The Role of Aerosols in the Transmission of COVID-19

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Topics

1. Terminology
2. Importance of droplet/aerosol size
3. Generation of aerosols
   1. Breathing, talking, and coughing
   2. Medical and dental procedures
4. Evidence for SARS-CoV-2
5. Interventions

The origin of the 5-µm cutoff is not clear. This cutoff is not supported by modern aerosol science. This distinction has hampered our understanding of transmission.

Adapted from http://www.phac-aspc.gc.ca/cpip-pclcpi/annf/v2-eng.php
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best cutoff is 100 μm

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<td>Droplet nuclei</td>
<td>Evaporated residue of droplets that is &lt; 5 µm</td>
<td>Evaporated residue of large droplets</td>
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Defining Transmission by Exposure Path

LARGE DROPLETS are sprayed onto the body, a form of contact transmission.

AEROSOLS are inhaled into the respiratory system.

This distinction drives:
- Control strategies
- Infectious dose
- Severity of disease

(The physics-based cutoff is 60-100 µm)

(1) Wells, W.F., 1934, On air-borne infection. Study II. Droplets and droplet nuclei, Am J Epidemiol
(3) Tellier, R., Li, Y., Cowling, B.J., Tang, J.W., 2019, Recognition of aerosol transmission of infectious agents: a commentary, BMC Infect Dis
Close Contact: Droplets vs. Aerosols

Physics-based model of large droplet spray and aerosols in jets produced by talking and coughing

Ratio of exposure by large droplet spray (L) to inhalation of short-range aerosols (S)

(1) Chen, W., Zhang, N., Wei, J., et al., 2020, Short-range airborne route dominates exposure of respiratory infection during close contact, Build Environ
Plume Scale vs. Room Scale

(1) Khare, P., Marr, L.C., 2015, *Simulation of vertical concentration gradient of influenza viruses in dust resuspended by walking*, Indoor Air (2)
Asadi, S., Gaaloul ben Hnia, N., Barre, R.S., et al., 2020, *Influenza A virus is transmissible via aerosolized fomites*, Nature Comm
Transmission by inhalation of aerosols can happen at short and long range.

Why is size so important?
Virus Size

- **influenza**: 0.1 µm
- **SARS-CoV-2**: 0.12 µm
- **rhinovirus**: 0.03 µm
- **adenovirus**: 0.1 µm

Images and data sources:
- [http://solutionsdesignedforhealthcare.com/rhinovirus](http://solutionsdesignedforhealthcare.com/rhinovirus)
- [https://pdb101.rcsb.org/motm/132](https://pdb101.rcsb.org/motm/132)
Size of Droplet/Aerosol is Critical

1. Airborne virus is not naked
2. Size of carrier droplet/aerosol defines transport
   - How long it stays aloft
   - How far it can travel
   - How quickly it falls to surfaces
   - Where it deposits in the respiratory system
   - How efficiently it is removed by masks and filters
   - Physics is the same for all viruses
3. SARS-CoV-2 vs. measles vs. other viruses: (1) viral load in different size droplets/aerosols, (2) inactivation rate in droplets/aerosols, (3) location and dose to initiate infection
Droplets/aerosols smaller than 10 \( \mu \text{m} \) can remain suspended for many minutes. 

The setting velocity \( v = \frac{gD_p^2 \rho_p}{18\mu} \)

- \( D_p \): Particle diameter
- \( \rho_p \): Particle density
- \( \mu \): Dynamic viscosity of air

Droplets/aerosols smaller than 10 \( \mu \text{m} \) can remain suspended for many minutes.
They Can Travel More Than 2 m

Position of droplets/aerosols released from a height of 1.5 m

(1) Nazaroff, 2020, personal communication
Humidity Controls Evaporation

Droplet/aerosol size is really important!

How do they get into the air in the first place?
Coughing Produces Aerosols

Totals over the size range 0.35-10 µm:
75,000 ± 97,000 when sick
52,000 ± 99,000 after recovery

Viable influenza A virus was found in
coughs from 7/17 subjects, in
droplets/aerosols 0.3-8 µm

Speaking Produces Aerosols

5 nl and 30 viral RNA copies from saying “Hello, World!”

125 nl and 900 viral RNA copies from one cough

Flu Virus in Exhaled Breath

More virus in aerosols <5 µm than >5 µm, detected with no cough.

(1) Yan, J., Grantham, M., Pantelic, J., et al., 2018, Infectious virus in exhaled breath of symptomatic seasonal influenza cases from a community college, Proc Natl Acad Sci
Normal respiratory activities produce aerosols that may contain viruses.

What about aerosol generating procedures in medicine and dentistry?
Bronchoscopy

Nebulized medication administration (NMA) produced aerosols, but bronchoscopy alone did not.

Extubation generated more aerosols than intubation, especially when patient coughed, but coughing alone generated at least 35x more aerosols.

Dental Procedures

Dental AGPs

Mainly on the basis of culturable bacterial counts:

• Ultrasonic scaler
• Air-driven high-speed handpiece
• Air polisher
• Air/water syringe
• Drills, wet and dry
• Air abrasion

Bacterial Aerosols

High-velocity suction reduced emissions with air turbine handpiece, air/water spray from 3-way syringe, and bristle brush by >96%.

Bacterial Splatter

(1) Miller, R.L., Micik, R.E., Abel, C., et al., 1971, Studies on Dental Aerobiology: II. Microbial Splatter Discharged from the Oral Cavity of Dental Patients, J Dental Res
Bacteria Settled Many Feet Away

“It is indeed imprudent to have a patient sneeze, shout, hiss, or give a Bronx cheer directly in your face, however, dentists and auxiliary personnel are exposed daily to a comparable barrage of bacterial splatter while practicing dentistry.”

(1) Miller, R.L., Micik, R.E., Abel, C., et al., 1971, Studies on Dental Aerobiology: II. Microbial Splatter Discharged from the Oral Cavity of Dental Patients, J Dental Res
Many Activities Produce Aerosols

Composition and source not known. They could be from the mouth, skin, tool, gloves, or could be resuspended dust.

(1) Polednik, B., 2020, Exposure of staff to aerosols and bioaerosols in a dental office, Building Environ
Contamination by Large Droplets

- Add fluorescein to irrigation reservoirs
- Detect fluorescence on filter paper
- This method is sensitive to large droplets that settle quickly, but is blind to aerosols
- Where there are droplets, there are usually aerosols

Contaminated Area

Suction reduced contamination by 67-75% at 0.5-1.5 m.

Enamel Cleanup with Bur

SEM image of particles collected on a polycarbonate filter

EDS showing high calcium (Ca) and phosphorous (P) content of particle O

Opportunities

• Majority of studies looked at settled particles ⇒ bias toward larger ones

• Modernize methods
  • Particle counters and sizers (optical particle counter, aerodynamic particle sizer)
  • Sensitive genomic techniques (qPCR, high-throughput sequencing)
  • Characterization of morphology and chemistry of particles

• Need to account for background aerosols

Medical procedures do not release more aerosols than coughing. Dental procedures release large droplets and bacteria, but little is known about aerosols.

What happens to them in the air?
Virus Removal in Indoor Air

(1) Yang, W., Marr, L.C., 2011, *Dynamics of airborne influenza A viruses indoors and dependence on humidity*, Plos One
(2) Nazaroff, W.W., 2016, *Indoor bioaerosol dynamics*, Indoor Air
Dynamics of Virus in Air

\[ \lambda = 1 \text{ ACH at RH} = 50\% \]

There is a size shift due to loss of larger droplets by evaporation and gravitational settling.

(1) Yang, W., Marr, L.C., 2011, *Dynamics of airborne influenza A viruses indoors and dependence on humidity*, *Plos One*
Removal Mechanisms

• Settling: main removal mechanism, efficient for large but not small droplets
• Ventilation: effective for all sizes, important in public buildings
• Inactivation (influenza): depends on the virus, may depend on humidity

(1) Yang, W., Marr, L.C., 2011, *Dynamics of airborne influenza A viruses indoors and dependence on humidity*, Plos One, 6, e21481
(3) Kormuth, K.A., Lin, K., Qian, Z., et al., 2019, *Environmental persistence of influenza viruses is dependent upon virus type and host origin*, mSphere
It Moves Like Cigarette Smoke

Viruses are removed naturally from indoor air by settling, ventilation, and inactivation.

Which interventions are effective?
Fogging (Chemical Disinfection)

Disinfectants
Hydrogen peroxide ($\text{H}_2\text{O}_2$)
Hypochlorous acid (HOCl)

$\text{H}_2\text{O}_2 + \text{virus} \rightarrow \text{dead virus}$

$\text{H}_2\text{O}_2 + \text{you} \rightarrow \text{airway irritation}$

$\text{H}_2\text{O}_2 + \text{other chemicals} \rightarrow \text{byproducts}$

- More effective to wipe surfaces instead of fog
- Should ventilate after fogging, and ventilation will remove virus from the air anyway

Fogging is not recommended by CDC or EPA.

Partitions in hospital ward lead to increased airborne infection risk in some locations and decreased risk in others.

Suction at the Source

High-Volume Evacuator

HVE reduced particles by 25-44%, while a surgical mask reduced them by up to 96%.

HVE + rubber dam isolation (RDI) reduced particles significantly compared to standard suction.

Ventilation, Filtration, UV

- Upper room germicidal UV is effective
- Must be installed carefully to protect humans

Summary

- Many studies of dental procedures have found settled bacteria and droplets. Where there are droplets, there are usually aerosols.

- Updated studies of aerosolization during dental procedures are needed.

- Interventions can reduce the risk of transmission.
  - Plume-scale: suction
  - Room-scale: ventilation, filtration, germicidal UV

References:
2. Fennelly, K.P., 2020, Particle sizes of infectious aerosols: implications for infection control, Lancet Resp Med
5. Wilson, N., Corbett, S., Tovey, E., 2020, Airborne transmission of covid-19, BMJ