Where is SARS-CoV-2 and how does it get there?
Current and future research on environmental surveillance and transmission

Part 2. SARS-CoV-2 in aerosols

direct contact

indirect contact

close-range only (<2 m)

large droplets

aerosols
Aerosols: liquid or solid particles suspended in air (or other gas)

Droplets:
So large, Hard to remain airborne (liquid)

Like cloud or rain droplets

Size Matters

• Airborne virus is not naked!

• Size determines
  • Lifetime in the atmosphere
  • Where it deposits in the respiratory system
Aerosol generated by Breathing, speaking, and coughing
High air velocity shears respiratory fluids during expiration

Modes:
< 0.3 (possible)
0.8 µm (largest mode)
2-4 µm (two modes)
100 µm (smaller)

Droplets (100 µm):
By number, 0.8µm mode is 100 times larger (coughing)

Breathing
Speaking/singing
Coughing

Morowska et al.
Journal of Aerosol Science
Volume 40, Issue 3, March 2009,
Pages 256-269
Relative emission rate of aerosol particles between activities

<table>
<thead>
<tr>
<th>Activity</th>
<th>Concentration (cm⁻³)</th>
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<tbody>
<tr>
<td>Breathing (nose/mouth)</td>
<td>b-n-m</td>
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<tr>
<td>Sustained “aah” (voiced/whispered)</td>
<td>aah-v-p</td>
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<tr>
<td>Counting (voiced/whispered)</td>
<td>c-v-p</td>
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<tr>
<td>Cough</td>
<td>cough</td>
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</tbody>
</table>

Infected people *could* emit viable CoV-2-containing aerosol all the time

CoV-2 is present in the respiratory tract (Zhu et al., 2020)

Booth et al (2005) established that hospitalized SARS patients emit viable aerosolized virus

CoV-2 has been measured in hospital aerosol:
- infectious, replicating virions measured in three <1 μm aerosol samples in hospital rooms (Santarpia et al., *unrefereed preprint* 2020)
- And in 4 samples from a pair of patients (Lednicky et al., )

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Asadi et al. (2020) *Aerosol Sci. Technol.*, 54, 635-638
Viability of aerosolized CoV-2. Papers report half-life of 1 to several hours. (for particles < 5 µm)

Viruses remain viable longer at lower RH (influenza); lower temps


Collection of **viable** virus aerosol (MS2)

BioSpot's virus collection efficiency is 10-100 fold that of SKC BioSampler

| **Concentrated** | Increased analysis sensitivity (LOD/LOQ) |
| **High Efficiency** | >95% for particles 5nm – 10µm diameter |
| **Sample Quality** | Maintain sample integrity and microorganism viability |

BioSpot operates bundle of eight: Hence, total F is **8 Lpm**

Aerosol scientists: Turpin, Surratt, Baumann
Indoor air: Morrison, Turpin
Microbiologists: Brown, Stewart, Fisher
Infectious disease: Baric

Controlled experiments, well-characterized aerosols, varied environmental conditions

M. Pan et al., Journal of Applied Microbiology; 120, 805-815: 2016.
Size determines time airborne

Aerosol particles smaller than 1 \( \mu m \) can remain airborne for hours to days. Move with air flow

Solve:
\[
m \frac{dv}{dt} = \sum \text{forces}
\]

\[
settling \ velocity \ v = \frac{g D_p^2 \rho_p}{18 \mu}
\]

14 hours for 0.8 \( \mu m \) dia. particle
1 minute for 30 \( \mu m \) dia. particle
Virus Dynamics in Indoor Air

estimate concentration of virus-containing particles (number conc.)

\[ \frac{dV}{dt} = S - (k_{dep} + \lambda + k_{inact.})CV \]

\[ C_{SS} = \frac{S}{V(k_{dep} + \lambda + k_{inact.})} \]

S = Aerosol-borne virus emission rate

\[ \lambda = \frac{\text{Volumetric flow rate (ft}^3/\text{hr)}}{\text{Room volume (ft}^3)} \]

new home: 0.5 hr\(^{-1}\); Classrooms: 1 - 5 hr\(^{-1}\); Grocery: 5 hr\(^{-1}\); Hospital: 15 hr\(^{-1}\)
At steady state:

\[ C = \frac{S}{V(k_{dep} + \lambda + k_{inact})} \]

Dose = \( C \times \text{InhR} \times \text{ET} \)

Time to reduce conc by 90%:
\[ t = -\ln(0.1) \frac{1}{(k_{dep} + \lambda + k_{inact})} \]

\( t = 1.5 \text{ hr} \) for \( \lambda = 0.5 \text{ hr}^{-1} \)

\( t = 9 \text{ min} \) for \( \lambda = 15 \text{ hr}^{-1} \)

We know:
• <6 feet – higher droplet and aerosol conc.
• > 6 ft - longer you stay, higher your dose

We do not really know:
• The emission rate of viable virus
• The dose – response

(How high a dose would it take to be infected from across the room?)
Skagit Valley Chorale

Precautions to avoid contact
Transmission broadly spread across room
52 + index case of 61 total people

Authors estimate, from this and other singing events: $S = 1,000 – 10,000$ quanta/hr

(Buonano – predicts 1000 quanta/hr for speaking with “light activity, 300 quanta/hr for speaking at rest – greater than influenza and less than measles)

*a “quantum” is the dose of airborne droplet nuclei required to cause infection in 63% of susceptible persons

Dinner in China

Waiters not infected; families came different times

Miller et al. (2020) medRxiv, doi: https://www.medrxiv.org/content/10.1101/2020.06.15.20132027v2.full.pdf+html

Li et al. (2020) medRxiv, doi: https://www.medrxiv.org/content/10.1101/2020.04.16.20067728v1
Quanta emission rates for **influenza** have been reported to be in the range 15 - 128 quanta h\(^{-1}\)

for **measles**: 5,580 q h\(^{-1}\)

and for **tuberculosis**: 1.25 to 30,840 q h\(^{-1}\)
(the high value attributed to intubation)

**OF COURSE**: no way to know for certain that there was not other contact
It does not look like CoV-2 is spread through the air as easily as smallpox or measles.

Airborne Spread of Smallpox in the Meschede Hospital

Transmission of smallpox via airborne spread documented:
- Patient on ground floor of hospital with natural ventilation
- Spread for case patient to other patients on floor and higher level floors

Fenner. 1988. Fig. 4.9
Skagit Valley Chorale

810 m$^3$ is 28,600 ft$^3$
(ROS 133 is 24,200 ft$^3$)

Inferred $S = 970$ quanta/hr
Higher than influenza, lower than measles

Increasing loss rate:
e.g., Ventilation or HEPA filter air cleaner

Masks – reduce emission rate
Skagit Valley Chorale

Effect of reduced exposure time
2.5 hr to 30 min

MASKS/testing: reducing S by a factor of 10 reduces probability by factor of 10

Source reduction is most effective approach

Figure 2. Probability of infection as a function of loss rates for varying event duration (D, h). A mean emission rate (970 q h⁻¹) and constant volumetric breathing rates of 1.0 m³ h⁻¹ were assumed.
Important lessons

• Wear a mask (even when more than 6 feet apart) - test/trace/isolate
• Maintain distance – fewer people  (reduces potential total source)
• Do not linger
• Outdoors is safer than indoors

If aerosol transmission is important:
• CDC “exposed” definition (>15 min within 6 feet) is not adequate – could receive the same dose with long (e.g. 8 hour exposure) at > 6 feet

• Will COVID patients infect family members when recovering at home?
• Plexiglass shields only protect against droplets, not aerosols

Save singing for the shower  : )
a combination of epidemic, mechanistic transmission, and dose-response modeling with available empirical data on mechanisms of SARS-CoV-2 dynamics and human behaviors

**Mean estimates:**
short-range 35%  long-range 35%  fomite transmission 30%

**After quarantine began:**
Short-range transmission dominated  --  due primarily to aerosols, not droplets.
One more message:
CO₂ concentrations are often used as a surrogate measure of the adequacy of ventilation. They can be measured easily, increase with occupancy. The usual rule of thumb (pre-pandemic) is to keep CO₂ < 1000 ppm for adequate ventilation for the number of people inside.

Good article on portable air cleaners (below)

Materials for Masks (from a Cambridge University study):


Simple sew yourself mask patterns

https://masksnow.org/patterns/
https://tinyfleetingsteps.wordpress.com/2020/02/21/492/

Note: you can add filter material into the sleeve of your mask. It will help if the air goes through it and not around it.
Graph from https://smartairfilters.com/en/blog/best-materials-make-diy-face-mask-virus/
Based on: Davis et al. 2013