UNCOVER

Usher Network for COVID-19
Evidence Reviews

Review: What is the evidence for outdoor transmission of SARS-CoV-2?

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THE UNIVERSITY of EDINBURGH | usher institute

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Background and Aims

An infected person produces infectious droplets of varying sizes by breathing, coughing or sneezing. Transmission of the virus between individuals can happen in various ways:

- Large droplets (diameters 100-1000 μm) follow a ballistic trajectory (i.e. they fall mostly under the influence of gravity) and reach the ground in less than 1 s without time to evaporate. Infection occurs either when droplets come into direct contact with mucosal membranes in the eyes, nose or mouth, or when deposited on a surface and successively to a mucosal membrane through physical contact.
- Smaller droplets evaporate fast (in less than a second) into dessicated droplet nuclei known as aerosols (< 5–10 μm). Aerosols are ejected in a jet-like flux which, within a few metres, bends upwards because it is warmer than the surrounding air. Aerosols remain in suspension in the air for hours. However, the half-life of the SARS-CoV-2 virus is about one hour. Aerosols are potentially capable of short and long range transmission.
- Intermediate particles (diameters 10–20 μm) share some properties of both large droplets and aerosols: being larger and heavier than aerosols, they will fall to the ground more quickly. They may carry a smaller infectious dose than large droplets (Tellier et al, 2019).
- A fomite is any object that may be contaminated with infectious agents and serve in their transmission. Virus particles from aerosols, droplets or people's hands can contaminate surfaces in this way. If they are then touched by a susceptible person and transported by hands into mucosal membranes they can cause infection.
- Emerging epidemiological evidence suggests that SARS-CoV-2 may also be transmissible via the faecal-oral route.

Whether or not transmission occurs depends on a range of factors:

- The surface it lands and how long the virus remains viable on that surface;
- The environmental conditions (e.g. temperature, humidity) and how long the virus remains viable under those environmental conditions;
- The susceptibility of the different exposed tissues to infection by the virus.

There are different approaches in the scientific literature to understand some of these factors in relation to SARS-CoV-2:

- **Mechanistic approaches** model the physical and dynamic behaviour of small and large droplets under different climatic conditions. As modelling studies, they are dependent on making assumptions about key parameters, and are limited in what they can tell us about the viability or infectivity of particles in 'real-world' conditions. Also included in this category are experiments which investigate particle emission during speech or breathing. These studies can help us understand the mechanisms of droplet and aerosol formation, but do not normally test for the presence or infectivity of viruses in such particles, and so are limited in what they can tell us about the role of these as routes of transmission.

- **Epidemiological approaches** interrogate descriptive data on case clusters from the early stages of the pandemic to try to identify the most likely routes of transmission. A limitation of these approaches is that data are limited and that observational findings have a high risk of bias.
- **Environmental approaches** include studies which look for correlations between disease incidence and climatic factors (such as temperature and relative humidity). Correlation studies are useful for generating hypotheses but they cannot demonstrate a causal relationship between an exposure and an outcome. They are susceptible to confounding.
- **Microbiological experiments** investigate the viability of the virus under different environmental and time periods under controlled laboratory conditions. The limitation of this sort of study is that the results may not be generalizable to the real world.

The results of this rapid review are presented under these headings.

Methods

This is an update of a rapid review originally (UNCOVER 002-01 – literature search conducted 31 March 2020)]. The original review had a slightly different focus (indoor vs. outdoor transmission). A full description of the methods for the first review can be found here. In summary, the original review sought publications of any study design providing data on indoor or outdoor transmission and of published or pre-published status, excluding publications from nosocomial settings, modelling data, animal models and articles providing commentary but no data.

For this update, we re-examined articles identified by the initial search, using revised screening criteria (see below). We searched PubMed and MedRxiv on 30 April 2020 (MD) for articles added since 1 April. We adapted the search strategy to focus explicitly on outdoor transmission. Full search details are in the appendix. Our modified screening criteria includes articles that report data on outdoor transmission, airborne transmission, surface transmission, environmental factors affecting virus transmission (e.g. virus viability and persistence on different surfaces and at different temperatures and levels of humidity). We excluded papers exclusively about indoor transmission. We also excluded statistical modelling studies. We identified additional relevant articles by searching reference lists. T&A screening of the articles identified by the new search was conducted by one reviewer (RM, LG). Rejections were reviewed by a second reviewer (LG, RN). A third reviewer checked all abstracts identified by the new search for relevance (ET). Full text screening of each article (including reviewing those from the initial search) was conducted by one reviewer (EM, LG, RM, RN). A second reviewer then screened all excluded full texts (EM, LG, RM, RN). Conflicts were resolved by discussion. Data extraction and quality assessment for each article was conducted by a single reviewer (EM, LG, RM, RN). Data extraction was limited to a minimal set of required data items. Because of the highly heterogeneous nature of the study types identified by the search, it was not possible to assess quality using validated risk of bias tools. Instead, we critically appraised each study individually. Computational Fluid Dynamics studies were critically appraised by an expert in this field (IMV). Data were synthesized narratively. Because of the heterogeneity of the evidence, a meta-analysis was not appropriate. Using the GRADE system (Guyatt et al, 2008) a single reviewer (RM) graded the certainty of the evidence overall.

Results

We found 635 potentially relevant papers. After screening and quality assessment, we retained 26 articles. The overall quality of the evidence is **low**. The results of our analysis are presented under these headings:

1. Summary of findings from original review
2. Summary of additional findings, under the following headings:
   - Evidence from **epidemiological** studies
   - Evidence from **microbiological** studies
   - Evidence from **mechanistic** studies
   - Evidence from studies exploring **correlations with environmental factors**

For each category, we briefly summarise the literature that is of a reasonable quality, highlighting relevant findings and commenting on study quality and limitations.

Summary of findings from original review

- SARS-CoV-2 is transmissible by contact (fomites) and droplets.
- SARS-CoV-2 can be detectable and viable in aerosols, suggesting possible transmission routes by aerosols. However, little evidence is available so far demonstrating actual aerosol transmission episode by SARS-CoV-2.
- We found **no direct evidence** on transmission in outdoor settings

Evidence from descriptive epidemiological studies

We found very little epidemiological evidence about outdoor transmission. The quality of the evidence we found was **very low**.

A descriptive epidemiological study of a disease cluster from China suggests that indoor transmission has a greater potential of causing outbreaks than outdoor transmission (Qian, 2020).

We found descriptive epidemiological evidence on faecal-oral transmission. Evidence from case reports suggests that faecal-oral transmission is possible. Zhang et al (2020) report three cases of children with SARS-CoV-2 from Tianjin, China. All three cases had mild symptoms and quickly recovered. Despite testing and remaining negative for nucleic acid throat swabs, all three cases had SARS-CoV-2 positive stool samples. The authors suggest that faecal-oral transmission might be particularly important to be aware of for those taking care of sick children. However, gastrointestinal symptoms are not restricted to children and live viral RNA has been detected in adult stool samples too (Holshue et al, 2020). Two Chinese reports from early in the pandemic reported that between 2 and 10% of patients had gastrointestinal symptoms (Wang et al, 2020; Chen et al, 2020). Tian et al (2020) analysed case reports and retrospective clinical studies and found that gastrointestinal symptoms were common in patients with covid-19 in China. Nicastri et al (2020) report on an Italian patient, who exhibited persistent viral shedding in stools despite having no gastrointestinal signs or symptoms. Gu et al (2020) reported that two Chinese laboratories had succeeded in independently isolating live SARS-C0V-2 from patient stool samples.

The possibility of faecal-oral transmission is relevant to the issue of outdoor transmission in two ways: firstly, indirect transmission can occur if the virus is transferred from people's hands onto external surfaces such as fences, gates, petrol pump handles, pedestrian crossing buttons, etc. Secondly, those coming into contact with raw sewage may potentially be directly at risk. More research is needed to determine whether the virus remains viable in such conditions (Yeo et al, 2020).

To et al (2020) conducted a cross-sectional study in a sample of 45 patients in a hospital in Hong Kong, 12 with with laboratory-confirmed Covid-19 and 33 who were negative for covid-19. The participants provided saliva specimens when hospitalised, which were tested for viral load. Virus was detected in the saliva of 11 out of 12 Covid-19 patients. Six of the covid-19 patients provided serial specimens and in these samples, viral load decreased over time. One patient still had viral shedding in saliva 11 days after hospitalisation. This study suggests that it is possible for the virus to be transmitted, directly or indirectly, by saliva.

Evidence from microbiological studies

Microbiological experiments investigate the viability of the virus under different environmental and time periods under controlled laboratory conditions. One limitation of this sort of study is that the results may not be generalizable to the real world. Also, each study was conducted in different laboratory settings, potentially implying distinct control conditions.

The duration of persistence for SARS-CoV-2 was investigated on different surfaces for various time periods. van Doremalen et al (2020) generated aerosolised particles to simulate samples obtained from the upper and lower respiratory tract in humans and tested stability on plastic, stainless steel, copper, and cardboard surfaces. Viable SARS-CoV-2 was detected up to 72 hours after application to plastic and stainless steel, and was more stable on these surfaces than on copper and cardboard.

Chin et al (2020) also found strong variability in the length of time the virus remains viable on different surfaces. SARS-CoV-2 was found to be more stable on smooth surfaces. However, no infectious virus could be detected from treated smooth surfaces on day 4 (glass and banknote) or day 7 (stainless steel and plastic).

In the same study Chin et al (2020) investigated stability at different temperatures and found SARS-COV-2 to be highly stable, able to survive for long periods at low temperatures (4°C), but sensitive to heat. At 4°C, there was only around a 0·7 log-unit reduction of infectious titre on day 14. At 22°C it was detectable at 7 days but not at 14 days. With the incubation temperature increased to 70°C, the time for virus inactivation was reduced to 5 mins.

Using a strain from the nasal-pharyngeal swab of a clinically confirmed COVID-19 patient in Shanghai, Sun et al (2020) measured the stability of SARS-CoV-2 in wet (in 100 uL culture medium) and dry (10 uL supernatant on filter paper) environments at room temperature (22°C) each day for 7 days, as well as its stability at pH2.2 condition. Although the virus survived for 3 days in both the wet and dry environments, the dry environment was less favourable for virus survival. Viable virus was not observed after 4 days in either the wet or dry condition. The authors concluded that COVID-19 virus is highly infectious and high concentrations can also survive under an acidic condition that mimics the gastric environment.

In a 2016 review of the evidence on influenza and human coronavirus survival on dry surfaces, Otter et al found that SARS and MERS appear to survive better than influenza. Surface survival was reported to be affected by strain variations; a “dose-response” relationship; the surface material; the medium (such as mucus) in which the virus was suspended; the way in which the virus was deposited onto the surface; temperature and relative humidity; and the method used to detect the presence of the virus. This review pre-dates Covid-19 so is not directly relevant. It is not a systematic review and does not formally evaluate study quality. For these reasons, it should be regarded as low-quality evidence.

Kampf et al (2020) reviewed all the available literature on the persistence of human and veterinary coronaviruses on inanimate surfaces. Summarising the results of 22 studies, they found that human coronaviruses such as Severe Acute Respiratory Syndrome (SARS) coronavirus, Middle East Respiratory Syndrome (MERS) coronavirus or endemic human coronaviruses (HCoV) can persist on metal, glass or plastic for up to 9 days. Again, though, this review was not systematic, did not formally evaluate study quality and is not about SARS-CoV-2 but about other coronaviruses.

Overall these studies indicate that low temperatures and wet environments are most conducive to persistence of SARS-COV-2. Also, it has been suggested that the gastrointestinal environment could facilitate its viability. It must be stressed that since these studies were laboratory-based, generalisability to real-world and outdoor contexts may be limited as all studies were set in highly-controlled and indoor environments.

Evidence from mechanistic studies

Mittal et al (2020) have recently published an excellent review of flow physics and fluid dynamics in understanding the transmission of SARS-CoV-2. This article is highly recommended and worth reading in full.

Our literature search revealed five additional relevant studies. One modelling study (Guererro et al, 2020) simulated a person sneezing in a moderately windy urban environment and modelled the distance travelled by respiratory droplets of different sizes; finding that droplets would travel much further than the precautionary 2 metres. However, there was limited information on the study methodology, meaning that the validity of these simulations could not be assessed. Furthermore, droplet evaporation does not appear to have been considered. This would be a major limitation to the study because evaporation changes significantly the droplet size distribution over time and thus their kinematics (the features or properties of motion in an object).

Blocken et al (2020) conducted a computational fluid dynamics study of people walking and running. Airflow and water droplets are ejected from the mouth of the upstream person and the downstream concentration of particles is investigated. The main conclusions of the study are that in the absence of wind, most of the droplets are found in the wake of the person from which they were ejected and that the concentration decreases with the distance travelled by the jet. These findings are reliable and are supported by the findings of previous studies (Bourouiba et al, 2014); however the study is not sufficiently robust to be able to estimate a safe social distance. Another key limitation of the study is that it only accounts for large droplets between 40 and 200 microns.

Buonanno et al (2020) principally modelled transmission in indoor environments, but provided estimates of the quanta of virus emitted during various activities (resting, standing, light exercise) and when breathing or speaking. It found significant variation, with the lowest quanta emitted during breathing while resting, and the greatest during talking while undertaking light activity.

This finding is mirrored in an experimental study by Asadi et al (2020). This study found that even quiet speech emits significantly more and larger particles than normal breathing, and emissions increase with volume.

Anfinrud et al (2020) conducted a laser light-scattering experiment to visualise speech-generated droplets and their trajectories. They repeated the experiment with and without a damp washcloth over the speaker's mouth and at different volumes of speech. They found that the amount of droplets increased with the volume of speech and that the damp washcloth prevented the emission of droplets during speech. A drawback of this study is that it did not distinguish between droplet and aerosol transmission.

Although these studies were all conducted in a laboratory, they are relevant to outdoor transmission because they seek to simulate realistic conditions (windy city streets) or realistic activities (people walking or running together). They suggest that infection could be transmitted by speech in the absence of coughing or sneezing and that in certain circumstances, the recommended two metre guideline for social distancing may not eliminate the risk of droplet transmission. However, these findings are tentative and have not been tested in 'real world' conditions, and none of the studies provided sufficient information about their methods to enable their validity or reliability to be assessed.

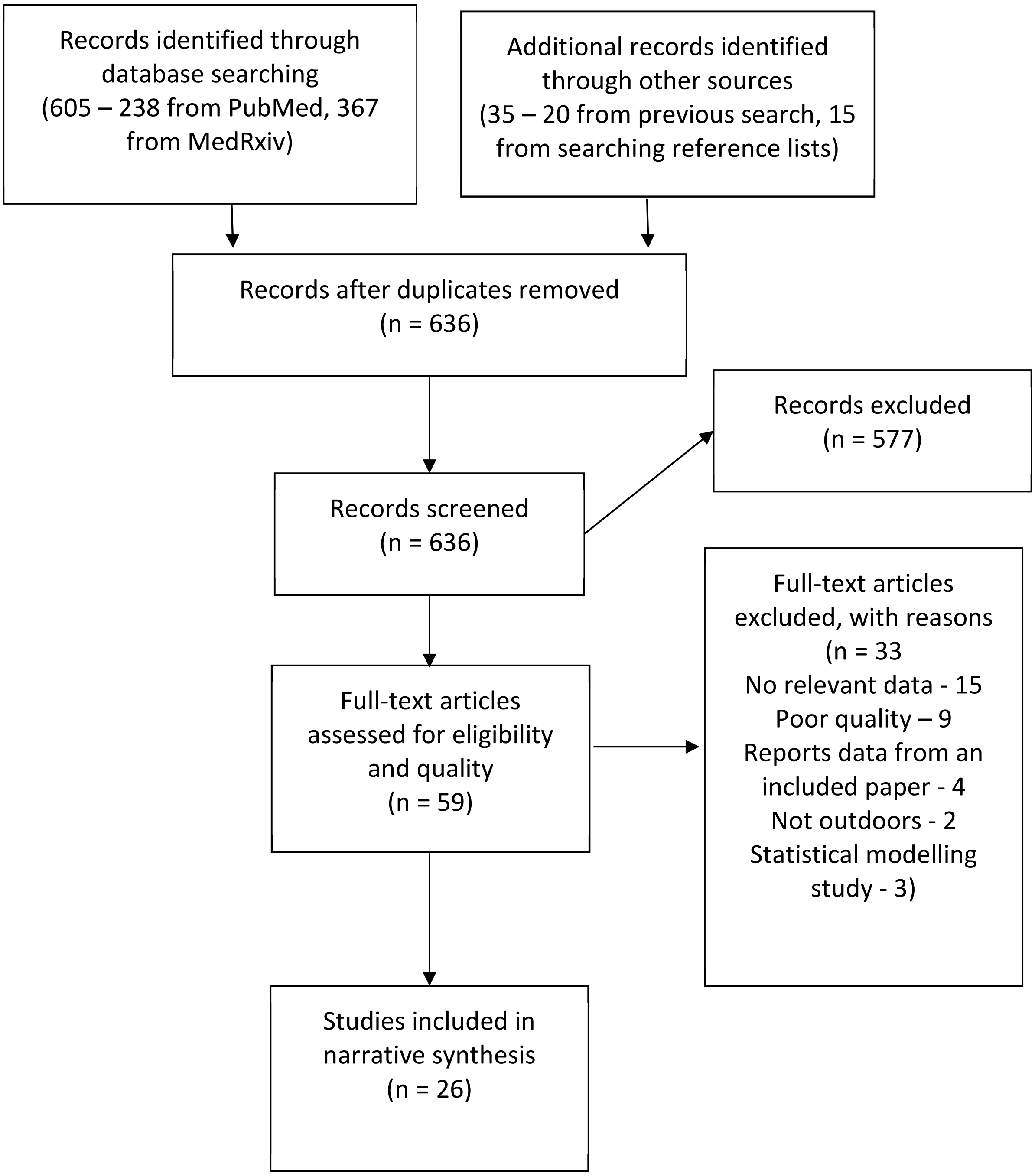
Evidence from studies exploring correlations with environmental factors

We found four studies looking at the relationship between climatic factors (predominantly temperature and humidity) and incidence or severity of Covid-19. These were correlation studies and thus can do nothing more than propose hypotheses for further exploration using more robust study designs.

Chiyomaru et al (2020), Pirouz et al (2020) and Rodrigues et al (2020) found an inverse correlation between temperature and incidence, with the number of new cases decreasing as temperature increased. Shi et al (2020) reported a biphasic relationship with temperature, suggesting that daily incidence of COVID-19 decreased at values above and below 10 degrees C.   The major limitation of all of these studies is that they simply report correlation and are highly susceptible to confounding from a range of factors.

We found one article which investigated whether SARS-CoV-2 can be detected on particulate matter, suggesting that air pollutants themselves may contribute to the transmission of Covid-19 (SIMA, 2020).

Prisma flow diagram of publications screening and appraisal



Discussion:

- This updated rapid review did not find any significant new evidence on outdoor transmission.
- SARS-CoV-2 is transmissible by contact (fomites) and droplets.
- It can be detectable and viable in aerosols, suggesting possible transmission routes by aerosols. However, little evidence is available so far demonstrating actual aerosol transmission by SARS-CoV-2.
- Emerging evidence suggests it is likely to be transmissible via the faecal-oral route.
- For outdoor transmission, key questions are how long the virus can survive on different surfaces and under different environmental conditions. There is no direct evidence on this.
- Indirect evidence from computational fluid dynamics modelling the movement of respiratory particles through the air suggest that the virus may travel longer distances than the 2 metre social distancing limit, but results are inconclusive and do not address questions of virus viability.
- Indirect evidence from microbiological studies evaluating virus viability under different environmental conditions suggests that the virus can persist for long periods, particularly at lower temperatures and under wet conditions. Evidence also suggests considerable variability in virus persistence on different surfaces, with persistence up to 72 hours on plastic and stainless steel. However this evidence comes from laboratory experiments, so it is unclear how applicable it is to real-world scenarios.

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Appendix: search strategy

Pubmed 20200430

238 results

("Betacoronavirus"[Mesh] OR "Coronavirus Infections"[MH] OR "Spike Glycoprotein, COVID-19 Virus"[NM] OR "COVID-19"[NM] OR "Coronavirus"[MH] OR "Severe Acute Respiratory Syndrome Coronavirus 2"[NM] OR 2019nCoV[ALL] OR Betacoronavirus*[ALL] OR Corona Virus*[ALL] OR Coronavirus*[ALL] OR Coronovirus*[ALL] OR CoV[ALL] OR CoV2[ALL] OR COVID[ALL] OR COVID19[ALL] OR COVID-19[ALL] OR HCoV-19[ALL] OR nCoV[ALL] OR "SARS CoV 2"[ALL] OR SARS2[ALL] OR SARSCoV[ALL] OR SARS-CoV[ALL] OR SARS-CoV-2[ALL] OR Severe Acute Respiratory

Syndrome CoV*[ALL]) AND ((2020/04/01[EDAT] : 3000[EDAT]) OR (2020/04/01[PDAT] : 3000[PDAT]))

AND

outside[tw] OR outdoor*[tw] OR external[tw] OR parks[tw] OR “public space*”[tw] OR “social distanc*[tw]” OR “physical distanc*[tw]” OR “population mixing[tw]” OR “social mixing”[tw] OR exercis*[tw] OR jogging[tw] OR walking[tw] OR cycling[tw] OR running[tw] OR surface*[tw] OR metal[tw] OR plastic[tw] OR wood[tw] OR fence*[tw] OR gate*[tw] OR "outdoor gym*"[tw] OR stone*[tw] OR fomites[tw]

medRxiv via medRxivr 20200430

covid+outdoor+exercise terms – 216 results

covid+surfaces terms = 151 additional results

covid set combined with OR

COVID-19

[Cc]oronavirus

SARS-CoV-2

2019-nCoV

Outdoor / exercise set combined with OR, then with the covid set using AND

outside

outdoor

external

parks

public space

social distanc

physical distanc

population mixing

social mixing

exercis

jogging

walking

cycling

running

surfaces set combined with OR with outdoor set, then with the covid set using AND surface

metal

plastic

wood

fence

gate

outdoor gym

stone

fomite