Air Transmission and Role of Ventilation in Minimizing Exposure to Pathogens by Inhalation

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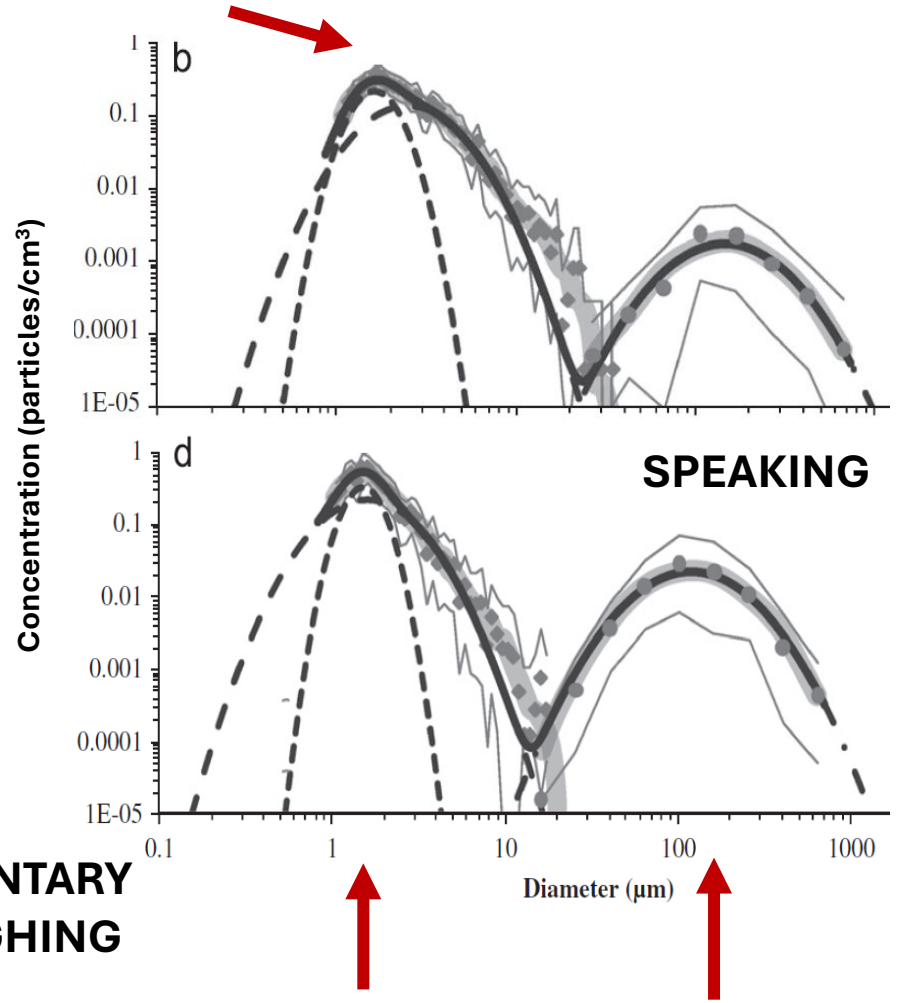
Key Points

- Particle inhalation is the predominant mode of transmission by air both near and far from a source.
- Risk is a function of particle concentration in the air and exposure time.
- Pathogen survival in air for several hours is not confined to just a few organisms.
- Infection control guidelines in healthcare settings should be focused on source and pathway controls that reduce particle concentration and minimize exposure time.
- More consideration of local exhaust ventilation solutions is needed.

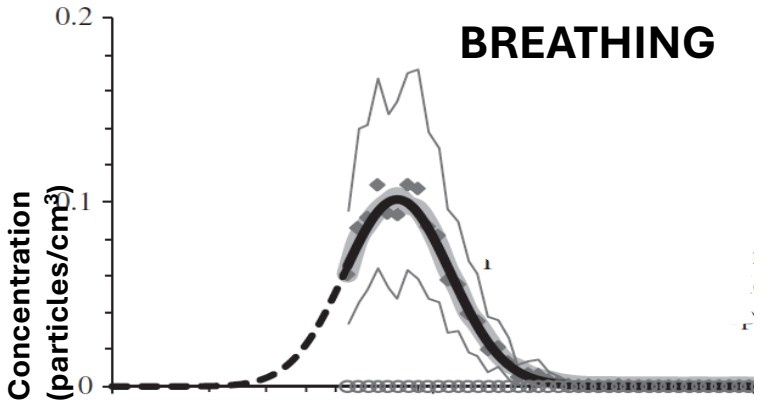
Human-Generated Particles

Higher concentration of small particles



VOLUNTARY COUGHING

Two peaks: 1-2 μm & 100-200 μm

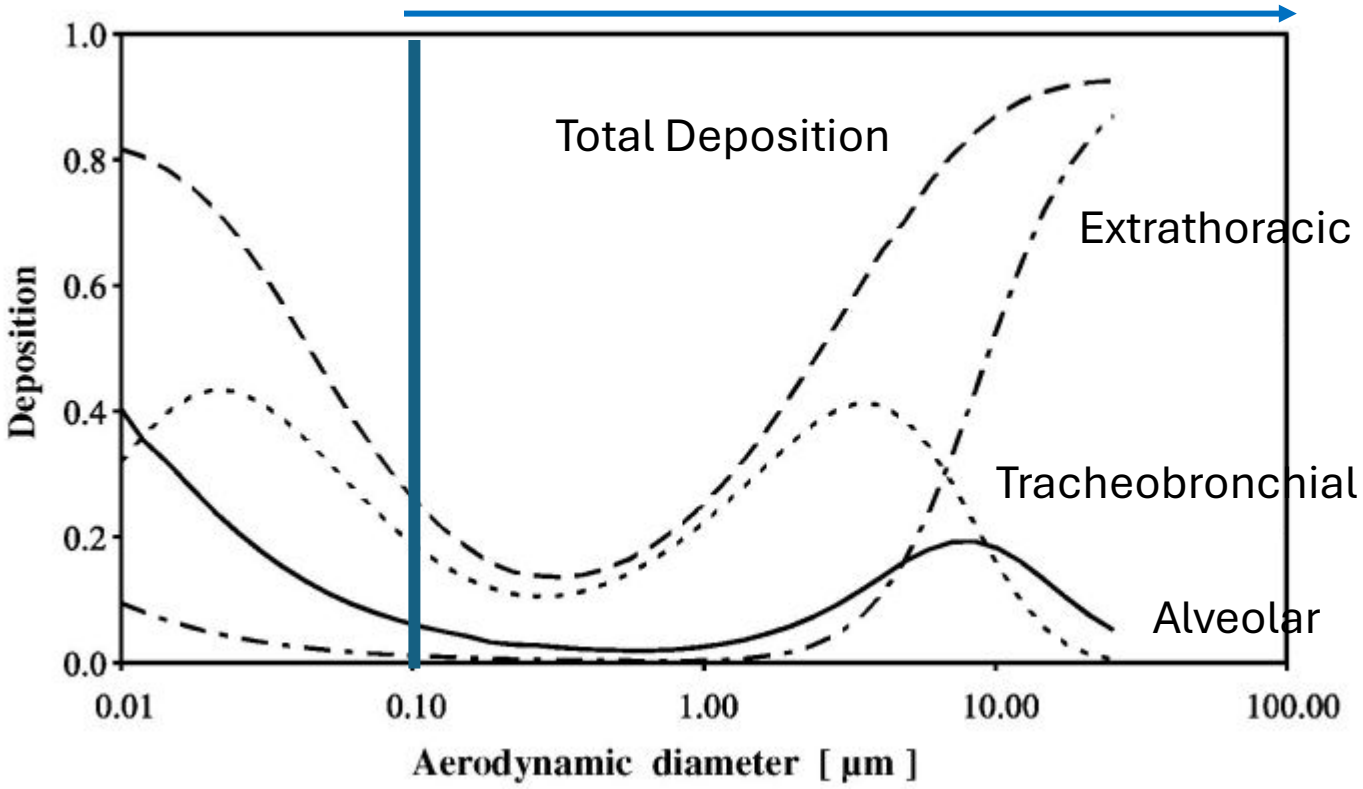


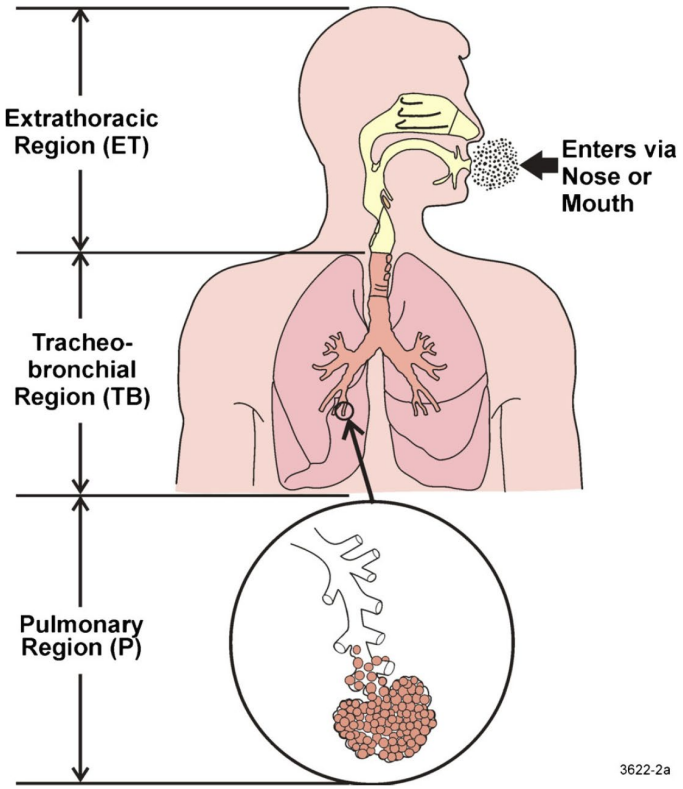
Peak at 0.7-1 μm

Viruses are very small (SARS-CoV-2 = 0.1 μm)
A 2 μm particle could contain up to 8000 virions
Infectious dose for SARS-CoV-2 = 10-100 virions

Figures from Johnson, G. R., et al. "Modality of human expired aerosol size distributions." Journal of Aerosol Science 42.12 (2011): 839-851.
*Han, Z. Y., W. G. Weng, and Q. Y. Huang. "Characterizations of particle size distribution of the droplets exhaled by sneeze." *Journal of the Royal Society Interface* 10.88 (2013): 20130560.

Human-generated particles are mostly greater than 0.1 µm





Most likely to deposit in the upper respiratory system (nose, larynx, pharynx) – 5-100+ µm
Moderate deposition in the lungs – 0.1-30 µm
Least deposition occurs in the alveoli (lung exchange region) – 3-30 µm

Major Reference Works, Pages: 272-292, First published: 31 January 2012, DOI: (10.1002/3527600418.mb0aeroaere0012)

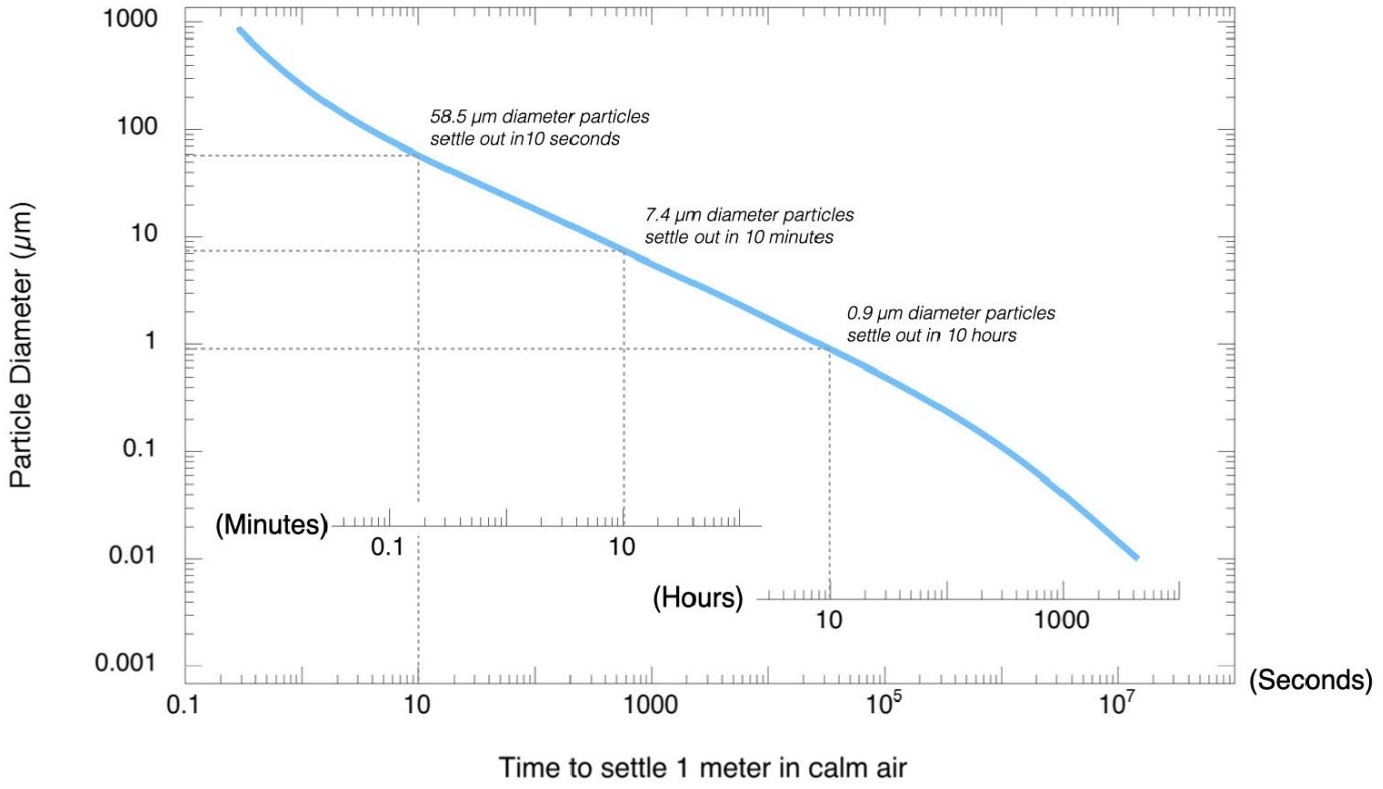
Cheng YS. Mechanisms of pharmaceutical aerosol deposition in the respiratory tract. AAPS PharmSciTech. 2014 Jun;15(3) 630-640. doi:10.1208/s12249-014-0092-0. PMID: 24563174; PMCID: PMC4037474.

Time to Fall One Meter

Particles > 10 µm = seconds

Particles 3 to 10 µm = minutes

Particles < 3 µm = hours



Particle Size (µm)	Settling Velocity (cm/sec)	Time to fall 1 m (in still air)
100	25	3.3 sec
30	2.7	23 sec
10	0.31	5.6 min
3	0.028	1 hour
0.3	0.00042	2.8 days
0.03	0.000022	53 days

https://therealandrewmaynard.com/category/health/

Hinds, William C., and Yifang Zhu. *Aerosol technology: properties, behavior, and measurement of airborne particles*. John Wiley & Sons, 2022.

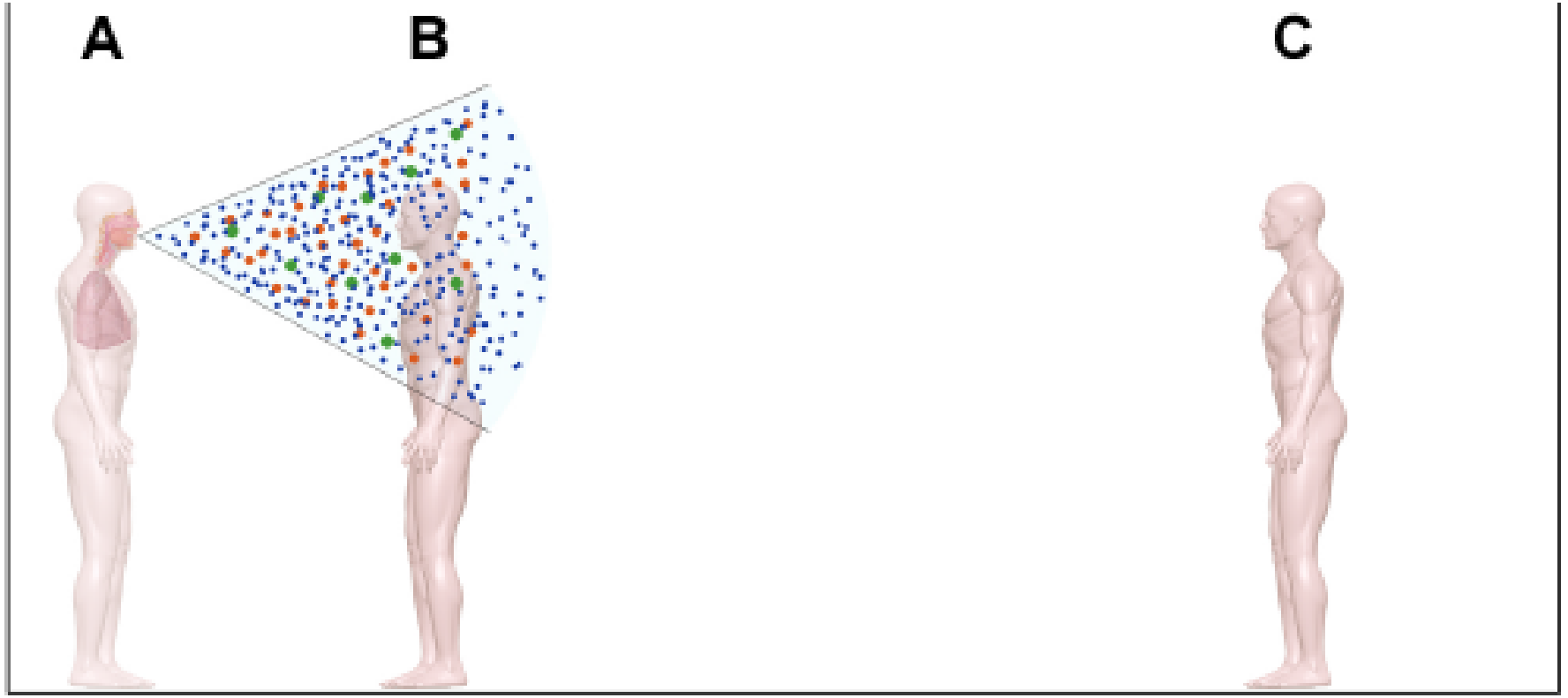
AIR TRANSMISSION – SINGLE COUGH OR SNEEZE

Inhalation predominates near the source (Chen et al. 2020)

Predominant Mode of Particle Transmission

Large and small particles inhaled by someone standing nearby.

Large particles may be propelled into the nose, mouth & eyes of someone directly facing the source (within 0.5 ft talking & 1.5 coughing). (Not the predominant mode of transmission.)

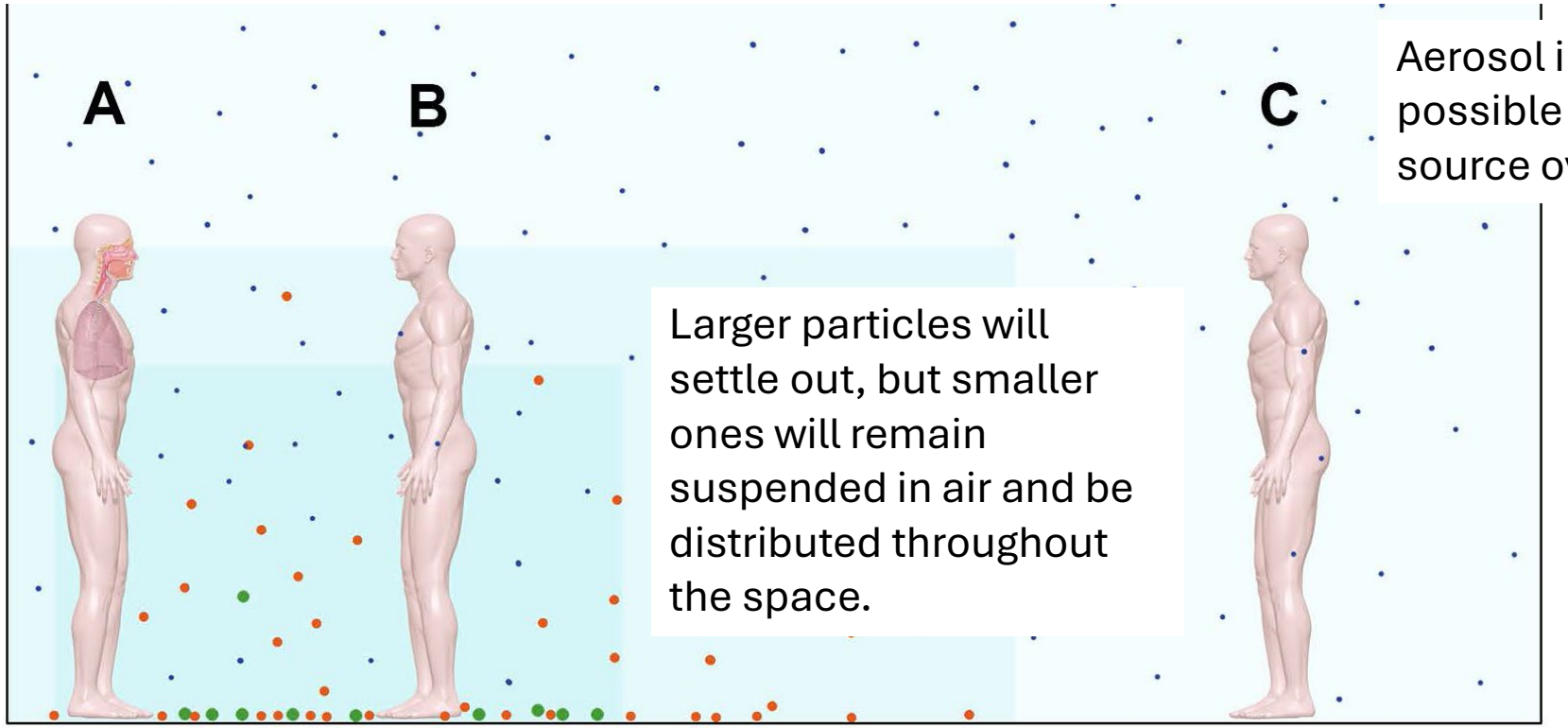


AIR TRANSMISSION OVER TIME

Inhalation occurs near and far from the source.
Concentration increases over time with ongoing breathing and talking.

Inhalation is ongoing near the source as small particles disperse and large particles fall to surfaces.

Particles continue to be added to the space as the source breathes, talks, etc. Concentration will increase throughout the space over time. Ventilation will remove particles but is usually not adequate to achieve zero concentration if source continues to produce particles.



Aerosol inhalation is possible further from the source over time.

Risk of receiving an infectious dose is a function of particle concentration in the air and exposure time.

Many Small Particles with Viral RNA and Viable Organisms Human and Healthcare Sampling for Influenza

- Influenza patients produce many small particles (87% < 1 μm) containing viral RNA. (Fabian et al. 2008)
- Majority of viable influenza found in smaller particles from humans (0.3 to 8 μm). (Lindsley et al. 2015)
- Viral RNA two times higher in small particles (< 5 μm) in exhaled breath samples from subjects with active COVID-19 infection. (Adenaiye et al. 2022)
- Emergency room samples found many small particles with influenza viral RNA (53% of RNA in particles between 1-4 μm). (Blachere et al. 2009)
- Sampling in urgent care facility found highest concentrations of influenza RNA in areas and times with highest patients loads: 40-50% of virus in particles < 4 μm. (Lindsley et al. 2010)

Air Transmission = Particle **Inhalation**

Inhalation should be the primary focus of a risk assessment for infectious respiratory organisms

Whether an organism is capable of transmission by inhalation depends on:

1. Is there a source of infectious particles?
2. Does the organism remain viable in air long enough for transmission from source to receptor to occur by inhalation?
3. Is the cellular target accessible via inhalation (or subsequent transport in the body)?

Criteria for Biological Plausibility of SARS-CoV-2 Particle Transmission by Inhalation

Criteria	Weak	Moderate	Strong
Particle Generation [SOURCE]	In body fluids; Measured on surfaces near source ✓	Symptoms or procedures that create aerosols; Detected in aerosol emitted by animals ✓	Detect in aerosols from patient ✓
Viability in the Environment [PATHWAY]	Survives on surfaces ✓	Genetic material persists in air; Viable surrogate survives in air ✓	Remains viable in air; Epidemiologic evidence of transmission via air ✓
Access to Target Tissue [RECEPTOR]	Tissue identified in animals, and accessible to particles ✓	Tissue identified in humans and accessible to particles; Transmission demonstrated in animals ✓	Experimental infection in humans ✓

Jones and Brosseau "Aerosol Transmission of Infectious Disease" (2015) J Occup Environ Med 57(5): 501-508

Pathogen Survival in Air

- Half-life of measles virus (de Jong et al. 1964)
  - Low humidity (20-30% RH) ≈ 200 min (**3.3 hr**)
  - High humidity (60-70% RH) ≈ 30 min (0.5 hr)
- Half-life of *M. tuberculosis*
  - **6 hr** at low humidity (Louden et al. 1969)
  - < 10 min at high humidity (75%) (Lever et al. 2000)
- Varicella zoster virus believed to survive for a "**few hours**"*
- Half-life of SARS-CoV-2 = **3-6 hr** depending on variant (Bushmaker et al. 2023)
- Half-life of SARS-CoV-1 is similar to SARS-CoV-2 (Van Doremalen et al. 2020)

*https://www.canada.ca/en/public-health/services/laboratory-biosafety-biosecurity/pathogen-safety-data-sheets-risk-assessment/varicella-zoster-virus.html

Risk is a Function of Particle Concentration in Air and Exposure Time

- An infectious dose is possible at a **high concentration for a short time period** or a **low concentration over a longer time period**.
- Exposure in healthcare occurs over many short encounters with infectious patients (and co-workers) over the course of a workday.
- Room ventilation can remove particles from a space, but it takes time to fully clear a room. If an infected person remains in the room, the particle concentration will never be zero.
- Being near a source can increase exposure, but **exposure can occur by inhalation throughout a shared space – near and far from the source**.

Hierarchy of Controls

SOURCE

DECREASE CONCENTRATION

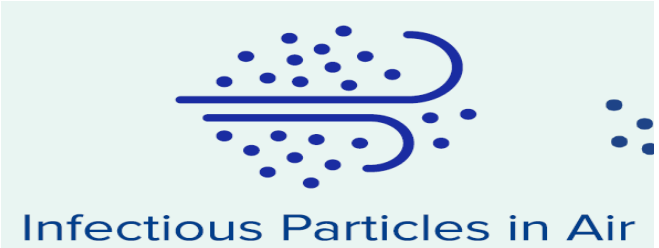
- Eliminate sources (testing)
- Limit number of sources
- Use source controls (preferably respirators)
- Enclose (isolate) the source

MINIMIZE TIME

- Limit time source spends in space

DO THESE FIRST!

PATHWAY



DECREASE CONCENTRATION

- Increase building ventilation & clean recirculated air
- Use local exhaust ventilation to collect particles (e.g., portable air cleaners)
- Prevent air movement from source to receptors (e.g., negative pressure)

LOWER AIRFLOW (LESS VENTILATION) MEANS LONGER TIME TO CLEAR PARTICLES

RECEPTOR

DECREASE CONCENTRATION

- Use respiratory protection to lower inhaled concentration
- Enclose receptor to exclude infectious particles

CONSIDER EXPOSURE TIME

- Need higher levels of respiratory protection for higher concentrations or longer time spent in shared space

COVID-19 Transmission in Hospitals

New Jersey Hospital (Barrett et al 2020)

- Prevalence of infection was 18 times greater in healthcare workers compared to the community
- **Highest positivity rates**
  - **Nurses (11%)**
  - **Emergency department (8%)**
  - **Operating room (10%)**
- **Lowest rates**
  - **Attending physicians (2%)**
  - **Intensive care unit (2%)**

Meta-analysis of 97 Studies (Gomez-Ochoa et al., 2021)

- Healthcare workers had high rates of positive PCR (11%) and antibodies (7%). **Nurses and healthcare personnel in non-emergency departments were most affected**.

Outbreak at Boston Hospital (Klompas et al., 2021)

- Index patient with history of lung disease had 2 negative COVID-19 tests.
- Not isolated while in the hospital for the next 11 days after which had a positive COVID-19 test.
- Cluster included 11 patients and 27 staff
  - **Physicians, nurses, patient care assistants & environmental services workers**
- **Two clear cases of infection from patient where healthcare worker was wearing a surgical mask, eye protection and gloves and no aerosol-generating procedures were being conducted.**

Why are non-ICU HCW at risk?

1. People are most infectious early in their infection: 2-5 days before and 8-10 days after symptoms start.
2. Many people are asymptomatic (up to 30%).

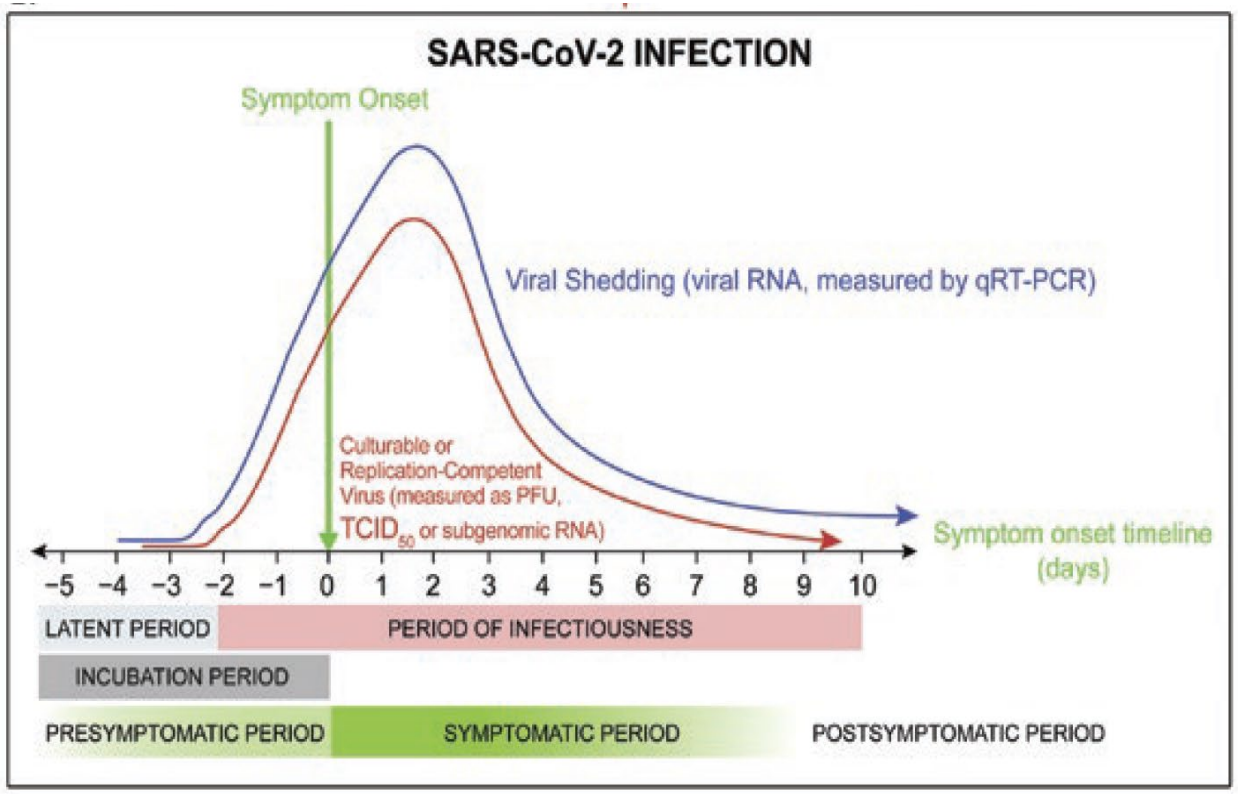
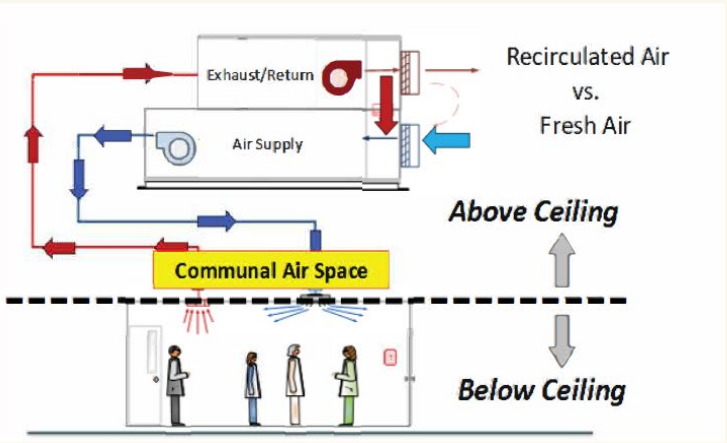


Figure from: Brosseau LM, et al. "Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) Dose, Infection, and Disease Outcomes for Coronavirus Disease 2019 (COVID-19): A Review." Clinical Infectious Diseases (2021).

COVID-19: Airflow Patterns Matter

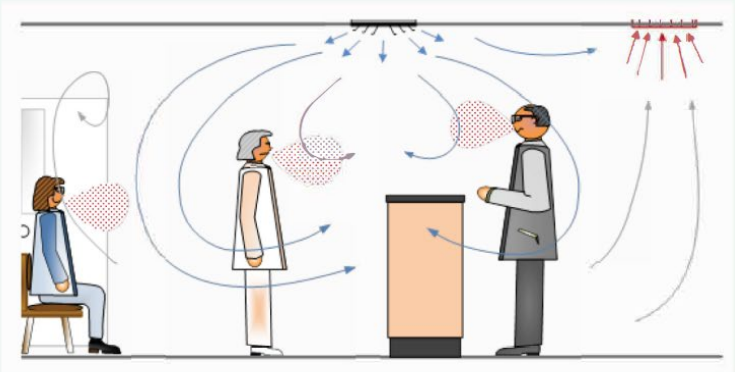
BUILDING VENTILATION SYSTEMS ARE NOT DESIGNED TO REMOVE PARTICLES EMITTED FROM AN INFECTIOUS SOURCE



Instead, their purpose is for comfort and general air quality.

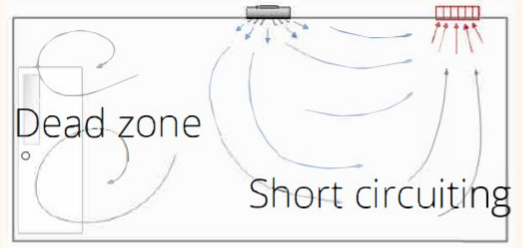
Interventions above the ceiling can yield benefits, but may not be sufficient to prevent exposure in occupied spaces below the ceiling.

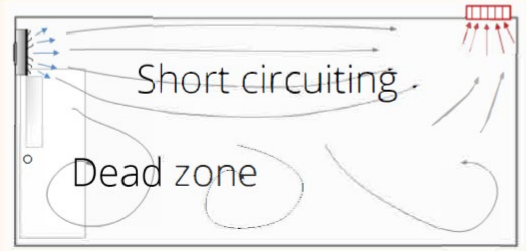
WHAT'S THE EXPOSURE?



- Anyone can be a source of infectious particles.
- Particles follow air currents.
- Particle concentrations increase over time.
- Exposure may result from the transport of particles from an infectious person to an uninfected person.

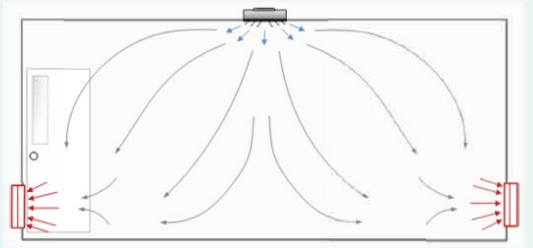
AIRFLOW PATTERNS ARE IMPORTANT





Placement and design of inlets and outlets can cause poor mixing, dead zones, short circuiting and concentration build-up.

PROPER SUPPLY AND EXHAUST CAN SIGNIFICANTLY REDUCE THE RISK OF EXPOSURE



Consider optimizing the type and location of supply and exhaust to enhance airflow, mixing, dilution and removal of contaminants.

Portable Air Cleaners and Other LEV Solutions

Ventilated headboard for patient care (NIOSH)

Portable air cleaners for small and large spaces

Conclusions

- People generate lots of **small particles that remain suspended in air** for long periods of time and **disperse throughout an indoor space**.
- **Particle inhalation** is the most likely mode of transmission via air **both near and far from a source.**
- **Sprays and splashes are relatively unimportant in comparison to particle inhalation.**
- Risk is a function of **particle concentration in the air and exposure time.**
- Pathogen survival in air for several hours is not rare and not confined to just a few organisms.
- **Focus should be on source and pathway controls that reduce particle concentration and minimize exposure time.**
- More attention to **local exhaust ventilation solutions** is needed.

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