REALM PROJECT
REopening Archives, Libraries and Museums

REALM Systematic Literature Review

The REopening Archives, Libraries, and Museums (REALM) Project has produced a systematic literature review to help inform the scope of the project's research and the information needs of libraries, archives, and museums (LAMs). Battelle researchers completed the review, which includes findings from available scientific literature. This review focused on studies of virus attenuation on commonly found materials, such as paper, plastic, cloth, and metal; methods of virus transmission; and effectiveness of prevention and decontamination measures.

As you read this literature review, keep in mind a few key points:

1. The research and information captured in the findings include both peer-reviewed and non-peer-reviewed studies. In the interest to publish emerging research related to the COVID-19 pandemic as quickly as possible, publication has been expedited rather than waiting for time-intensive peer review.
2. The studies included in the review have been conducted by different researchers, under different conditions, likely using different concentrations—and possibly sources—of the virus. This makes it difficult, if not impossible, for a reviewer to make a straight comparison across studies; and, interpreting the results may be challenging for readers without a science background. Part of the REALM Project's future efforts will be more interpretation of these results for a lay audience.
3. The review includes findings for industries, such as health care, that operate under considerably different constraints and risk factors than do LAMs. However, for the research it was important to consider a broad range of available research to determine what may be applicable to LAM operations and identify what research gaps exist. The research captured in the review does not represent recommendations or guidance for LAMs; but, commonalities with other fields and industries may be found as the research proceeds, and the project will continue to monitor the science literature for emerging science-based information that relates to LAM operations.

Highlights of literature review findings

Please note that these highlighted findings in the literature review may be relevant to libraries, archives and museums, but inclusion does not constitute a recommendation or guidance.

How the virus spreads

- SARS-CoV-2 is generally thought to spread through:
    1. Virus-containing water droplets expelled from infected persons through sneezing, coughing, speaking, and other breathing-related actions, and
    2. Objects (sometimes called fomites) that contain the virus on their surfaces.
- Other possible ways in need of more study are small aerosol particles, fecal matter (in solid and aerosol forms), and other airborne routes.
- Environmental factors such as humidity, temperature, ventilation/air flow, and air conditioning may also affect the spread of SARS-CoV-2. But additional research is needed to verify and/or clarify these ideas.

Survival on surfaces

- If SARS-CoV-2 gets spread to surfaces or materials, it seems to survive for different amounts of time depending on the type of surface or material, before dying off on its own.
- A few early studies (not peer-reviewed) reported that the virus may survive longer on plastics and stainless steel than on paper products and other metals, such as copper.
- However, it is not possible to draw firm conclusions from their results at this time. That's because there were a small number of studies, differences in the way scientists conducted the studies, and other confounding factors.

Prevention and decontamination

- Researchers suggested several feasible, low-cost options for reducing the presence of SARS-CoV-2, which may help keep people from getting the virus:
  - Cleaning surfaces often. Use cleaning agents such as sodium dichloroisocyanurate, sodium hypochlorite, ethanol, and hydrogen peroxide.
  - Practicing social distancing. This can help stop the virus from spreading between people through sneezing, coughing, speaking, etc.
  - Frequent handwashing. Soap and water or alcohol-based hand sanitizers were recommended.
  - Wearing of personal protective equipment (PPE). PPE that covers the mouth and nose may be most helpful.
- Other ways that need more studies to find out if they work are heat treatment, sunlight and other light-based treatments, ventilation systems, and open spaces.

Additional resources

These spreadsheets may be useful to reviewers:

- Compilation of all referenced sources (spreadsheet)
- Surface attenuation results and methods (spreadsheet)

A preliminary literature review was released on June 3, 2020, and is available for download. The project team will continue to collect and review published literature related to COVID-19 and share out those findings with the LAM community.

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Systematic Literature Review of SARS-CoV-2: Spread, Environmental Attenuation, Prevention, and Decontamination

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REALM REopening Archives, Libraries and Museums PROJECT

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Executive Summary

To help inform handling of physical library collections and local library facilities in anticipation of a phased-in or full reopening, Battelle conducted a systematic literature review of relevant research publications that were released about the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) through mid-May 2020. The literature review gathered, evaluated, and synthesized research literature published on SARS-CoV-2 as it relates to three key topics:

- Virus spread through public library general operations
- Virus survival on material surfaces through environmental attenuation
- Effective prevention and decontamination measures that are readily available to public libraries in the near term.

Documents were identified based on a preliminary search as well as a systematic search of four scientific databases: Scopus, Web of Science, SciTech, and MEDLINE, which were selected for their comprehensive coverage of the literature. These search processes ultimately yielded 100 relevant research articles.

Given the emerging nature of SARS-CoV-2, the research literature presented as a work-in-progress, with many of the articles being pre-prints, letters to the editor, articles in press, and other types of publication that had not undergone the scholarly vetting process of peer review. In general, additional rigorous experimental research is needed that focuses specifically on SARS-CoV-2 to replicate early experiments and verify their findings (especially those studies that didn't complete peer review) as well as to explore the impact of the diverse variables that could affect the virus' ability to spread and persist in local libraries and other similar environments, such as temperature, humidity, fomite, the presence of biological substances (e.g., saliva, feces), and so on. Furthermore, this literature review investigated findings related to the spread of SARS-CoV-2, but additional research into the mechanisms of transmission and contraction of the virus, such as the minimum viral count leading to infection, may provide additional insight into exposure risks and highest-impact prevention strategies.

Until then, some of the high-level findings of this literature review are as follows:

- SARS-CoV-2 is generally understood to spread through virus-containing water droplets (from sneezes, coughing, speaking, etc.) expelled from infected persons as well as objects (sometimes called fomites) that contain the virus on their surfaces.
- Preliminary research has been conducted on other means of transmission, such as small aerosol particles, fecal matter (in solid or aerosolized form), and other airborne transmission routes, but additional research is needed to clarify the extent of transmissibility via these pathways. Some studies have reported that breast milk and tears do not spread the virus.
- Environmental factors such as humidity, temperature, ventilation/air flow, and air conditioning have been identified as having the potential to impact the spread of the SARS-CoV-2, though additional research is needed to understand the complexities of these variables' impact on the virus.

- SARS-CoV-2 seems to survive on various surface materials for different lengths of time before naturally attenuating, and the early findings suggest that the virus may survive longer on plastics and stainless steel than on paper products and other metals, such as copper. However, these reports are not peer-reviewed scholarly publications and seem to have been released to offer early support in decision-making, while acknowledging their own limitations. Furthermore, comparisons between studies and conclusive determinations based on these studies are largely untenable at this time, given the small number of publications on this topic, diverse methodologies employed, wealth of potential variables that can impact results, and the inconclusive range of findings reported thus far.
- Prevention and decontamination tactics presented in the literature offer several feasible, low-cost options for reducing presence of SARS-CoV-2 in environments, which may help prevent transmission of the virus. One of the most effective strategies found is decontaminating surfaces with cleaning agents, and the research suggests that several common chemicals can be effective viricides, including sodium dichloroisocyanurate, sodium hypochlorite, ethanol, and hydrogen peroxide. Another is practicing social distancing to prevent transmission between individuals.
- Additional strategies thought to be effective for reducing the presence of the virus in environments include frequent handwashing (soap and water or alcohol-based hand sanitizers) and wearing of personal protective equipment (PPE) (especially mouth and nose-covering masks.
- Further research is needed to confirm their efficacy, but other potential avenues for prevention and decontamination of SARS-CoV-2 include thermal treatment, sunlight and other light-based treatments, ventilation systems, and open spaces.

The results of this literature review conclude that the knowledgebase about SARS-CoV-2 remains nascent at this time, but additional research is being published—in peer-reviewed and less optimal forms—on a rolling basis. Additional high-quality experimental research will prove useful both to confirm the early findings reported thus far and to expand the field's understanding of the complexities that impact the way the virus spreads, its survivability on diverse surfaces, and effective prevention and decontamination strategies.

1. Introduction

This project is funded by the Institute of Museum and Library Services (IMLS) to conduct scientific research regarding SARS-CoV-2 and develop information, communications, and materials for libraries, archives and museums as they plan to resume operations with the public. These institutions have unique operations, tactile surfaces, and a high volume of staff and patrons. Through a collaborative relationship, OCLC and Battelle will merge their expertise to best support libraries and museums in their efforts to reduce the transmission of SARS-CoV-2 and Coronavirus Disease 2019 (COVID-19), the disease caused by SARS-CoV-2.

The first phase of this project is focused primarily on collecting, curating, and disseminating information related to handling of physical library collections and local library facilities in anticipation of a phased-in or full reopening. As part of those efforts, Battelle conducted a literature review and evaluation of relevant research publications that were released about SARS-CoV-2 through May 2020.

1.1. Purpose of Literature Review

The purpose of this review was to systematically gather, evaluate, and synthesize research literature that was published about SARS-CoV-2 related to the following research questions:

1) How could the virus spread through public library general operations?
2) How long does the virus survive on material surfaces through environmental attenuation?
3) How effective are various prevention and decontamination measures that are readily available to public libraries in the near term?

The literature review also identified gaps in the research literature and recommendations for additional research that could support libraries and will identify sources of data that can be used to inform sections of the PMTA in addition to highlighting evidence gaps, clinical guidelines, measures, issues, and controversies surrounding topics of harm or perceived harm of ENDS.

2. Methods

The literature review consisted of two steps: 1) a preliminary scan of the available literature, and 2) a systematic literature search. These methods are outlined in the sections that follow, including a description of the search process, abstraction process, and quality control process.

2.1. Preliminary Scan

Battelle performed an organic, targeted search of the research landscape as an exploratory preliminary step. Battelle research staff searched research tools such as PubMed, WorldCat Discovery, and Google Scholar to identify scholarly articles that addressed SARS-CoV-2 in terms of the three research questions above. As such, emphasis was given to peer-reviewed articles that directly discussed SARS-CoV-2 in terms of its survivability on surfaces, effective prevention and decontamination measures, and how the virus could spread through library operations. Articles that focused on other types of coronaviruses (e.g., those that caused the SARS and Middle Eastern Respiratory Syndrome (MERS) outbreaks) or that focused on aspects of SARS-CoV-2 other than the research questions (e.g., epidemiology, genetic structure, etc.) were excluded from consideration.

Due to the emerging nature of the research topic and the amount of time typically required for publication of rigorous scientific studies, the relevant articles, in many cases, were published online in “pre-print,” letter to the editor, “early release,” or other sub-optimal forms. In these cases, the articles had not undergone the traditional scholarly peer review needed to vet the scientific quality of research methods and findings and were, therefore, approached with caution and identified as such in the preliminary report.

Battelle reported on the results of the preliminary search on May 14, 2020, which included findings from 18 articles. The findings of that search, review, and report served as the foundation for the subsequent systematic literature search process.

2.2. Systematic Literature Search

The systematic literature search was initiated after production of the preliminary report. It involved search string development, executing the searches, reviewing results for relevancy, abstracting key information from relevant articles, summarizing key findings, and conducting quality control reviews.

2.2.1 Search String Development

For the systematic search process, search strings were developed iteratively and included variations of the term “SARS-CoV-2” and the research questions (e.g., transmission routes, attenuation, and decontamination/prevention) using Boolean operators. The Boolean operator “AND” was used to separate SARS-CoV-2 and research question terms, while different variations of the virus name and verbs related to the research questions were grouped by category using parentheses and the Boolean operator “OR” [e.g., ("SARS-CoV-2" OR "2019-nCoV" OR "COVID-19") AND (decontam* OR attenuat*)]. Two different search strings were produced: one focused on decontamination and surface attenuation of the virus and a second search focused on avenues of indoor transmission. The virus SARS-CoV-2 (and its variants) were included in both searches to focus results on the virus of interest. The search string developed for transmission included an additional parenthetical to focus results on transmission methods relevant to library settings (e.g., “indoor” OR “aerosol”).

A Battelle librarian performed ad hoc testing of search terms related to the research questions, removing terms and adding exclusions to further refine the search string to increase relevant results and decrease non-relevant results. This library professional had previously collaborated with other Battelle staff on SARS-CoV-2-related literature reviews, which helped inform the ad hoc testing and optimization of search results. The search strings were executed on May 11, 2020 (focus: decontamination and surface attenuation) and May 19, 2020 (focus: avenues of indoor transmission). The final listing of search strings can be found in Appendix A.

Battelle conducted a systematic literature review using the specified search terms and inclusion criteria (see section 2.3.1.). Searches were conducted using Scopus, SciTech, Web of Science, and MEDLINE databases. These databases were selected due to their ability to provide comprehensive search capacity, being inclusive of many smaller databases.

Prior to identifying final search strings and databases, staff conducted preliminary reviews of search results. The strings were revised if the tested strings yielded a significant amount of irrelevant content. For example, articles related to changes in pollution during the pandemic sometimes arose in the results, so the strings were revised by adding a NOT Boolean operator followed by “pollution” and any other terms found to recur in non-relevant results. Further, search staff filtered by date (2018-current) and language (English) to reduce non-relevant results. The same search strings were entered into all databases. Furthermore, results from the four databases overlapped in some cases, and so duplicates were removed from the search results to produce a single results list. Ultimately, the searches produced 527 unique results, which were then reviewed for relevancy.

2.2.2 Abstraction Process

Battelle staff were trained in the project, the research topics of interest, relevancy considerations, and a two-step abstraction process. In the first step, staff conducted an initial review of the title and abstract of articles, grouped in batches of 50 to 60 articles, and determined if the article indicated relevancy to the literature review objectives. Staff were instructed to reach out to the task lead for additional guidance on inclusion/exclusion. Articles identified as relevant in the initial step (n=98) were consolidated into a list for the second step. Next, staff reviewed the full text of the articles to confirm relevancy, and if relevant, categorized them by research topic and subtopic, summarized relevant results, and identified limitations and qualifications for the articles. A total of 24 articles were identified as non-relevant, most commonly due to not having English full-text available (e.g., some articles published in Mandarin Chinese had English translations for the title and abstract but not the full article). The relevant articles and abstracted data were organized into lists according to research topic area and provided to the report writing team, along with 15 additional articles from the preliminary search results.

Furthermore, a key article in the results was the Department of Homeland Security's *Master Question List for COVID-19 (caused by SARS-CoV-2)*, a literature review updated on a weekly basis to provide up-to-date findings and guidance (note: the latest version available at time of writing was the May 26, 2020 edition). Battelle cross-checked its results against those found in relevant topic areas of this document and supplemented the relevant results list with any new articles found there.

In total, 100 relevant articles were identified through the preliminary search, systematic search, and abstraction processes (see **Table 1** below for a summary of the article count). Battelle synthesized the findings of 52 of these relevant documents in this report. In addition, an EndNote database was created to house reference information for all relevant articles captured during this review, which will be exported to Excel spreadsheet format and provided as part of the overall systematic literature review deliverable. Additionally, a full reference list, including clickable links to the publisher websites, is also included at the conclusion of this report.

Table 1. Summary of Article Count

Process Step	Number of Articles Under Consideration After Process Step
Database Searches	527
Relevancy Reviews	98
Abstraction	89
Additional Reference Reviews	100
Final	100

2.2.3 Inclusion/Exclusion Criteria

For inclusion in the literature review, articles needed to be written in or translated to English, include information specific to SARS-CoV-2, and address at least one of the three research questions. Published scholarly peer-reviewed research was prioritized, but other literature meeting the previously stated criteria was also included, such as "pre-prints," letters to the editor, reports, and "articles in press."

Articles published prior to 2018, in languages other than English, not about SARS-CoV-2, or did not address at least one of the three research questions were excluded from the literature review. The year 2018 was selected to exclude articles unrelated to SARS-CoV-2, which first emerged in late 2019. Literature reviews and reports were scrutinized closely to ascertain what findings were developed from SARS-CoV-2 research and what arose from research of other coronaviruses (e.g., SARS and MERS).

2.2.4 Quality Control Process

A quality control (QC) process was developed to check if articles were appropriately identified as non-relevant and relevant. Battelle staff performed two levels of QC. The first level involved reviewing the initial abstraction results in which staff identified articles as relevant or non-relevant. QC staff randomly selected 20% of the articles from each batch and reviewed the titles and abstracts to verify the relevancy determinations. If an incorrect determination was identified, QC staff conducted a full review of that abstractor's batch and corrected determinations as needed (note: this occurred in the case of one 50-article batch). The second level of QC occurred during the second abstraction step, during which staff reviewed the full text of articles to confirm relevancy. Any articles that proved non-relevant during this review were excluded and not abstracted/summarized. Additionally, the 18 articles included in the preliminary search report were also QC checked at this time to ensure they met the final relevancy guidelines, which led to four articles being excluded and one article being deemed relevant that was not included in the preliminary report.

3. Findings

3.1 Spread of SARS-CoV-2 through Public Library Operations

According to the Department of Homeland Security's Master Question List for COVID-19 (caused by SARS-CoV-2) (May 26, 2020), SARS-CoV-2 is thought to mostly spread between people in close contact to one another and through respiratory droplets.

SARS-CoV-2 can be transmitted by individuals who are in the incubation stage, symptomatic, or by individuals who are contagious but asymptomatic (referred to as super spreaders) (Qu, Li, Hu, & Jiang, 2020). Breathing and talking produce aerosol particles of varied sizes. Larger-sized droplets generally fall to the ground due to gravity; however, smaller sized particles may remain suspended in the air long enough to be spread by wind or air conditioning and diffused in contact with other people, surfaces, or environments (Meselson, 2020). Recent research on transmission of SARS-CoV-2 through person-to-person droplets (e.g., direct coughs), aerosol transmission, fomites (infected surfaces), and impact of environmental factors (e.g., humidity) are described below. Note, no evidence specific to public libraries and spread was found.

3.1.1 Person-to-Person Droplets

Transmission of SARS-CoV-2 due to close contact from person-to-person (e.g., coughing, sneezing, breathing, and/or talking) has been documented in a variety of settings, including, but not limited to hospitals.

Wang and Du (2020) reported that when an individual infected with SARS-CoV-2 coughs, sneezes, or breaths heavily, the virus is excreted and suspended in the air as bio-aerosols. Bio-aerosols ranging from 1 to 10μm are likely to be suspended in the air and are at a respirable fraction size (i.e., they can be inhaled). Particles larger than 5μm have the ability to fall on nearby surfaces. Droplets of saliva excreted by coughing or sneezing can spread 1 to 2 m from the source, while aerosols can travel up to hundreds of meters.

Ferioli, et al. (2020) conducted a literature review to assess findings related to SARS-CoV-2 transmission risk for healthcare workers in contact with patients undergoing respiratory therapies, safety measures to minimize transmission from contact with exhaled droplets, and suggested precautions that can minimize aerosol-based transmission of SARS-CoV-2 in patients with COVID-19. They reported that cough droplets could travel 68 cm without a mask, 30 cm with a mask, and 15 cm with an N95 mask. This did not however account for side leakage. SARS-CoV-2 transmission has been found to be passed through droplets, which can be exhaled up to 1 meter from the source, depending on force and environmental conditions, and only suspend in the air for a “short time.”

Stadnytskyi, et al. (2020), used a laser light to visualize expelled droplets produced while speaking. The number of particles was approximated by the average number of particles in a frame of the movie clip captured by the volume ratio of the testing area to the light sheet. After participants repeated the phrase "stay healthy," the fan was turned off and the camera recorded for 80 minutes. Results showed that the weighted average decay rate is a half-life of ca. 8 minutes. In other words, the authors estimated that "1 minute of loud speaking generates at least 1,000 virion-containing droplet nuclei that remain airborne for more than 8 minutes. These therefore could be inhaled by others and, according to IAH, trigger a new SARA-CoC-2 infection." (p. 2).

Cheng et al. (2020) reported that airborne transmission was found to be minimal, though this may have been due to a small sample size or the specific air filtration system in the research setting. The authors reported that, in an “airborne infection isolation room” in a Hong Kong hospital, an experienced infection control nurse collected air samples 10 cm from the mouth of a patient diagnosed with SARS-CoV-2 infection as the patient engaged in four types of respiratory activities: breathing normally, breathing deeply, speaking continuously, and coughing continuously. This was repeated with and without the patient wearing a surgical mask (i.e., eight samples total). The results showed that SARS-CoV-2 RNA was not detected in the air samples. The patient’s nose/throat swabs had a "moderate" viral load of 3.3

x106 copies per mL, and saliva produced 5.9 x106 copies per mL. The authors could not make a definitive conclusion based on one patient sample size, but they attributed the lack of detectable virus in the eight air samples to the use of air cleaning in the isolation rooms (12 air changes/hour) or to limited airborne transmission of SARS-CoV-2.

3.1.2 Aerosolization

In addition to transmission via person-to-person contact with droplets, virus transmission has been found to be possible from aerosolization of the virus. In particular, Cai et al. (2020) note the potential risk of spread of aerosolized droplets in confined public spaces. Evidence related to the spread of SARS-CoV-2 via virus aerosolization is discussed in turn.

Guo et al. (2020) presented results in an early release article from air sampling in an intensive care unit (ICU) and a general SARS-CoV-2 ward to evaluate the distribution of and potential exposure to SARS-CoV-2 in full or near capacity hospitals. The authors collected indoor air samples from sites in close proximity to 15 ICU patients and 24 general ward patients. SARS-CoV-2 was found to be widely distributed in the air in both the ICU and general ward. The authors concluded that virus aerosol distribution characteristics in the general ward indicate that the transmission distance of SARS-CoV-2 could be four meters. The authors noted two limitations with the study. Firstly, the results of a nucleic acid test did not indicate the amount of viable virus. Secondly, the authors note that a precise aerosol transmission distance cannot be calculated for a minimal infectious dose.

Van Doremalen et al. (2020), in their correspondence to the editor, presented findings from an experiment in which an aerosol containing SARS-CoV-2 “was generated with the use of a three-jet Collison nebulizer and fed into a Goldberg drum to create an aerosolized environment” (pg. 1). The concentration of virus in the sample was 105.25 50% tissue culture infectious dose per milliliter (presented in this section as “105.25 TCID50 per mL”). SARS-CoV-2 remained viable for more than three hours, “with a reduction in infectious titer from 103.5 to 102.7 TCID50 per liter of air” (p. 1). It is important to note that while the duration of the experiment was three hours, SARS-CoV-2 remained viable throughout – it is unknown how long virus remains viable in aerosol form. The half-life of SARS-CoV-2 in aerosolized form was approximately 1.1 – 1.2 hours, with 95% of the half-life values falling between 0.64 and 2.64 hours. Others have calculated a longer half-life; Wu et al., (2020) put the half-life of SARS-CoV-2 at about 2.7 hours.

Liu and colleagues (2020a) described the aerodynamic nature of SARS-CoV-2 by measuring viral RNA in aerosols in 30 different areas of two hospitals (The Renmin Hospital of Wuhan University and Wuchang Fangcang Field Hospital) in Wuhan, China. Observations were made during the COVID-19 outbreak in February and March 2020. Ventilated areas and isolation areas showed low concentrations of the virus but levels in restrooms (specifically, toilet areas) were elevated. Public areas show relatively low levels of SARS-COV-R RNA except where crowds had gathered.

In contrast, Faridi et al. (2020) examined air samples from rooms of confirmed COVID-19 patients experiencing severe and critical symptoms in a hospital in Tehran, Iran. The researchers used the impinger technique to collect air samples (i.e., from 1.5 to 1.8 meters from the floor and 2 to 5 meters away from patients' beds). These samples were tested for presence of SARS-CoV-2. The indoor CO2 concentration, relative humidity and temperature in the rooms were also recorded. Findings indicated that SARS-CoV-2 was not detected in any air samples. These findings are inconsistent with other investigations and suggest that in vivo experiments utilize samples of droplets/aerosols from actual coughs, sneezes, and breaths from people who have tested positive for the virus.

3.1.3 Fomites

Fomites, or objects with which people come into contact and can carry the virus (e.g. doorknobs), are another likely contributor to the spread of SARS-CoV-2, as infected people spread the virus to fomites through direct contact or possibly aerosols.

The Department of Homeland Security Science and Technology Directorate (May 26, 2020) published their literature review titled “Master Question List for COVID-19 (caused by SARS-CoV-2),” which concluded that, “SARS-CoV-2 can persist on surfaces for at least 3 days and on the surface of a surgical mask for up to 7 days depending on conditions” (p.13). It was also noted that “additional testing on SARS-CoV-2, as opposed to surrogate viruses, is needed to support initial estimates of stability” (p. 13).

The Guo et al., (2020) pre-release article that assessed aerosolization of SARS-Cov-2 took swab samples of potentially contaminated objects. There were many positive results in the floor samples which authors hypothesize that this could be due to environmental factors (e.g. gravity and air flow) causing droplets to fall to the ground. Besides floors and shoes, other surfaces with high positives included computer mice, trash cans, handrails, and doorknobs.

Ye et al. (2020; article in press) evaluated the potential contamination of surfaces of 13 hospital function zones, 5 major objects, and 3 major PPE with SAR-CoV-2 in a hospital in Wuhan, China. Reverse transcription polymerase chain reaction (RT-PCR) was used for the detection of SAR-CoV-2. The results of the study revealed that of the 626 hospital environmental surface swabs collected, 13.6% were found to be positive for SARS-CoV-2. The most contaminated objects were self-service printers (20%), desktops/keyboards (16.8%), and doorknobs (16.0%). SARS-CoV-2 was also detected in 20.3% of hand sanitizer dispensers; 15.4% of gloves, and 1.7% of eye protection or face shields. The authors concluded that their study highlights the importance of environmental cleaning, strong infection prevention training and improved prevention precautions in minimizing the risk of the spread of SARS-CoV-2.

In a research letter (i.e., not peer-reviewed research) in *JAMA*, Ong, Tan, Chia, Lee, Ng, Wong, and Marimuthu (2020) conducted environmental assessments of 26 different sites in each of three patient rooms at a SARS-CoV-2 outbreak center in Singapore while patients were treated in those rooms. Samples from two patient rooms returned negative results for SARS-CoV-2 after two collection periods. In the third patient room, 13 of 15 room sites (including air outlet fans) and 3 of 5 toilet sites tested positive.

Wu, Wang, Jin, Tian, Liu and Mao (2020; under review) evaluated the presence of SARS-CoV-2 on contact surface areas and in the air in a designated COVID-19 hospital setting. The authors collected 200 surface samples and analyzed them using RT-PCR and sequencing, followed by statistical analysis using the $\chi 2$ test or the Fisher exact test if data was limited. The surfaces that were found to have a positive rate at least 25% of the times tested included beepers (50%), water machine buttons

(50%), elevator buttons (42.86%), computer mouses (40%), telephones (40%), keyboards (33.33%), medical equipment (30.77%), and the oxygen cylinder valve (25%). Considering all of the surfaces sampled, the detection rate for SARS-CoV-2 was 19%. A higher positive rate was found in staff areas versus patient rooms, which the authors attributed to physical barriers between the areas to separate staff and patients and more thorough disinfection in patient rooms. The authors noted that high touch surfaces that may not be cleaned as much as other surfaces, such as elevator and water machine buttons, exhibited the highest positive rates of SARS-CoV-2 when tested. Similarly, the authors recommended using keyboard covers to enable easy disinfection after use. The authors also noted that "gloves are not a substitute for hand hygiene" as one in seven gloves tested was found to be positive for the virus. The authors concluded that "the environment is a potential medium of transmission" and provided recommendations for disinfection methodology (see Discussion section below).

Cheng et al. (2020) conducted an environmental pilot experiment in a Hong Kong hospital testing transmission of SARS-CoV-2 within the "airborne infection isolation room" of an infected patient. The patient was said to have a "moderate" viral load of 3.3 $x10^6$ copies per mL and the saliva was 5.9 $x10^6$ copies per mL. In the environmental experiment, an experienced infection control nurse collected air samples 10 cm from the patient's mouth while the patient breathed, spoke, and coughed. The researchers collected specimens from the room (bench, bed railing, locker, bed table, alcohol dispenser, and window bench; exact surface types were not named) before and after the air samples were conducted to assess distribution of the virus by air. No samples were detectable for SARS-CoV-2 RNA, except for the window bench, which measured 6.5×10^2 copies per mL. The authors said they could not make a definitive conclusion based on having one patient sample, but they attributed the limited transmission (only 1 environmental sample was found) to the use of air cleaning in the isolation rooms (12 air changes/hour) or to limited airborne transmission of SARS-CoV-2, though they acknowledged the possibility of indirect transmission through environmental surfaces, consistent with SARS-CoV.

Transmission via fecal shedding is a growing concern in the SARS-CoV-2 research. McDermott, Alicic, Harden, Cox, and Scanlan (2020) in a pre-proof article stated that the transmission of SARS-CoV-2 via shedding virus in stool is an underrecognized problem. Multiple articles that tested for virus found RNA samples on toilet seats and/or bathroom floors (Taskforce for the COVID-19 Cruise Ship Outbreak; Santarpia et al., 2020; Liu et al., 2020b; Ong et al., 2020), and in stool samples (Wang, Feng, et al., 2020). In addition, Cai et al. (2020) believe that the spread of SARS-CoV-2 in their research could have resulted via fomites including restroom taps. However, as stated by La Rosa, Bonadonna, Lucentini, Kenmoe, and Suffredini (2020), "Transmission of COVID-19 through the fecal-oral route, however, has not been demonstrated, nor occurrence of SARS-CoV-2 in water environments has been proved to date" (p.2). More research with consistent air sampling methods and technology is needed to know how transmission occurs.

3.1.4 Environmental Factors

A variety of researchers have investigated environmental factors that affect the spread of SARS-CoV-2. In particular, humidity, temperature, ventilation/air flow, and air conditioning have been identified as influential factors.

A pre-print of an experimental study by Chaudhuri, Basu, Kabi, Unni and Saha (2020) sought to investigate the evaporation rate of droplets through observation in controlled temperature and humidity simulations as well as formulation of reaction rate to model the pandemic. Results indicated that potentially warmer weather can contribute to decreased spread of the virus. Yao, Zhang, Ma, and Zhou (2020) provided evidence that SARS-CoV-2 could be transmitted via air in inadequately ventilated environments and such transmission was reduced in environments with high temperature and low humidity (i.e., "increasing ambient ozone concentration level from 48.83 to 94.67μg/m3" ($p = 0.039$) and decreasing relative humidity from 82.67 to 23.33% ($p = 0.002$)" and increasing temperature from −13.17 to 19 °C)" ($p = 0.003$) (p.1)). However, other evidence suggests that environmental factors are not conclusive. In particular, a review by Eslami and Jalili (2020) suggested that increased temperature has decreased prevalence in some cities while increased humidity and wind speed was not statistically significant.

Air flow produced by air conditioning and indoor ventilation systems may also impact transmission of SARS-CoV-2. In a research letter, Lu et al. (2020) described the infection of 10 individuals from 3 families with SARS-CoV-2 while dining at a restaurant in Guangzhou, China. Dining tables were about one meter apart and the restaurant was an air-conditioned space with no windows. Based on contact tracing and diner seating information, the authors concluded that transmission was likely due to droplets circulated by air conditioning, as strong airflow extended droplet travel distance. However, authors noted two limitations specific to their investigation: 1) it was not "an experimental study simulating the airborne transmission route" and 2) "serologic studies of swab sample–negative asymptomatic family members and other diners to estimate risk for infection" were not performed (n.p.). A pre-print of Correia, Rodrigues, Gameiro da Silva and Goncalves (2020)'s work "Airborne route and bad use of ventilation systems as non-negligible factors in SARS-CoV-2 transmission" explored SARS-CoV-2 transmission via HVAC systems. The authors noted that HVAC systems can be used to clean and purify air, but absent of filters, HVAC systems could spread SARS-CoV-2. The article also mentioned that because findings suggest the virus is excreted via urine and feces, bathrooms should be regarded as places with potentially high contamination, so the authors suggested that bathroom HVAC systems should be especially filtered or separated off.

3.1.5 Non-routes of Transmission

Although evidence suggests that direct contact with infected people, contaminated surfaces, as well as inhalation of airborne droplets and aerosols are likely to transmit the virus, some routes studied did not show likelihood of transmission. Findings related to unlikely transmission routes such as tears, breast milk, food packages, and drinking water are noted below.

In particular, tears have been shown to present a low chance of transmission (Seah et al., 2020). Researchers conducted a prospective study using RT-PCR analysis to determine whether SARS-CoV-2 is transmitted through tears. This small study included 17 SAR-CoV-2 patients from Singapore. Nasopharyngeal swabs and tear samples were collected. None of the patients had ocular symptoms, and 14 patients had upper respiratory symptoms. Sixty-four samples were collected over a three-week period, all testing negative for SARS-CoV-2 on viral isolation as well as RT-PCR. This study found no evidence of viral shedding via tears. The authors cited use of two laboratories analyzing samples using two different assays as well as small sample size as limitations of this study. They also noted that only tears were sampled rather than conjunctival tissue and concluded that their results suggest transmission through tears is low, but recommend future studies using more in-depth analysis and larger sample size are conducted.

There is currently no evidence to suggest human breast milk contains the virus; however, surface contamination from droplet spread is still a concern for safely handling milk containers and breast pumps. With this in mind, Marinelli and Lawrence (2020), encourage mothers in their pre-print article to wear masks and wash their hands before and after expressing milk. The authors further recommend disinfecting containers to protect from spreading the virus.

In addition, in a review by Eslami and Jalili (2020), the authors noted the CDC's conclusion that food packages and handlers are not identified as a risk factor for the disease; however, hand washing followed by disinfection were encouraged. The authors also cited the latest World Health Organization (WHO) report, which suggested there is no evidence of transmission through drinking water.

3.2 Survival of SARS-CoV-2 on Material Surfaces Through Environmental Attenuation

There is a growing body of evidence that suggests that it may be possible for SARS-CoV-2 to be spread via contact with surfaces and materials containing active virus (Chin et al., 2020; van Doremalen et al., 2020; Grinchuk et al., 2020). To better understand the threat of contracting the virus through contact with infected surfaces and materials, researchers have begun investigating how long the virus can survive on various surfaces and materials. This section describes research findings organized by surface type, and **Table 2** provides at-a-glance ranges for virus stability for a variety of different surfaces. A more detailed table including methodological details (where provided) can be found in **Appendix B.**

Generally speaking, attenuation tests follow a standard procedure, although methods do vary across the experiments described below. To conduct attenuation tests, scientists choose the material and pathogen they'd like to test. Live virus is obtained and infectibility is confirmed using the tissue culture infectious dose assay ($TCID_{50}$). This assay, also called viral titer or viral load, measures the amount of virus in given volume of fluid. After the test surfaces are sterilized to prevent confounding by other contaminants, the pathogen is mixed with synthetic saliva or biomedium and is applied to a surface by pipetting, smearing, or via aerosol. At pre-designated time points, the virus is extracted from the surface using an extraction medium and a $TCID_{50}$ is performed. This process is typically replicated several times to minimize likelihood of error (called 'replicates'). Environmental parameters like temperature and relative humidity are typically kept constant throughout the experiment.

3.2.1 Surfaces Tested for Survivability of SARS-CoV-2

Plastic

In their preprinted article, Grinchuk et al. (2020) evaluated virus viability on plastic (polypropylene) at environmental conditions of 21-23°C (approximately room temperature) and 40% relative humidity (RH, lower end of air-conditioned indoor space). Initial concentration of SARS-CoV-2 in the sample droplets was $10^{3.4}$ – $10^{3.7}$ or 2500-5000 ml^{-1}, which was consistent with the level of virus concentration in samples from the upper and lower respiratory tract. Fifty microliters of viral culture were added to liquid biomaterial and applied to each surface tested. Smears from the surfaces were taken at pre-designated time intervals. Grinchuk et al. reported that SARS-CoV-2 remained viable for 50 hours after application on plastic.

Van Doremalen and colleagues (2020) authored a letter to the editor in which they evaluated viability of SARS-CoV-2 under the exact same environmental conditions (temperature and RH) as Grinchuk et al. and found that viable virus remained 72 hours after application to a plastic surface, although the virus titer was greatly reduced "from $10^{3.7}$ to $10^{0.6}$ $TCID_{50}$ per mL of medium after 72 hours" (pg. 1). Among the surfaces tested, the researchers found that viability was longest on plastic, with a median half-life of 6.8 hours. Virus viability remained relatively constant for the first 24 hours and then dropped off significantly.

In a preprinted article, French researchers also sought to determine SARS-CoV-2 viability on polystyrene plastic (Pastorino et al., 2020). At 45-55% RH and a temperature of 19-21°C, the researchers applied samples of SARS-CoV-2 (10^6 $TCID_{50}$ per mL inoculum, suspended with and without bovine serum albumin (BSA)) in 50 µL droplets to polystyrene plastic and other surfaces. After 92 hours, virus viability remained approximately steady, with a reduction of less than one log_{10} drop (i.e., the amount of virus decreased by about 10 times). Notably, virus suspended in BSA remained viable for significantly longer than samples that did not use BSA. BSA was used in this study because the protein content closely mimics that of airway secretions. This pattern was seen on other materials tested by Pastorino and colleagues (glass and aluminum). Echoing Pastorino's finding regarding prolonged stability of SARS-CoV-2 on plastics, Chin et al., (2020) describe in their letter to the editor that no infectious virus was detected on plastic on day seven (168 hours) after inoculation. Overall, SARS-CoV-2 appears to have the longest survivability on plastic surfaces.

Stainless steel

Grinchuk et al. (2020) found that SARS-CoV-2 remained viable on stainless steel (alloy 304 – the most common type of stainless steel) for 30 hours, while van Doremalen and colleagues (2020) observed viable virus 48 hours after application (viral load decrease from $10^{3.7}$ to $10^{0.6}$ $TCID_{50}$ per mL). Half-life of SARS-CoV-2 on stainless steel was measured at a median value of 5.6 hours. Chin et al., found that viability of the virus on stainless steel was equivalent to plastic, at seven days (168 hours).

Cloth

Chin et al. (2020) tested SARS-CoV-2 viability on a large number of surfaces, including cloth. To do this, a five-microliter droplet of culture (concentration of 7.8 log unit of $TCID_{50}$ per mL) was pipetted onto various surfaces at 22°C and 65% RH. No infectious virus was detected on day two after inoculation.

Cardboard

Van Doremalen and colleagues (2020) found that no viable virus was detected on cardboard after 24 hours but advised caution in interpretation of results due to the variability in the calculated half-life.

However, Grinchuk et al. (2020) observed the same finding, noting that no viable virus remained on cardboard 24 hours after application.

Copper

In testing survival of SARS-CoV-2 on copper, Grinchuk et al. (2020) found that no viable virus remained after five hours. Similarly, van Doremalen et al. (2020) found that no viable virus remained after four hours.

Glass

In Pastorino et al. (2020), a 3.5 $\log_{10}$ decrease in virus occurred 44 hours after placement on a glass surface, indicating that viable virus was still present at that time. Chin et al., found that virus remained viable on glass for around four days (96 hours).

Aluminum

Pastorino et al. (2020) also tested SARS-CoV-2 viability on aluminum and found the sharpest drop among surfaces tested – a 6 $\log_{10}$ drop in less than four hours.

Wood

Chin et al., (2020) found that no infectious virus was detected on treated wood on day two of the experiment (48 hours).

Banknote

On banknotes (paper money), Chin et al. (2020) found that no infectious virus remained after four days (96 hours).

Paper

Also, in Chin et al.'s (2020) analysis of surface attenuation, no infectious virus was detected on printing or tissue paper after three hours.

Table 2. Reported ranges of survival of SARS-CoV-2 on various surfaces.[a]

Surface or material	Attenuation range results	Number of sources
Surgical mask	168 hours	1
Plastic	50 – 168 hours	4
Stainless steel	30 – 168 hours	3
Banknote	96 hours	1
Glass	>44 – 96 hours	2
Cloth	48 hours	1
Wood	48 hours	1
Cardboard	24 hours	2
Copper	4 – 5 hours	2
Aluminum	<4 hours	1
Paper	3 hours	1

[a] These experiments did not use the same methodologies to conduct testing. More information on each test can be found in Appendix B.

Surgical Masks

Lastly, Chin et al., (2020) found that SARS-CoV-2 could still be detected on the outside of a surgical mask seven days after inoculation (168 hours).

3.2.2 Environmental Factors Affecting Attenuation

Researchers have worked to determine how environmental factors (e.g. temperature, humidity, etc.) impact the survival of SARS-CoV-2 on surfaces and materials. Grinchuk et al. (2020) argued that the ability of SARS-CoV-2 to remain viable on a surface may be mediated by the thermal conductivity of that surface. Thermal conductivity, in this case, is a surface's ability to transfer heat, and Grinchuk et al. hypothesize that characteristics of heat transfer may influence evaporation rate of droplets and impact viability of the virus on surfaces.

Others have explored additional potential factors of environmental attenuation. With regard to temperature, in a lab setting, Chin et al. (2020) detected viable virus after 14 days at 4°C (0.7 $\log_{10}$ reduction); however, at 70°C no viable virus was detected after 5 minutes. Similarly, in studies of environmental temperature, Wang, Jiang, et al. (2020) found that as the ambient air temperature increased by 1°C, the cumulative number of cases decreased by 0.86% in Hubei Province, China. This finding was echoed by Bhattacharjee (2020) who found that increased humidity and ambient temperature were associated with decreased prevalence in cases in nine cities in China and Italy. Despite associations between temperature, humidity, and virus viability, Luo et al. (2020) and Merow and Urban (2020) both urged caution in the interpretation of such results. Both emphasize that changes in weather alone (humidity and temperature) will not be sufficient to control the spread of COVID-19. However, it should also be noted, that the focus of these studies was on outdoor conditions and that authors were not speaking to the impact of indoor air temperature and humidity on viability of SARS-CoV-2 of surfaces specifically.

3.3 Effectiveness of Prevention and Decontamination Measures for SARS-CoV-2

The research literature explored the efficacy of a variety of prevention and decontamination measures to eliminate the presence of SARS-CoV-2, including thermal and light treatments, personal protective equipment (PPE), hand hygiene, ventilation and open space, and surface cleaners and disinfectants.

Several researchers have provided general guidelines and recommendations for mitigating the presence of SARS-CoV-2. For example, Ferioli and colleagues (2020) presented recommendations for protecting healthcare workers from SARS-CoV-2. Preventative measures that could be applicable in other settings included frequent hand washing with an alcohol-based detergent if hands are not apparently dirty and with soap and water if they are; avoiding contact with eyes, nose, and mouth; sneezing and coughing into the elbow or a tissue; wearing masks; and maintaining a one meter distance from others. Additionally, in a report on the spread of COVID-19 among workers in meat and poultry processing facilities, Dyal et al. (2020) provided several strategies for minimizing the risk of transmission among workers in those facilities that could be applied to other settings, including symptom screening programs, discouraging employees from working when symptomatic, social distancing, use of cloth face masks, and increased disinfection of high-touch surfaces.

3.3.1 Thermal and Sunlight Treatments

In their correspondence article, Chin and colleagues (2020) described their examination of the stability of SARS-CoV-2 at different temperatures, they found that the virus is highly stable at 4°C but is susceptible to heat. There was an approximately 0.7 log-unit reduction of infectious titer on day 14 at 4°C; however, when the incubation temperature was increased to 70°C, virus inactivation was reduced only to five minutes.

Ratnesar-Shumate et al. (2020) tested whether natural sunlight was capable of inactivating SARS-CoV-2 on surfaces, specifically stainless steel. In this study, five microliter droplets of virus were suspended in culture media (gMEM) or simulated saliva and were deposited on stainless steel coupons (i.e., flat, rectangular pieces of stainless steel). The concentration of the virus was $1.5 \times 10^7 \pm 7.5 \times 10^6$ TCID50 per mL. Sunlight was simulated to represent a summer solstice at a latitude of 40°N at sea level on a clear day. The primary finding of this study was that simulated sunlight inactivated 90% of SARS-CoV-2 every 14.3 minutes in culture media and every 6.8 minutes in simulated saliva, at the highest UVB radiation level tested. Inactivation of the virus also occurred as lower simulated sunlight levels, but at a slower rate.

3.3.2 Personal Protective Equipment (PPE)

In "Master Question List for COVID-19 (caused by SARS-CoV-2)," a literature review published by Department of Homeland Security (DHS) Science and Technology Directorate (2020), it was concluded that although "masks may be effective at slowing transmission," "the effectiveness of PPE for SARS-CoV-2 is currently unknown, and data from other related coronaviruses are used for guidance" and "most PPE recommendations have not been made on SARS-CoV-2 data, and comparative efficacy of different PPE for different tasks (e.g., intubation) is unknown" (p. 14).

Cheng et al. (2020) reported on the emergency response and infection control preparedness in a Hong Kong hospital, where 413 healthcare workers were in contact with patients infected with SARS-CoV-2, including 11 staff with unprotected exposure; however, zero cases of infection transmission to healthcare workers at the hospital was reported. The authors attributed this lack of transmission to a bundled prevention approach of mask wearing by all staff and visitors and enhanced hand hygiene.

In their literature review of SARS-CoV-2 transmission risk for healthcare workers, Ferioli et al. (2020) recommended that healthcare workers can reduce exposure to exhaled droplets from infected patients by wearing medical or surgical masks that cover nose and mouth were recommended, not fabric masks, and wearers were encouraged to follow directions for proper wear. Physical barriers were also recommended to reduce exposure, such as glass or plastic windows.

Considering the recommendations by various organizations and government for the general public to wear face coverings to minimize the spread of COVID-19, Pleil and colleagues (2020) provided a scientific rationale for such face coverings. Specifically, the authors argued that simple medical masks and improvised face coverings may capture exhaled aerosols and prevent the transmission of SARS-CoV-2 as aerosols and particles "crash" on to the mask surface.

In a letter to the editor, Hsaio et al. (2020) echoed the idea that the use of face coverings may aid in preventing the transmission of SARS-CoV-2. The authors argued that while several studies have highlighted the inadequacies of face masks in offering protection, worldwide trends suggest that there have been fewer uncontrolled outbreaks of COVID-19 in countries where mask-wearing was common. They suggested that masks reduce expired air velocity and provide a barrier that prevent droplets from exhalations, sneezes, and coughs from spreading. Additionally, masks reduce "the effective radius from which the mask wearer is drawing air" (p.907).

Konda et al. (2020) noted that there is limited knowledge on the performance of various fabrics used for cloth masks. Thus, the researchers tested how effective various common fabrics (including cotton, silk, chiffon, flannel, various synthetics, and their combinations) were at filtering out aerosol particles. Findings revealed that fabric with tight weaves and low porosity, like high-thread-count cotton, performed better while materials like natural silk, chiffon weave, and flannel may be effective in electrostatic filtering of particles. Konda et al. suggested that hybrid masks which combine layers of fabrics that offer mechanical and electrostatic filtering (e.g. a layer of high thread count cotton and two layers of natural silk) are the most effective. They also emphasized the importance of the fit of masks as openings and gaps greatly reduce their protective capabilities.

3.3.3 Hand Hygiene

In DHS Science and Technology Directorate (2020), it was concluded that soap and water and hand sanitizers are effective at decontaminating hands of SARS-CoV-2.

In an early release article, Kratzel and colleagues (2020) examined whether alcohol-based hand sanitation formulations effectively inactivated SARS-CoV-2. Specifically, the researchers evaluated different concentrations of original and modified World Health Organization formulations which utilized ethanol or propanol. They conducted "virucidal activity studies by using a quantitative suspension test with 30-[second] exposure time" and looked at the cytotoxic effects of disinfectants to assess virus infectivity (n.p.). Findings showed that all the original and modified formulations effectively inactivated SARS-CoV-2.

The report of a Hong Kong hospital's response by Cheng et al. (2020) attributed the lack of transmission of SARS-CoV-2 to 413 healthcare workers to a bundled prevention approach of mask wearing and enhanced hand hygiene, which was monitored for compliance.

In their perspective article, Kapoor and Saha (2020) discussed the various methods of maintaining hand hygiene to minimize the spread of COVID-19. Specifically, they recommended the use of soap and water for obviously contaminated hands and alcohol-based preparations when hands are not visibly dirty. They indicated that chlorine solutions and iodide or iodophors can potentially be used as hand cleaning agents in the absence of soap and alcohol. The authors mentioned that chlorhexidine may not be as effective in inactivating human coronaviruses.

3.3.4 Ventilation and Open Space

In an accelerated article preview (Liu et al., 2020a) and a preprint article (Liu et al. 2020b), Liu et al presented the results of an aerosol study to quantify concentrations, aerodynamic size distributions, and dry deposition rate of airborne SARS-CoV-2. The authors collected aerosol samples collected from patient and staff areas in two hospitals and outdoor public areas in Wuhan, China during the SARS-CoV-2 outbreak (Liu et al., 2020a). Three types of aerosol samples were collected: aerosol samples of total suspended particles, aerodynamic size segregated, and aerosol deposition aerosols. The authors found that ample ventilation and open space was found to be effective at limiting aerosol transmission of SARS-CoV-2. Specifically, negative pressure ventilation and high air exchange rate were found effective at minimizing the concentration of airborne SARS-CoV-2. The authors concluded that there was low risk of transmission in open, outdoor spaces. The authors also confirmed " aerosol transmission as an important pathway for surface contamination" in small spaces, such as bathrooms (Liu et al., 2020b; p. 6). The authors noted two exceptions to the finding of undetectable or low concentrations of SARS-CoV-2 in outdoor public spaces. First, the exceptions occurred close to building entrances where people congregated and passed through with frequency, and second, the authors suggested that the positive aerosol samples in these areas could be attributed asymptomatic carriers of SARS-CoV-2. Based on these findings, Liu et al. (2020a) recommended that efforts to reduce the risk of infection by the virus attend to the ventilation and sterilization of toilets, minimizing crowds, and caring for patients in naturally ventilated stadiums to limit the aerosol transmission of SARS-CoV-2.

Additionally, a cross-sectional study conducted by Japan’s Taskforce for the COVID-19 Cruise Ship Outbreak (2020) tested environmental surface and air samples from a cruise ship that had experienced an outbreak of COVID-19. One to 17 days after passengers had disembarked, non-case-cabins next to case-cabins, as well as case-cabins were selected for air sampling. Samples were collected through a special gelatin filter which was placed on the bed and toilet seat. SARS-CoV-2 was not detected in any of the air samples. The authors posited that stopping the recirculation of air may have prevented airborne transmission.

Ham (2020) provided their perspective on the proposal by the Korean Ministry of Employment and Labor to install air purifiers as part of their efforts to prevent the spread of COVID-19 in call centers. The author indicated that air purifiers use a diluted ventilation method which is ineffective due to the small size of SARS-CoV-2. Additionally, the air dispersion methods employed could actually lead the dispersion of the virus. Ham (2020) examined these ideas in a pilot study which showed “that that the flow of water mist into an air purifier inlet depended on the height of the source. (p.2).” This finding supports the possibility that air purifiers distribute air without actually filtering out SARS-CoV-2.

3.3.5 Surface Cleaners and Disinfectants

In “Master Question List for COVID-19 (caused by SARS-CoV-2),” a literature review published by Department of Homeland Security Science and Technology Directorate, it was concluded that, “Soap and water, as well as common alcohol and chlorine-based cleaners, hand sanitizers, and disinfectants are effective at inactivating SARS-CoV-2 on hands and surfaces” (p. 13).

Chin et al. (2020) investigated the viricidal effects of various disinfectants, including household bleach, hand soap solution, ethanol, povidone-iodine, chloroxylenol, chlorhexidine, and benzalkonium chloride. With the exception of a 5-minute incubation with hand soap, SARS-CoV-2 was undetectable after 5-, 15-, and 30-minute incubations at room temperature for all of the disinfectants, demonstrating susceptibility of the virus to these common disinfectants.

Chin et al. (2020) also examined the stability of SARS-CoV-2 across a wide range of pH values. Findings indicated that the virus was very stable from pH 3-10.

Surface Disinfection in Clinical Settings

Several researchers have investigated the efficacy of various disinfection strategies in clinical settings. For example, Abramowicz et al. (2020) discussed methods to disinfect ultrasound equipment to prevent the spread of SARS-CoV-2. The study implemented a methodology based on CDC and Environmental Protection Agency (EPA) recommendations using 62-71% ethanol, 0.5% hydrogen peroxide, or 0.1% sodium hypochlorite. The authors suggested the ultrasound room and specific items such as monitors, computer keyboards and mouse, stretcher rails, gel containers, door handles, cabinet knobs, light switches, chairs, and counter tops be wiped with a quaternary ammonium compound each morning. The study also suggested the replacement of fabric covered chairs with hard-surface chairs.

In a technical note, Henwood (2020) described the disinfection procedures and histotechnology processes that should be implemented to reduce the risk of the infection with SARS-CoV-2 to laboratory staff. Based on a review of the current literature, they indicated that 62–71% ethanol, 0.5% hydrogen peroxide, or 0.1% sodium hypochlorite may inactivate the virus within 1 minute on inanimate surfaces. Other biocidal agents such as 0.05% to 0.2% benzalkonium chloride or 0.02% chlorhexidine digluconate have been shown to be least effective in inactivating the virus.

In their research letter (i.e., non-peer-reviewed) in *JAMA*, Ong et al. (2020), reported that successful decontamination was achieved in hospital rooms of patients diagnosed with SARS-CoV-2 infection through "Twice-daily cleaning of high-touch areas…using 5000 ppm of sodium dichloroisocyanurate" and cleaning the floor "daily using 1000 ppm of sodium dichloroisocyanurate" (p. 1610). However, the authors acknowledged the following limitations: "viral culture was not done to demonstrate viability" and "due to operational limitations during an outbreak, methodology was inconsistent and sample size was small" (p. 1611).

In a letter to the editor, Moravvej et al. (2020) detailed approaches that were implemented to decontaminate SARS-CoV-2 on floor surfaces in ophthalmic practices based on guidelines set by the CDC. Specifically, "Examination and waiting room floors were cleaned on a 4-hour routine with suitable disinfectants (sodium hypochlorite, 70% ethanol, or an alternative disinfectant);" however, the floor material was not indicated (p. 1).

Similarly, in a peer reviewed article, Zhao et al. (2020) conducted a systematic review in the strategies to prevent COVID-19 in the radiologic department of a Wuhan hospital. Decontamination procedures included floor disinfection using 1000 mg/ml of chlorine-containing disinfectant, twice a day at any time of day in the event of potential contamination.

4. Discussion, Gaps, and Recommendations for Future Research

4.1 Discussion

4.1.1 Spread of SARS-CoV-2 through Public Library Operations

According to the CDC, SARS-CoV-2 is thought to mostly spread between people in close contact to one another and through respiratory droplets passed form person-to-person. Even though there are still questions on *exactly* how SARS-CoV-2 is transmitted, there is evidence to suggest that transmission via fomites is possible, with several articles taking samples high touch surfaces (e.g., doorknobs, bathroom floors, computers) that tested positive for the virus. Preliminary research has been conducted on other means of transmission, such as small aerosol particles, fecal matter, and airborne transmission, but additional research is needed to clarify the extent of transmissibility via these pathways. To date there has been no evidence of transmission via tears or human breast milk. Furthermore, humidity, temperature, ventilation/air flow, and air conditioning have been identified as environmental factors that can impact the spread of the virus. Specifically, relatively colder temperatures, higher humidity, lack of ventilation, and unfiltered HVAC systems have been shown to facilitate the spread of the virus. Several experimental studies in the determination of air purification and ventilation to limit transmission revealed gaps in effectiveness of preventing the spread of SARS-CoV-2. Ham's (2020) findings of the potential that air purification can lead to further dispersion of SARS-CoV-2 indicates more research is needed, but key takeaways emphasize minimizing crowding by adhering to social distancing guidelines and limiting re-circulation of potentially contaminated air. Thus, evidence so far is inconclusive, but there continues to be concerns that air conditioning systems and HVAC systems could aid the spread of SARS-CoV-2 in indoor environments.

It is important to note that most of the literature described above has not been through peer-review. In other words, these preprints, reports, and articles under review have not undergone rigorous scholarly review before publication, which means these articles did not receive the typical vetting and scrutiny that peer-reviewed publications undergo. Additionally, sampling methods were inconsistent and often were not taken of pertinent routes of transmission (i.e., droplets from breathing, coughing, sneezing, talking, etc.). As a result, the findings of many of the articles should be approached with caution, and the inconsistencies make study-to-study comparisons untenable.

4.1.2 Survival of SARS-CoV-2 on Material Surfaces through Environmental Attenuation

In the search of the literature, eleven surfaces were tested to determine how long SARS-CoV-2 remained viable on a given surface via environmental attenuation. There was wide variability in attenuation among surfaces, and in some instances, there was wide variability in the findings of individual studies testing the same surface. Generally speaking, SARS-CoV-2 may survive longer on smooth surfaces than rough surfaces (Chin et al., 2020). Plastic was tested in the most studies and had the most variability between estimates on virus viability. Glass and stainless steel also had wide ranges in terms of estimates of virus viability. One limitation of these data was that, in some cases, characteristics of the surface were not fully explained (e.g. type of plastic, 'treated' wood). For example, virus on bare wood may behave differently than virus on painted wood. In addition, each group of researchers conducted tests under slightly different conditions and used different methodologies, which may weaken the ability to compare findings across studies.

The small amount of literature surveyed here did seem to coalesce around attenuation times for cardboard and copper, with two studies each describing similar time frames for the virus to be become inactive. However, two studies showing similar findings does not confirm a pattern and should still be viewed with caution. Additionally, Chin et al. (2020) used days as an endpoint to measure viability, whereas the other studies used hours. This may have resulted in various degrees of sensitivity in the results across studies. More research needs to be done in order to confirm hours to inactive virus on various surfaces and to narrow the ranges for those surfaces that seem to have high variability. Further research could also be done to control for testing and environmental differences among studies.

The virus appeared to have the shortest survivability on paper, although the reasons for this are not clearly understood. Copper and aluminum are known to have antibacterial and antiviral properties so low virus survivability on these surfaces is not altogether surprising (van Doremalen et al., 2020; Grinchuk et al., 2020; Pastorino et al., 2020).

It is important to note that the majority of articles reviewed in this document are not peer-reviewed. It is important that the research community can publish urgently to inform pandemic decision making with emerging data, and so many journals have released articles as pre-prints that have not gone through the strengthening peer review process. While these findings have the ability to guide decision-makers if considered in conjunction with other available information, all findings discussed in this section are based upon a small body of literature, which must be taken into consideration. When in doubt, authors always advocate for a measured approach.

One topic of dissent seems to be the impact of porosity on virus survivability. In their examination of cardboard, Grinchuk et al. (2020) stated that the low stability of SARS-CoV-2 on cardboard may be due to the porosity of the surface. Conversely, Pastorino et al. (2020) attributed the high stability of SARS-CoV-2 on plastic to the porosity of the surface. Porosity is not a property that a surface does or does not have, but rather is measured as a fraction and represents the volume of empty space in a material relative to the total volume of a material (Danielson & Sutherland, 1986). The porosity of the materials tested was not measured in this research, so it is unclear how porosity impacts virus viability. Researchers should also test how different formulas of a given material (e.g. polystyrene plastic vs. polypropylene plastic) impact porosity.

Another topic of dissent is the impact of environmental parameters on surface attenuation. Few articles address indoor changes to humidity and temperature as a means of limiting spread of COVID-19 via surfaces, but in their peer-reviewed paper, Dietz et al. (2020) discussed optimal indoor conditions to mitigate spread while keeping the environment comfortable. Research has shown that relative humidity above 40% is detrimental to viruses generally (Casanova et al., 2010; Chan et al., 2011; Kim et al., 2012). Based on these findings, Deitz et al. (2020) recommended maintaining a relative humidity of 40% to 60% indoors to create less hospitable conditions for SARS-CoV-2. However, any higher than 60% may induce mold growth and should be avoided. Dietz et al. noted that installation of humidity monitoring and control systems may require significant investment on HVAC systems, but asserted that benefits could far outweigh the costs. However, given the uncertainty of the data on the impact of humidity on survivability of SARS-CoV-2, it may be prudent to wait for more definitive research before undergoing costly updates to ventilation and HVAC systems. Libraries may conduct cost-benefit analyses to determine if an update to the HVAC system is right for them. Additionally, although Dietz et al. (2020) were making recommendations for SARS-CoV-2, many of their recommendations are based upon studies analyzing other coronaviruses. In some cases, research cited on the impact of relative humidity on SARS-CoV-2 cited in this document seem to confirm the assertions of Dietz et al.; hence inclusion of their findings.

4.1.3 Effectiveness of Prevention and Decontamination Measures for SARS-CoV-2

The literature review provides a number of measures that have been reported to be effective in eliminating the presence of SARS-CoV-2. One of the most effective strategies is decontaminating surfaces with cleaning agents, which may provide an inexpensive and accessible option in most settings. Research has indicated that common chemicals such as sodium dichloroisocyanurate, sodium hypochlorite, ethanol, and hydrogen peroxide can be successful in removing SARS-CoV-2 from a variety of surfaces (Abramowicz et al.; 2020, Chin et al.; 2020, Henwood, 2020; Moravvej et al.; Ong et al., 2020; Zhao et al., 2020). Wang, Tian, et al. (2020; under review) asserted: "1) environmental surface disinfection should include wiping in an “S”-shaped motion and not repeating the area that has already been cleaned...; 2) the frequency of disinfection should be increased appropriately, at least three times per day: twice during the day and once at night (disinfection should be conducted at any time in case of obvious contamination); and 3) cleaners should be trained repeatedly to ensure that they are qualified for their job."

Hand hygiene has also been identified as a key strategy for minimizing the spread of SARS-CoV-2 (Cheng et al., 2020). Research indicates that simply washing hands regularly with soap and water or using alcohol-based solutions (in the absence of soap and water) can greatly reduce the risk of transmitting the virus (Kapoor and Saha, 2020; Kratzel et al., 2020).

Additionally, the use of protective facial coverings such as medical and cloth face masks have been shown to be a key preventative strategy in reducing SARS-CoV-2 transmission. While the literature clearly indicates that such face coverings do not completely protect wearers, they do offer a viable way of preventing aerosol transmission of SARS-CoV-2 (Ferioli et al., 2020; Hsaio et al., 2020; Pleil et al., 2020). For cloth face coverings in particular, consideration should be given to the types of materials used, as some fabrics (e.g. high thread count cotton and natural silk) provide more effective barriers against potentially contaminated droplets than other fabrics (Konda et al., 2020).

The literature has pointed to other potentially effective strategies for preventing the spread of SARS-CoV-2, including thermal and light treatments. SARS-CoV-2 has been shown to be highly susceptible to heat (Chin et al., 2020) and sunlight (Ratnesar-Shumate et al., 2020). However, additional research is needed to determine how this knowledge can be used to reduce the spread of the virus. For example, for sunlight treatments, surface attenuation may vary based on whether the surface is indoors or outdoors as well as if only UVA light is sufficient or if UVB rays are also necessary (Ratnesar-Shumate et al., 2020).

Some studies have also considered how ventilation might impact the aerosol transmission of SARS-CoV-2. Findings of these studies suggest that adequate ventilation, which eliminates the recirculation of air, is essential in small spaces where there may be higher aerosol concentrations of SARS-CoV-2. Additionally, using open, outdoor spaces and limiting large gatherings of people can help minimize airborne transmission of SARS-CoV-2 (Liu et al., 2020).

When bundled together, the application of these measures seems likely to reduce the presence of SARS-CoV-2 in environments and, in turn, reduce the risk of exposure to the virus in those environments.

4.2 Gaps and Recommendations

4.2.1 Gaps in the SARS-CoV-2 Literature

Given the emerging nature of SARS-CoV-2, researchers are actively working to produce new data and develop a comprehensive understanding of the virus, especially how it's spread, its transmissibility, how long it persists on surfaces, effective means to prevent the spread of the virus and further transmission, and effective means to destroy the virus in the environment. However, at the time of this report, the scientific community's understanding of the virus remains a work-in-progress, which is also reflected in the nature of the available research literature about the virus, much of which consists of "pre-prints," letters to the editor, "articles in press," and other types of publication that have not yet undergone (and may never undergo) the scholarly vetting process of peer review. In general, additional rigorous experimental research is needed that focuses specifically on SARS-CoV-2 to 1) replicate and verify (or challenge) the findings of the experiments released to date, 2) resolve discrepancies in the current literature, and 3) explore the impact of the diverse variables that could affect the virus' ability to spread in local libraries and other similar environments. Some of the gaps in the literature that may prove useful to understanding the research questions of this literature review include:

- Detailed understanding of risks for airborne spread of the virus, including testing the dispersion of SARS-CoV-2 specifically through talking, breathing, coughing, sneezing, and other respiratory activities. Furthermore, when the virus is spread from an infected individual to fomites in the environment, further research may clarify the potential for transmission to other people who make contact with those fomites.
- Potential for and variables related to spread of the virus through non-respiratory means, such as urine, feces, and other biological substances.
- High-quality laboratory testing of SARS-CoV-2 attenuation patterns across a wide range of surface types, especially those most relevant to library collections and operations.
- Scrutiny of the effects of multiple diverse variables on the attenuation and spread of the virus, including temperature, humidity, surface porosity, presence of various biological substances, and so on.

- Effectiveness of thermal, light, and ventilation interventions to kill the virus, especially those means that are cost effective and practical for diverse indoor environments.
- Further exploration of the interaction of disinfectants, surfaces, and biological substances, to confirm effectiveness of various disinfectants on the wide range of surface types and biological substances, leading to the production of clear, comprehensive recommendations.
- Investigations of the virus' infectious dose (i.e. the minimum viral load that results in infection), including variations introduced by individual differences (e.g., immunological capabilities), to clarify what end point(s) for attenuation and decontamination are necessary to prevent spread of the virus and/or transmission to other people.

4.2.2 Recommendations for Specific Research to Inform Library Operations

Recommendations for additional research include those items listed in the gaps above, and novel research on these topics should be conducted with SARS-CoV-2 in particular (where safe and feasible) to avoid errors arising from assumptions of similarity between this virus and other coronaviruses. Additional testing is recommended to gather data on the efficacy of ambient environmental conditions (temperature and relative humidity [RH]) against SARS-CoV-2 on materials representative of those found in libraries, archives, and museums. Battelle's laboratory science work in this area will help fill some of these gaps in the field's understanding of attenuation patterns. Further, high-quality scientific experiments that sharpen the scientific community's understanding of how SARS-CoV-2 is spread in indoor environments through air and fomites are needed, in complement with studies of decontamination strategies that are cost effective, efficient, and realistic as well as studies of how people can contract the virus through these avenues. These findings could help inform how library operations can be modified to protect library patrons by reducing the risks of viral transmission. Lastly, the body of knowledge about SARS-CoV-2 is nascent at present but is expected to grow exponentially in the coming year as experiments (such as those suggested here) are completed and scholarly publications accomplish their peer review processes to vet emerging science. As such, periodic reviews of updates to the literature are recommended to ensure library operations are informed by the latest, highest-quality, and most significant research findings.

5. References

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Appendix A. Search Strings

Focus Area	Database	Search String	Search Date	Results Yielded*
Decontamination and Attenuation	Scopus	((TITLE-ABS (coronavir* OR "SARS-CoV-2" OR "2019-nCoV" OR "COVID-19" OR hcov) AND TITLE-ABS (sanitiz* OR decontam* OR steriliz* OR disinfect* OR inactivat* OR "half life" OR attenuat* OR persist*)) AND NOT TITLE-ABS (peptide OR cytokine OR pregnancy OR aperture OR iron OR cancer OR vaccine OR glycoprotein OR protease OR antibod* OR intravascular OR clinical OR opioid OR pollution OR mental)) AND PUBYEAR > 2018	11-May-2020	368
	SciTech	noft(coronavir* OR "SARS-CoV-2" OR "2019-nCoV" OR "COVID-19" OR hcov) AND noft(sanitiz* OR decontam* OR steriliz* OR disinfect* OR inactivat* OR "half life" OR attenuat* OR persist*) NOT noft(peptide OR cytokine OR pregnancy OR aperture OR iron OR cancer OR vaccine OR glycoprotein OR protease OR antibod* OR intravascular OR clinical OR opioid OR pollution OR mental)Date: After January 01 2018 Source type: Conference Papers & Proceedings, Dissertations & Theses, Evidence-Based Medical Resources, Government & Official Publications, Reports, Scholarly Journals, Standards & Practice Guidelines, Working Papers		
	Web of Science	TOPIC: (coronavir* OR "SARS-CoV-2" OR "2019-nCoV" OR "COVID-19" OR hcov) AND TOPIC: (sanitiz* OR decontam* OR steriliz* OR disinfect* OR inactivat* OR "half life" OR attenuat* OR persist*) NOT TOPIC: (peptide OR cytokine OR pregnancy OR aperture OR iron OR cancer OR vaccine OR glycoprotein OR protease OR antibod* OR intravascular OR clinical OR opioid OR pollution OR mental) Databases= WOS, BCI, CCC, DRCI, DIIDW, KJD, MEDLINE, RSCI, SCIELO, ZOOREC Timespan=2018-2020		
	MED-LINE	AB (coronavir* OR "SARS-CoV-2" OR "2019-nCoV" OR "COVID-19" OR hcov) AND AB (sanitiz* OR decontam* OR steriliz* OR disinfect* OR inactivat* OR "half life" OR attenuat* OR persist*) NOT AB (peptide OR cytokine OR pregnancy OR aperture OR iron OR cancer OR vaccine OR glycoprotein OR protease OR antibod* OR intravascular OR clinical OR opioid OR pollution OR mental) Limiters - Date of Publication: 20180101-; Publication Type: Clinical Trial, Phase II, Commentary, Comparative Study, Conference, Government Document, Guideline, Journal Article, Letter, Meta-Analysis, Multicenter Study, Report, Research, Systematic Review, Technical Report		

Focus Area	Database	Search String	Search Date	Results Yielded*
Transmission	Scopus	((TITLE-ABS ((coronavir* OR covid OR "COVID-19" OR cov OR hcov OR "SARS-CoV-2" OR "2019-nCoV")) AND TITLE-ABS (spread* OR transfer* OR transmi* OR persist* OR surviv*) AND TITLE (indoor OR office OR "climate controlled" OR ambient OR environment* OR air OR airborne OR aerosol*)) AND PUBYEAR > 2018)	19-May-2020	159
	SciTech	noft(coronavir* OR covid OR "COVID-19" OR cov OR hcov OR "SARS-CoV-2" OR "2019-nCoV") AND noft(spread* OR transfer* OR transmi* OR persist* OR surviv*) AND ti(indoor OR office OR "climate controlled" OR ambient OR environment* OR air OR airborne OR aerosol*) Date: After 2018 Source type: Conference Papers & Proceedings, Dissertations & Theses, Encyclopedias & Reference Works, Evidence-Based Medical Resources, Government & Official Publications, Reports, Scholarly Journals, Standards & Practice Guidelines, Working Papers		
	Web of Science	TOPIC: (coronavir* OR covid OR "COVID-19" OR cov OR hcov OR "SARS-CoV-2" OR "2019-nCoV") AND TOPIC: (spread* OR transfer* OR transmi* OR persist* OR surviv*) AND TITLE: (indoor OR office OR "climate controlled" OR ambient OR environment* OR air OR airborne OR aerosol*) Databases= WOS, BCI, CCC, DRCI, DIIDW, KJD, MEDLINE, RSCI, SCIELO, ZOOREC Timespan=2018-2020 Search language=Auto		
	MED-LINE	(AB (coronavir* OR covid OR "COVID-19" OR cov OR hcov OR "SARS-CoV-2" OR "2019-nCoV") AND AB (spread* OR transfer* OR transmi* OR persist* OR surviv*) AND TI (indoor OR office OR "climate controlled" OR ambient OR environment* OR air OR airborne OR aerosol*)) OR (TI (coronavir* OR covid OR "COVID-19" OR cov OR hcov OR "SARS-CoV-2" OR "2019-nCoV") AND TI (spread* OR transfer* OR transmi* OR persist* OR surviv*) AND TI (indoor OR office OR "climate controlled" OR ambient OR environment* OR air OR airborne OR aerosol*))		