternary ammonium	- King Research Inc - ABC Compounding Co Inc - Microgen Inc - National Chemicals Inc - Clorox Professional Products Company - Talley Environmental Care Limited - VI-JON INC	10 min	Dilutable	Hard nonporous
Quaternary ammonium	- Mason Chemical Company	10 min	Dilutable	Hard nonporous Porous (laundry pre-soak only)
Quaternary ammonium	- The Clorox Company	2 min	RTU	Hard nonporous
Quaternary ammonium	- Ecolab Inc	5 min	Dilutable	Hard nonporous
Quaternary ammonium	- Stepan Company	5 min or 10 min	Dilutable or wipe	Hard nonporous
Quaternary ammonium	- Lonza LLC	1 min	Dilutable	Hard nonporous
Quaternary ammonium	- Lonza LLC	2 min or 4 min	Wipe	Hard nonporous
Quaternary ammonium	- Diversey Inc	2 min or 3 min or 10 min	Dilutable	Hard nonporous
Quaternary ammonium	- Diversey Inc - Reckitt Benckiser	2 min	RTU	Hard nonporous
Quaternary ammonium	- Reckitt Benckiser	2.5 min	Wipe	Hard nonporous
Quaternary ammonium	- Professional Disposables International Inc	3 min	Wipe	Hard nonporous
Quaternary ammonium Ethanol	- Airkem professional - Micro- Scientific LLC	2 min	RTU	Hard nonporous
Quaternary ammonium Ethanol	- North American Infection Control LTD	1 min	Dilutable	Hard nonporous
Quaternary ammonium Isopropanol	- Palermo Healthcare LLC	0.5 min (30 s)	Wipe or RTU	Hard nonporous
Quaternary ammonium Isopropanol	- Metrex Research	2 min	RTU	Hard nonporous
Silver ion Citric acid	- ETI H2O Inc	1 min or 3 min	RTU	Hard nonporous

Table 2. *Cont.*

Active Ingredients	Company	Contact Time	Formulation Type	Surfaces
Sodium chlorite	- Selective Micro Technologies LLC	10 min	Dilutable or solid	Hard nonporous
Sodium chlorite	- Odorstart LLC	10 min	Dilutable	Hard nonporous
Sodium hypochlorite	- James Austin Company	5 min or 10 min	Dilutable	Hard nonporous
Sodium hypochlorite	- Ecolab Inc	5 min	RTU	Hard nonporous
Sodium hypochlorite	- Clorox Professional Products Company	2 min	RTU	Hard nonporous
Sodium hypochlorite	- The Clorox Company	5 min	Dilutable	Hard nonporous
Sodium hypochlorite	- Clorox Professional Products Company	1 min or 5 min	RTU	Hard nonporous
Sodium hypochlorite	- Clorox Professional Products Company	5 min	Dilutable	Hard nonporous
Sodium hypochlorite	- Current Technologies Inc	1 min	RTU	Hard nonporous
Sodium hypochlorite	- Diversey Inc	1 min	Wipe	Hard nonporous

RTU = ready to use (no further dilution required).

Table 3. Cleaning and disinfection policy and practice for different levels of risk areas of Oral and Maxillofacial Surgery Unit against SARS-CoV-2 (WST-512-2016 Guidance of Environmental and Surfaces Cleaning, Disinfection and Infection Control in Hospitals) [37].

Risk of Infection	Disinfection Method	Contact Time	Frequency
Low-risk environment: facilities not accessible by patients, including doctors' and nurses' lounges	- Water + detergent		1 or 2 times per day
Medium-risk areas: areas accessible by normal and stable patients, mainly referring to the general ward and doctors' office	- Surfaces: 500 mg/L chlorine-containing disinfectants followed by cleaning with water - Floor: 500 mg/L chlorine-containing disinfectants	Surfaces: 10 to 30 min Floor: 30 min	1 or 2 times per day
High-risk areas: infected or contaminated areas or isolation areas for highly susceptible individuals, such as operating theatres, intensive care units, post-anaesthesia care units, isolation rooms	- Surfaces: 500 mg/L chlorine-containing disinfectants followed by cleaning with water - Floor: 500 mg/L chlorine-containing disinfectant - Terminal cleaning: 3% sodium hypochlorite solution → disinfection with 1000 mg/L chlorine-containing compounds → repeat spray with 3% sodium hypochlorite solution → air dry	Surfaces: 10 to 30 min Floor: 30 min Terminal cleaning: 30 min (for sodium hypochlorite)	more than 2 times per day

4. Discussion

This paper had the objective of reviewing the existing literature, concerning the biocidal agents that are used in order to ensure healthcare settings surfaces disinfection against SARS-CoV-2.

The transmission of severe acute respiratory syndrome coronaviruses occurs not only thorough direct physical contact with infected subjects or large-droplet spread but also via contact with environmental contaminated surfaces (indirect transmission) [41,42]. Viruses are pathogens commonly present in hospitals and many of them, including human coronavirus, can survive for hours on hands but also on environmental surfaces [43,44], creating an outbreak of nosocomial transmission.

The experiment performed by Ashokka et al. [45] in which the production of aerosol was simulated by a three-jet Collision nebulizer and fed into a Goldberg drum, recorded that SARS-CoV-2 would be able to survive for 72 h on plastic and stainless steel, 24 h on cardboard, and 4 h on copper. The virus survived approximately 2.7 h in the simulated aerosol. Similar data were obtained during the same experiment conducted by van Doremalen et al. [21]. Therefore, healthcare settings surfaces decontamination results to be crucial in the prevention of SARS-CoV-2 spread [43].

All the studies proposed alcohol based disinfection agents against SARS-CoV [27,32,33,37,38]. Alcohol-based products inactivate virus particle by disrupting the structure of proteins on the surface of SARS-CoV-2, thorough the mechanism called protein denaturation: alcohol displaces the hydrogen bonds between amino acids holding the viral proteins in shape, and as a consequence, proteins lose their structure and function, thereby inactivating the virus. The research conducted by Hulkower et al. [46] tested the efficacy of 62%, 70%, and 71% ethanol (undiluted), 0.55% orthophthalaldehyde, sodium hypochlorite, and phenol (diluted in hard water) on coronaviruses contaminated healthcare settings hard surfaces, showing that only ethanol has the capacity to reduce the virus infectivity by $>3 \log_{10}$ after one minute of exposure. Another study [47] proved the efficacy of different biocidal agents against human coronavirus 229E, considering as virucidal effectiveness criterion a reduction of viral activity of $\geq 3 \log_{10}$: ethanol 70% alone or combined with chlorhexidine gluconate 0.008% and cetrimide 0.08%, phenol 5% plus sodium lauryl sulphate 0.06%, and alkaline glutaraldehyde 2% were able to guarantee an important activity against the virus, as opposed to sodium hypochlorite 0.01%, quaternary ammonium 0.04%, and triple phenolic 0.06%, whose action was not sufficient to inactivate the pathogen.

Several included articles inserted the use of chlorine-containing disinfectants in their cleaning protocols [29,30,32,38]. The exact mechanism by which chlorine kills the viruses is still unclear. The virus inactivation may result from inhibition of protein synthesis, loss of intracellular contents, reduction of nutrients or oxygen uptake, oxidation of amino acids, etc. Agolini et al. [48] reviewed the literature in order to find preventive measures to limit the spread of SARS-CoV. In addition to ethyl alcohol 70%, this review proposed the use of chlorine compounds solutions, after an accurate pre-cleaning, to obtain floor and large-surface decontamination. Phenolic detergent disinfectants could substitute chlorine when corrosion, bleaching, or gas production are to be avoided.

Another effective cleaning method is represented by ultraviolet light (UV-C), which reduces the viral contamination in healthcare settings thanks to its action on surfaces and air column [36]. UV-C (with wavelengths equal to 207–222) is able to damage the proteins on the surface of the virus, preventing them from attaching human cells. UV-C works through the use of lamps producing high-intensity ultraviolet C light, which is an electromagnetic radiation form [49]. The utility of this technology has been proven by Pavia et al. [50], who recorded a viral infection incidence reduction of 44% in a paediatric long-term facility, suggesting that UV-C could be able to eliminate the environment as a source of viral infection. However, according to literature, UV-C disinfection should always be performed in combination with chemical cleaning [51].

The disinfection of air should also be considered, since human coronavirus is able to survive in aerosol for few hours (2.7). Some of the selected items used UV lights twice per day for 1 h each time [37,38] or suggested to guarantee accurate ventilation of the area [38], while others chose to treat positive subjects only in negative-pressure rooms or airborne infection isolation rooms (AIIRs) [34].

One included article [34] explained the cleaning protocol for dental care settings. Dentists are the most exposed workers to the risk of COVID-19 transmission more than general physicians and nurses [52]. For this reason, specific SARS-CoV-2 management protocols are needed not only for hospitals but also for the personal protection and disinfection in dental care units.

5. Strengths and Limitations of the Study

The restricted number of studies reviewed in this paper may be considered a limitation; furthermore, study designs of the selected items are not uniform and most of them consist of descriptive articles, without any statistical analysis of data. On the other hand, this review succeeded in reporting disinfection protocols for many different hospital areas, giving a complete overview of healthcare settings surfaces management.

6. Conclusions

The current spread of novel SARS-CoV-2 to many countries requires the development of specific environment disinfection protocols in order to limit its nosocomial transmission. The main biocidal agents proposed by the articles included in this review were alcohol based or chlorine-containing disinfectants, while UV-C technology was suggested to be used only in addition to chemical cleaning. Environmental Protection Agency-registered disinfectants against human coronavirus are also considered effective against the virus. However, more specific disinfection measures, ad hoc for the different settings of healthcare sector, need to be formulated.

Author Contributions: Conceptualization, F.C. and D.L.; methodology, M.N.; validation, G.M., L.L.; investigation, D.L.; resources, F.C.; data curation, G.M.; writing—original draft preparation, D.L.; writing—review and editing, G.M.; visualization, L.L.; supervision, F.C.; project administration, D.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Guo, Y.-R.; Cao, Q.-D.; Hong, Z.; Tan, Y.-Y.; Chen, S.; Jin, H.; Tan, K.S.; Wang, D.; Yan, Y. The origin, transmission and clinical therapies on coronavirus disease 2019 (COVID-19) outbreak—An update on the status. *Mil. Med. Res.* **2020**, *7*, 11. [CrossRef] [PubMed]
2. Chen, Y.; Liu, Q.; Guo, D.-Y. Emerging coronaviruses: Genome structure, replication, and pathogenesis. *J. Med. Virol.* **2020**, *92*, 418–423. [CrossRef] [PubMed]
3. Sun, P.; Lu, X.; Xu, C.; Sun, W.; Pan, B. Understanding of COVID-19 based on current evidence. *J. Med. Virol.* **2020**, *92*, 548–551. [CrossRef]
4. Su, S.; Wong, G.; Shi, W.; Liu, J.; Lai, A.C.; Zhou, J.; Liu, W.; Bi, Y.; Gao, G.F. Epidemiology, Genetic Recombination, and Pathogenesis of Coronaviruses. *Trends Microbiol.* **2016**, *24*, 490–502. [CrossRef] [PubMed]
5. Chavez, S.; Long, B.; Koyfman, A.; Liang, S.Y. Coronavirus Disease (COVID-19): A primer for emergency physicians. *Am. J. Emerg. Med.* **2020**. [CrossRef]
6. Huang, C.; Wang, Y.; Li, X.; Ren, L.; Zhao, J.; Hu, Y.; Zhang, L.; Fan, G.; Xu, J.; Gu, X.; et al. Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. *Lancet* **2020**, *395*, 497–506. [CrossRef]
7. Adhikari, S.P.; Meng, S.; Wu, Y.-J.; Mao, Y.-P.; Ye, R.-X.; Wang, Q.-Z.; Sun, C.; Sylvia, S.; Rozelle, S.; Raat, H.; et al. Epidemiology, causes, clinical manifestation and diagnosis, prevention and control of coronavirus disease (COVID-19) during the early outbreak period: A scoping review. *Infect. Dis. Poverty* **2020**, *9*, 1–12. [CrossRef]
8. Gabutti, G.; D'Anchera, E.; Sandri, F.; Savio, M.; Stefanati, A. Coronavirus: Update Related to the Current Outbreak of COVID-19. *Infect. Dis. Ther.* **2020**, *9*, 241–253. [CrossRef]
9. Mash, B. Primary care management of the coronavirus (COVID-19). *S. Afr. Fam. Pract. (2004)* **2020**, *62*, e1–e4. [CrossRef]

10. Ling, L.; Wong, W.T.; Wan, W.T.P.; Choi, G.; Joynt, G.M. Infection control in non-clinical areas during the COVID-19 pandemic. *Anaesthesia* **2020**, *75*, 962–963. [CrossRef]
11. Lai, C.-C.; Shih, T.-P.; Ko, W.-C.; Tang, H.-J.; Hsueh, P.-R. Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and coronavirus disease-2019 (COVID-19): The epidemic and the challenges. *Int. J. Antimicrob. Agents* **2020**, *55*, 105924. [CrossRef] [PubMed]
12. Aitken, C.; Jeffries, D.J. Nosocomial Spread of Viral Disease. *Clin. Microbiol. Rev.* **2001**, *14*, 528–546. [CrossRef] [PubMed]
13. Ros, M.; Neuwirth, L.S. Increasing global awareness of timely COVID-19 healthcare guidelines through FPV training tutorials: Portable public health crises teaching method. *Nurse Educ. Today* **2020**, *91*, 104479. [CrossRef] [PubMed]
14. Powell-Jackson, T.; King, J.J.C.; Makungu, C.; Spieker, N.; Woodd, S.; Risha, P.; Goodman, C. Infection prevention and control compliance in Tanzanian outpatient facilities: A cross-sectional study with implications for the control of COVID-19. *Lancet Glob. Health* **2020**, *8*, e780–e789. [CrossRef]
15. Otter, J.A.; Yezli, S.; French, G. The Role Played by Contaminated Surfaces in the Transmission of Nosocomial Pathogens. *Infect. Control Hosp. Epidemiol.* **2011**, *32*, 687–699. [CrossRef] [PubMed]
16. Otter, J.A.; Donskey, C.; Yezli, S.; Douthwaite, S.; Goldenberg, S.D.; Weber, D. Transmission of SARS and MERS coronaviruses and influenza virus in healthcare settings: The possible role of dry surface contamination. *J. Hosp. Infect.* **2016**, *92*, 235–250. [CrossRef] [PubMed]
17. Casanova, L.M.; Jeon, S.; Rutala, W.A.; Weber, D.J.; Sobsey, M.D. Effects of Air Temperature and Relative Humidity on Coronavirus Survival on Surfaces. *Appl. Environ. Microbiol.* **2010**, *76*, 2712–2717. [CrossRef]
18. Booth, T.F.; Kournikakis, B.; Bastien, N.; Ho, J.; Kobasa, D.; Stadnyk, L.; Li, Y.; Spence, M.; Paton, S.; Henry, B.; et al. Detection of Airborne Severe Acute Respiratory Syndrome (SARS) Coronavirus and Environmental Contamination in SARS Outbreak Units. *J. Infect. Dis.* **2005**, *191*, 1472–1477. [CrossRef]
19. Dowell, S.F.; Simmerman, J.M.; Erdman, D.D.; Wu, J.-S.J.; Chaovavanich, A.; Javadi, M.; Yang, J.-Y.; Anderson, L.; Tong, S.; Ho, M.S. Severe Acute Respiratory Syndrome Coronavirus on Hospital Surfaces. *Clin. Infect. Dis.* **2004**, *39*, 652–657. [CrossRef]
20. Ong, S.W.X.; Tan, Y.K.; Chia, P.Y.; Lee, T.H.; Ng, O.-T.; Wong, M.S.Y.; Marimuthu, K. Air, Surface Environmental, and Personal Protective Equipment Contamination by Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) from a Symptomatic Patient. *JAMA* **2020**, *323*, 1610. [CrossRef]
21. Van Doremalen, N.; Bushmaker, T.; Morris, D.H.; Holbrook, M.G.; Gamble, A.; Williamson, B.N.; Tamin, A.; Harcourt, J.L.; Thornburg, N.J.; Gerber, S.I.; et al. Aerosol and Surface Stability of SARS-CoV-2 as Compared with SARS-CoV-1. *N. Engl. J. Med.* **2020**. [CrossRef] [PubMed]
22. Li, R.; Pei, S.; Chen, B.; Song, Y.; Zhang, T.; Yang, W.; Shaman, J. Substantial undocumented infection facilitates the rapid dissemination of novel coronavirus (SARS-CoV-2). *Science* **2020**, *368*, 489–493. [CrossRef] [PubMed]
23. Yen, M.Y.; Schwartz, J.; King, C.C.; Lee, C.M.; Hsueh, P.R.; Society of Taiwan Long-Term Care Infection Prevention and Control. Recommendations for protecting against and mitigating the COVID-19 pandemic in long-term care facilities. *J. Microbiol. Immunol. Infect.* **2020**, *53*, 447–453. [CrossRef] [PubMed]
24. Colaneri, M.; Seminari, E.; Novati, S.; Asperges, E.; Biscarini, S.; Piralla, A.; Percivalle, E.; Cassaniti, I.; Baldanti, F.; Bruno, R.; et al. Severe acute respiratory syndrome coronavirus 2 RNA contamination of inanimate surfaces and virus viability in a health care emergency unit. *Clin. Microbiol. Infect.* **2020**, *26*, 1094.e1–1094.e5. [CrossRef] [PubMed]
25. Colaneri, M.; Seminari, E.; Piralla, A.; Zuccaro, V.; Di Filippo, A.; Baldanti, F.; Bruno, R.; Mondelli, M.U.; Brunetti, E.; Di Matteo, A.; et al. Lack of SARS-CoV-2 RNA environmental contamination in a tertiary referral hospital for infectious diseases in Northern Italy. *J. Hosp. Infect.* **2020**, *105*, 474–476. [CrossRef]
26. Liberati, A.; Altman, U.G.; Tetzlaff, J.; Mulrow, C.; Gøtzsche, P.C.; Ioannidis, J.P.A.; Clarke, M.; Devereaux, P.J.; Kleijnen, J.; Moher, D. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: Explanation and elaboration. *BMJ* **2009**, *339*, b2700. [CrossRef]
27. Kampf, G.; Todt, D.; Pfaender, S.; Steinmann, E. Persistence of coronaviruses on inanimate surfaces and their inactivation with biocidal agents. *J. Hosp. Infect.* **2020**, *104*, 246–251. [CrossRef]
28. Dexter, F.; Parra, M.C.; Brown, J.R.; Loftus, R.W. Perioperative COVID-19 Defense: An Evidence-Based Approach for Optimization of Infection Control and Operating Room Management. *Anesth. Analg.* **2020**, *131*, 37–42. [CrossRef]

29. Ti, L.K.; Ang, L.S.; Foong, T.W.; Ng, B.S.W. What we do when a COVID-19 patient needs an operation: Operating room preparation and guidance. *Can. J. Anesth.* **2020**, *67*, 756–758. [CrossRef]
30. Li, N.; Liu, T.; Chen, H.; Liao, J.; Li, H.; Luo, Q.; Song, H.; Xiang, F.; Tan, J.; Zhou, J.; et al. Management strategies for the burn ward during COVID-19 pandemic. *Burns* **2020**, *46*, 756–761. [CrossRef]
31. Chandy, P.E.; Nasir, M.U.; Srinivasan, S.; Klass, D.; Nicolaou, S.; Babu, S.B. Interventional radiology and COVID-19: Evidence-based measures to limit transmission. *Diagn. Interv. Radiol.* **2020**, *26*, 236–240. [CrossRef] [PubMed]
32. Huang, Z.; Zhao, S.; Li, Z.; Chen, W.; Zhao, L.; Deng, L.; Song, B. The Battle Against Coronavirus Disease 2019 (COVID-19): Emergency Management and Infection Control in a Radiology Department. *J. Am. Coll. Radiol.* **2020**, *17*, 710–716. [CrossRef] [PubMed]
33. Goh, Y.; Chua, W.; Lee, J.K.; Ang, B.W.L.; Liang, C.R.; Tan, C.A.; Choong, D.A.W.; Hoon, H.X.; Ong, M.K.L.; Quek, S.T. Operational Strategies to Prevent Coronavirus Disease 2019 (COVID-19) Spread in Radiology: Experience from a Singapore Radiology Department After Severe Acute Respiratory Syndrome. *J. Am. Coll. Radiol.* **2020**, *17*, 717–723. [CrossRef] [PubMed]
34. List N: Disinfectants for Use Against SARS-CoV-2; Environmental Protection Agency. Available online: https://www.epa.gov/pesticide-registration/list-n-disinfectants-use-against-sars-cov-2 (accessed on 4 September 2020).
35. Ather, A.; Patel, B.; Ruparel, N.B.; Diogenes, A.; Hargreaves, K.M. Coronavirus Disease 19 (COVID-19): Implications for Clinical Dental Care. *J. Endod.* **2020**, *46*, 584–595. [CrossRef]
36. Yang, Y.; Soh, H.Y.; Cai, Z.G.; Peng, X.; Zhang, Y.; Bin Guo, C. Experience of Diagnosing and Managing Patients in Oral Maxillofacial Surgery during the Prevention and Control Period of the New Coronavirus Pneumonia. *Chin. J. Dent. Res.* **2020**, *23*, 57–62. [PubMed]
37. National Health and Family Planning Commission of People's Republic of China. Regulation for Cleaning and Disinfection Management of Environmental Surface in Healthcare (WST-512-2016). Available online: http://www.nhc.gov.cn/ewebeditor/uploadfile/2017/01/20170105092341798.pdf (accessed on 10 April 2020). (In Chinese)
38. Wei, W.; Zheng, D.; Lei, Y.; Wu, S.; Verma, V.; Liu, Y.; Wei, X.; Bi, J.; Hu, D.; Han, G. Radiotherapy workflow and protection procedures during the Coronavirus Disease 2019 (COVID-19) outbreak: Experience of the Hubei Cancer Hospital in Wuhan, China. *Radiother. Oncol.* **2020**, *148*, 203–210. [CrossRef]
39. Chen, W.; Su, X.-Y.; Wang, V.J.; Wang, E.C.; Xu, R.; Zhong, S.; Sun, G.; Xia, J. Novel Coronavirus International Public Health Emergency: Guidance on Radiation Oncology Facility Operation. *Adv. Radiat. Oncol.* **2020**, *5*, 560–566. [CrossRef]
40. Phua, J.; Weng, L.; Ling, L.; Egi, M.; Lim, C.-M.; Divatia, J.V.; Shrestha, B.R.; Arabi, Y.M.; Ng, J.; Gomersall, C.D.; et al. Intensive care management of coronavirus disease 2019 (COVID-19): Challenges and recommendations. *Lancet Respir. Med.* **2020**, *8*, 506–517. [CrossRef]
41. Scales, D.C.; Green, K.; Chan, A.K.; Poutanen, S.M.; Foster, D.; Nowak, K.; Raboud, J.M.; Saskin, R.; Lapinsky, S.E.; Stewart, T.E. Illness in intensive care staff after brief exposure to severe acute respiratory syndrome. *Emerg. Infect. Dis.* **2003**, *9*, 1205–1210. [CrossRef]
42. Law, S.; Leung, A.W.; Xu, C. Severe acute respiratory syndrome (SARS) and coronavirus disease-2019 (COVID-19): From causes to preventions in Hong Kong. *Int. J. Infect. Dis.* **2020**, *94*, 156–163. [CrossRef]
43. Abdullah, A.S.; Tomlinson, B.; Cockram, C.S.; Thomas, G.N. Lessons from the Severe Acute Respiratory Syndrome Outbreak in Hong Kong. *Emerg. Infect. Dis.* **2003**, *9*, 1042–1045. [CrossRef]
44. Kramer, A.; Schwebke, I.; Kampf, G. How long do nosocomial pathogens persist on inanimate surfaces? A systematic review. *BMC Infect. Dis.* **2006**, *6*, 130. [CrossRef]
45. Ashokka, B.; Loh, M.-H.; Tan, C.H.; Su, L.L.; Young, B.E.; Lye, D.C.; Biswas, A.; Illanes, S.E.; Choolani, M. Care of the pregnant woman with coronavirus disease 2019 in labor and delivery: Anesthesia, emergency cesarean delivery, differential diagnosis in the acutely ill parturient, care of the newborn, and protection of the healthcare personnel. *Am. J. Obstet. Gynecol.* **2020**, *223*, 66–74.e3. [CrossRef] [PubMed]
46. Hulkower, R.; Casanova, L.M.; Rutala, W.A.; Weber, D.J.; Sobsey, M.D. Inactivation of surrogate coronaviruses on hard surfaces by health care germicides. *Am. J. Infect. Control* **2011**, *39*, 401–407. [CrossRef]
47. Sattar, S. Microbicides and the environmental control of nosocomial viral infections. *J. Hosp. Infect.* **2004**, *56*, 64–69. [CrossRef] [PubMed]

48. Agolini, G.; Raitano, A.; Viotti, P.L.; Vitali, M.; Zorzut, F. SARS: Diagnosis, therapy, and especially prevention (Reveiw). *Ann. Ig. Med. Prev. Comunità* **2004**, *16*, 211–224.
49. Health Quality Ontario. Portable Ultraviolet Light Surface-Disinfecting Devices for Prevention of Hospital-Acquired Infections: A Health Technology Assessment. *Ont. Health Technol. Assess. Ser.* **2018**, *18*, 1–73.
50. Pavia, M.; Simpser, E.; Becker, M.; Mainquist, W.K.; Velez, K.A. The effect of ultraviolet-C technology on viral infection incidence in a pediatric long-term care facility. *Am. J. Infect. Control* **2018**, *46*, 720–722. [CrossRef]
51. Andersen, B.; Bånrud, H.; Bøe, E.; Bjordal, O.; Drangsholt, F. Comparison of UV C Light and Chemicals for Disinfection of Surfaces in Hospital Isolation Units. *Infect. Control Hosp. Epidemiol.* **2006**, *27*, 729–734. [CrossRef]
52. Spagnuolo, G.; De Vito, D.; Rengo, S.; Tatullo, M. COVID-19 Outbreak: An Overview on Dentistry. *Int. J. Environ. Res. Public Health* **2020**, *17*, 2094. [CrossRef]