Airborne transmission: the aerosol inhalation route of SARS-CoV-2

HiDATA webinar-Data Science in the Post-Covid World 11.5.2021
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Aalto University
Modelling aerosol transport and virus exposure with numerical simulations in relation to SARS-CoV-2 transmission by inhalation indoors
30/4/2021 Major change: WHO acknowledges short and long range aerosol inhalation as primary modes

https://www.who.int/news-room/q-a-detail/coronavirus-disease-covid-19-how-is-it-transmitted

- Current evidence suggests that the virus spreads mainly between people who are in close contact with each other, typically within 1 metre (short-range). A person can be infected when aerosols or droplets containing the virus are inhaled or come directly into contact with the eyes, nose, or mouth.

- The virus can also spread in poorly ventilated and/or crowded indoor settings, where people tend to spend longer periods of time. This is because aerosols remain suspended in the air or travel farther than 1 metre (long-range).

People may also become infected by touching surfaces that have been
Why Did It Take So Long to Accept the Facts About Covid?

May 7, 2021

https://www.nytimes.com/2021/05/07/opinion/coronavirus-airborne-transmission.html
Part 1: Background
Superspreading drives the COVID pandemic (20:80 rule)
https://www.nature.com/articles/d41586-021-00460-x
712 confirmed infections on the Diamond Princess


A computer model of the cruise-ship outbreak found that the virus spread most readily in microscopic droplets light enough to linger in the air.
E.g. Japan assumed airborne transmission from the beginning

Avoid the “Three Cs”!

1. Closed spaces with poor ventilation.
2. Crowded places with many people nearby.
3. Close-contact settings such as close-range conversations.

Source: https://www.mhlw.go.jp/content/10900000/000619576.pdf
2020: “Classical droplet transmission” → large droplets

https://doi.org/10.1016/j.ssci.2020.104866
2021: “Modernized version” → aerosols

https://doi.org/10.1016/j.ssci.2020.104866
Also cigarette smoke consists of aerosol particles
Infectious aerosol particles can be released during breathing and speaking by asymptomatic infected individuals. No masking maximizes exposure, whereas universal masking results in the least exposure.
Aerosols and droplets are formed along the respiratory tract.

Johnson et al. 2011: size distribution

~100 aerosols per 1 large droplet
How could an aerosol particle look like?
SEM image of coronaviruses (yellow) on a cell (blue)

https://www.statnews.com/2021/01/14/more-infectious-variants-could-make-things-much-worse/

Virus size ~ 100 nm = 0.0001mm
Aerosol concentrations can build-up in the air indoors
Air cleaning and disinfection

Recirculation

to be avoided if possible

Ventilation

Portable air cleaner

Microdroplets containing virus:

https://www.sciencedirect.com/science/article/pii/S0160412020317876#b0045
How much do I need to inhale viral aerosols to get infected?
Wells-Riley model can be utilized to estimate the infection risk from the air via inhalation.

\[ N_c = S \left(1 - e^{-\frac{Ipqt}{Q}}\right) \]

- \( # \) initially healthy (\( S \))
- \( # \) infectious (\( I \))
- \( # \) how many get infected (\( N_c \))
- Virus emission [quanta/h] (\( q \))
- Time [h] (\( t \))
- Room ventilation [m³/h] (\( Q \))
- Inhalation rate [m³/h] (\( p \))

Infection risk = \( 100 \% \times \frac{N_c}{S} \)
Wells-Riley model takes into account the room ventilation rate, exposure time, activity etc.

![Graph showing infection risk over time for different settings with varying ventilation rates.]

- **Home (ACH=0.3)**
- **School (ACH=1.5)**
- **Outside (ACH=50)**

Ventilation improves.
Coronavirus is in the air — there’s too much focus on surfaces

Catching the coronavirus from surfaces is rare. The World Health Organization and national public-health agencies need to clarify their advice.
Part 2: Physics
Large droplets:
heavy, fall in seconds

Aerosols:
Light particles, stay in the air for minutes/hours, transported over extended distances
Newton’s 2\textsuperscript{nd} law

\[ \vec{F} = m \vec{a} = m \frac{\Delta \vec{v}}{\Delta t} \]
Basic aerosol physics: Particle falling time from 1.5m height

Falling speed

\[ v_p = \tau_p g \]

Falling time

\[ t_s = h / v_p \]

Particle “timescale” in viscous flow

\[ \tau_p = \frac{\rho_p d^2}{18 \nu_{fg} \rho_g} \]
Aerosol vs droplet? → Fact checking revealed:

a dramatic 100-year old error in medical textbooks


Slide courtesy of Prof. Linsey Marr


https://doi.org/10.1016/j.jhinf.2020.12.022
To protect the people (FFP2/3) and e.g. to avoid superspreading: highly relevant to understand the size of infectious particles.

Fluid dynamics simulation by:
Mikko Auvinen ja Antti Hellsten/FMI
TUPA-project/Business Finland
Part 3: scientific arguments behind airborne transmission
Ten scientific reasons in support of airborne transmission of SARS-CoV-2

Trisha Greenhalgh, Jose L Jimenez, Kimberly A Prather, Zeynep Tufekci, David Fisman, Robert Schooley

Published: April 15, 2021  DOI: https://doi.org/10.1016/S0140-6736(21)00869-2

https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(21)00869-2/fulltext#
10 arguments on predominance of SARS-CoV-2 airborne transmission

- Transmission almost only indoors
- Superspreading
- Asymptomatic spreading
- Numerous long distance transmissions documented
- Infections with only droplet precautions
- Infectious SARS-CoV-2 sampled in air
- SARS-CoV-2 sampled from hospital air filters
- Airborne transmission in animal experiments
- No counter-evidence
- Little/no evidence on other transmission modes (droplet/fomite)
Katelaris et al. (2021), Emerging inf. diseases 27(6) 2021: Epidemiologic Evidence for Airborne Transmission of SARS-CoV-2 during Church Singing, Australia, 2020

https://wwwnc.cdc.gov/eid/article/27/6/21-0465_article

→ 12 cases
→ Upto 15m distance
→ Video: no close contact
→ Ventilation off
Lednicky et al. (2020) **Viable SARS-CoV-2 in the air of a hospital room with COVID-19 patients**

https://www.ijidonline.com/article/S1201-9712(20)30739-6/fulltext

Lednicky et al. (2021) **Isolation of SARS-CoV-2 from the air in a car driven by a COVID patient with mild illness**

https://www.ijidonline.com/article/S1201-9712(21)00375-1/fulltext
### Table 1. Comparison of Respiratory Virus Transmission Outdoors Compared to Indoors Ordered by Virus Studied

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Virus Studied</th>
<th>Estimate of Effect</th>
<th>Relative Estimate of Effect</th>
<th>Number of Participants in the Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of cases [14]</td>
<td>SARS-CoV-2</td>
<td>2/7324 cases</td>
<td>7322/7324 cases</td>
<td>&lt;1% of transmissions happened outdoors</td>
</tr>
<tr>
<td>Number of cases [15]</td>
<td>SARS-CoV-2</td>
<td>4/103 cases</td>
<td>99/103 cases</td>
<td>5% of work-related cases occurred outdoors</td>
</tr>
<tr>
<td>Odds of transmission [16]</td>
<td>SARS-CoV-2</td>
<td>Raw data not available</td>
<td>Raw data not available</td>
<td>Odds of transmission in closed environments 18.7 (95% CI, 6.0–579) times greater than in open air</td>
</tr>
<tr>
<td>Number of super-spreading events and odds of transmission* [16]</td>
<td>SARS-CoV-2</td>
<td>1/7 super-spreading events</td>
<td>6/7 super-spreading events</td>
<td>Odds ratio of super-spreading in closed environments: 32.6 (95% CI, 3.7–289.5)</td>
</tr>
<tr>
<td>Number of cases [17]</td>
<td>SARS-CoV-2</td>
<td>95/10 926 cases</td>
<td>10 831/10 926 cases</td>
<td>&lt;1% of transmissions happened outdoors</td>
</tr>
<tr>
<td>Number of cases [18]</td>
<td>H1N1 2009 influenza</td>
<td>0/3 cases</td>
<td>24/29 cases</td>
<td>Of 32 total people in a holiday camp, 29 traveled together in a train wagon</td>
</tr>
<tr>
<td>Mortality [19]</td>
<td>H1N1 1918 influenza</td>
<td>28/820 deaths sleeping in hammocks outside, 34.1 persons/1000</td>
<td>39/267 deaths sleeping in cabins inside, 146.1 persons/1000</td>
<td>Risk ratio 4.28 (95% CI, 2.69–6.81)</td>
</tr>
</tbody>
</table>

Abbreviations: CI, confidence interval; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2.

*Super-spreading defined as events where the number of secondary cases generated by a single primary case is greater than the 95th percentile of the distribution (ie, transmission to 3 or more persons).
SARS-CoV and SARS-CoV-2 are transmitted through the air between ferrets over more than one meter

https://www.nature.com/articles/s41467-021-21918-6
Lower your risk from #COVID19 by combining these 5 precautions:

1. Wear a mask 😷
2. Clean your hands 🧼
3. Keep physical distance 📊
4. Cough/sneeze away into your elbow 🏊
5. Open windows as much as possible 🏷️
Multidisciplinary collaboration has indicated aerosol inhalation as a core transmission mode of COVID-19
Socratic paradox: “I understand that I don’t understand.”