The Role of Aerosols in the Transmission of COVID-19

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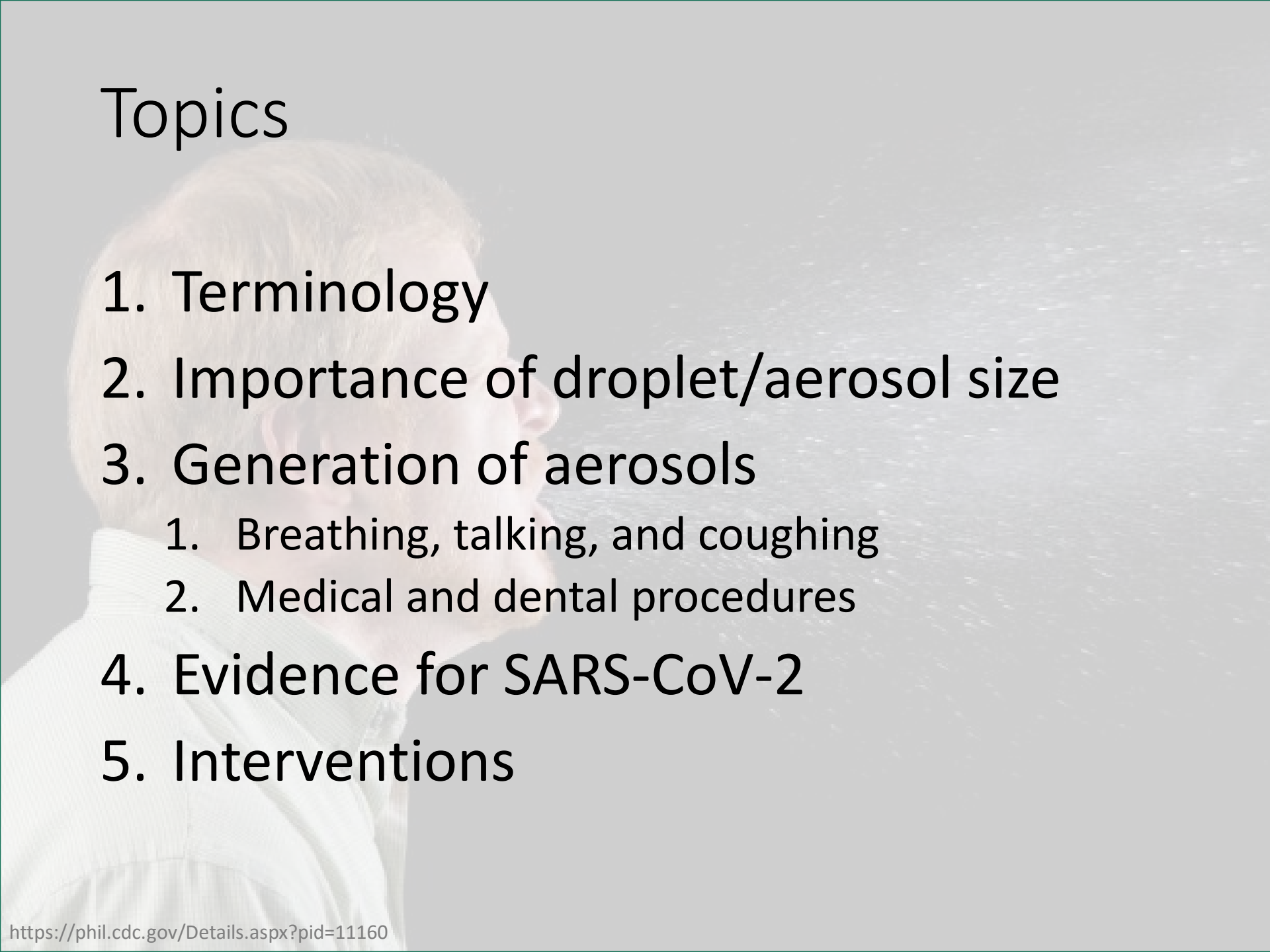
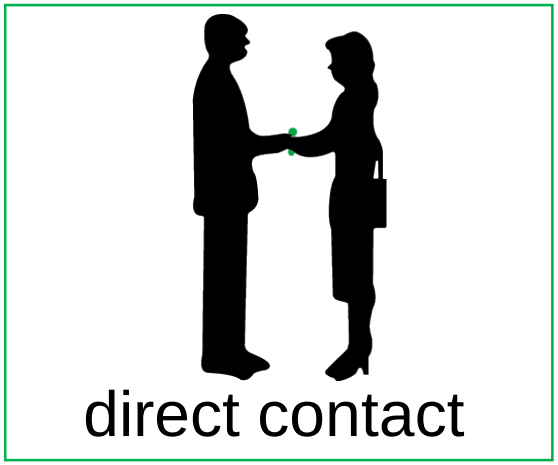
Topics

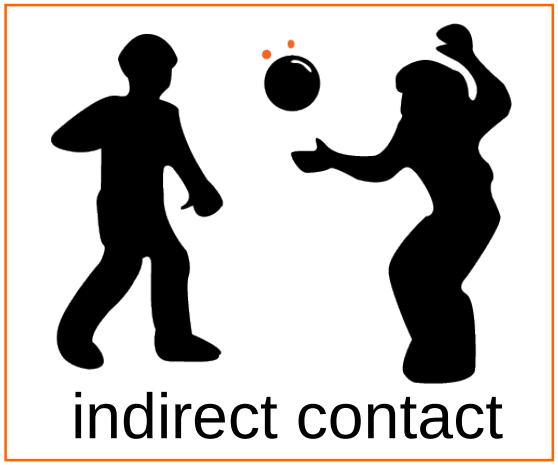
1. Terminology
2. Importance of droplet/aerosol size
3. Generation of aerosols
    1. Breathing, talking, and coughing
    2. Medical and dental procedures
4. Evidence for SARS-CoV-2
5. Interventions



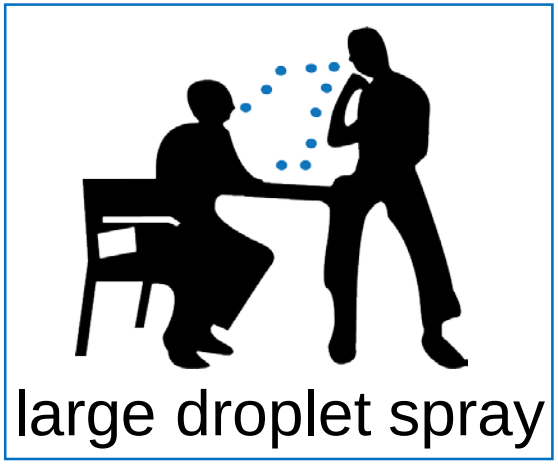
https://phil.cdc.gov/Details.aspx?pid=11160

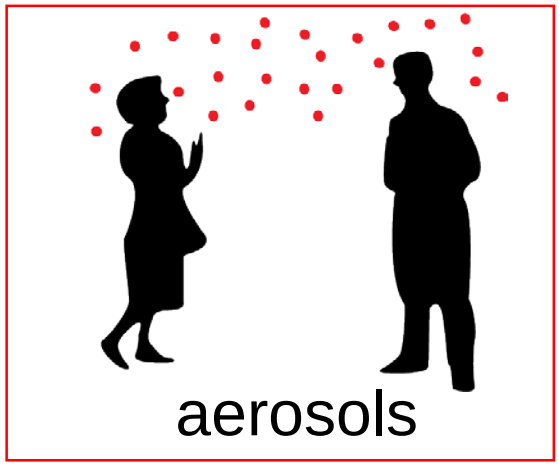
Transmission Routes





Traditionally defined as >5 μm and happening at close-range only (<2 m)





Traditionally defined as <5 μm and happening mainly at long-distance (>2 m)

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

Terminology

Term	WHO/Infectious Disease	Dental Community	Aerosol Science
Airborne	 Measles	N/A	In the air

Terminology

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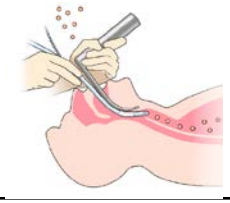
Aerosol	 < 5 μm	< 50 μm	Collection of solid or liquid particles suspended in a gas

best cutoff is 100 μm

(1) Prather, K.A., Marr, L.C., Schooley, R.T., et al., 2020, Airborne transmission of SARS-CoV-2, *Science*

Terminology

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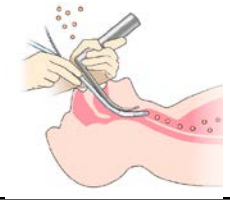
Aerosol	 < 5 μm	< 50 μm	Collection of solid or liquid particles suspended in a gas
Droplet	 > 5 μm	N/A	Liquid particle

(1) Prather, K.A., Marr, L.C., Schooley, R.T., et al., 2020, Airborne transmission of SARS-CoV-2, *Science*

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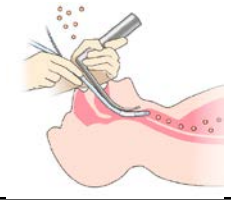
Aerosol	 < 5 μm	< 50 μm	Collection of solid or liquid particles suspended in a gas
Droplet	 > 5 μm	N/A	Liquid particle
Splatter	N/A	> 50 μm	N/A

(1) Prather, K.A., Marr, L.C., Schooley, R.T., et al., 2020, Airborne transmission of SARS-CoV-2, *Science*

Terminology

Term	WHO/Infectious Disease	Dental Community	Aerosol Science
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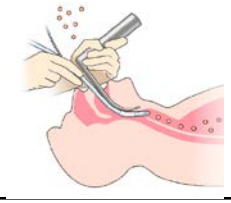
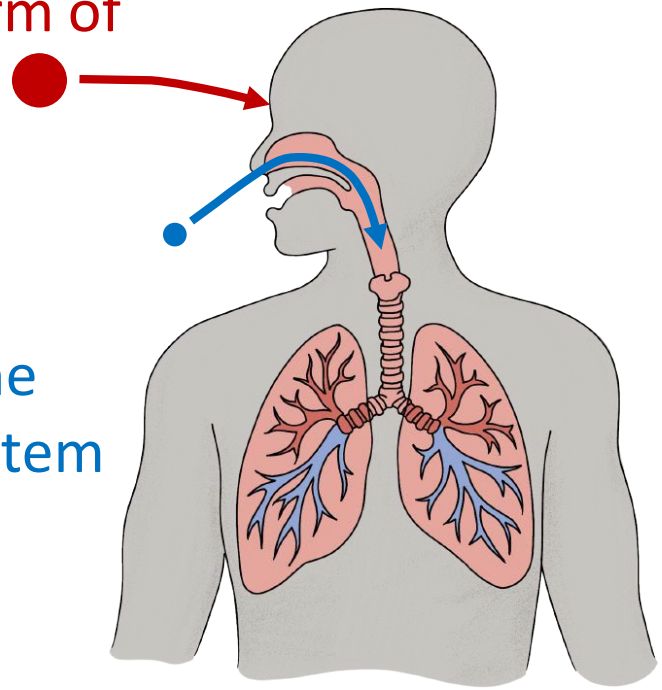
Aerosol	 < 5 μm	< 50 μm	Collection of solid or liquid particles suspended in a gas
Droplet	 > 5 μm	N/A	Liquid particle
Splatter	N/A	> 50 μm	N/A
Droplet nuclei	Evaporated residue of droplets that is < 5 μm	Evaporated residue of large droplets	?

(1) Prather, K.A., Marr, L.C., Schooley, R.T., et al., 2020, Airborne transmission of SARS-CoV-2, *Science*

Defining Transmission by Exposure Path

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

AEROSOLS are inhaled into the respiratory system



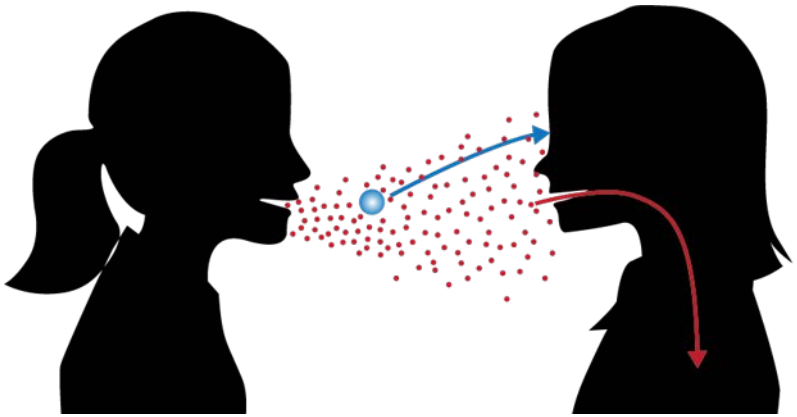
This distinction drives

- Control strategies
- Infectious dose
- Severity of disease

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

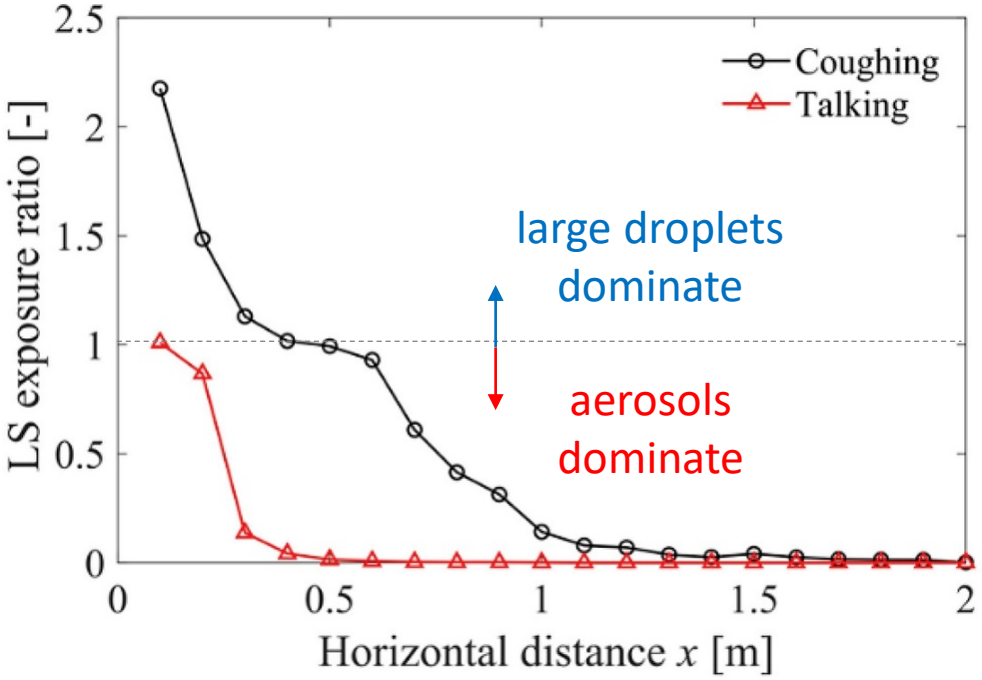
(1) Wells, W.F., 1934, On air-borne infection. Study II. Droplets and droplet nuclei, *Am J Epidemiol* (2) Xie, X., Li, Y., Chwang, A.T.Y., Ho, P.L., Seto, W.H., 2007, How far droplets can move in indoor environments – revisiting the Wells evaporation–falling curve, *Indoor Air* (3) Tellier, R., Li, Y., Cowling, B.J., Tang, J.W., 2019, Recognition of aerosol transmission of infectious agents: a commentary, *BMC Infect Dis* (4) Lindsley, W.G., Noti, J.D., Blachere, F.M., et al., 2015, Viable influenza A virus in airborne particles from human coughs, *J Occupat Environ Hyg*

Close Contact: Droplets vs. Aerosols



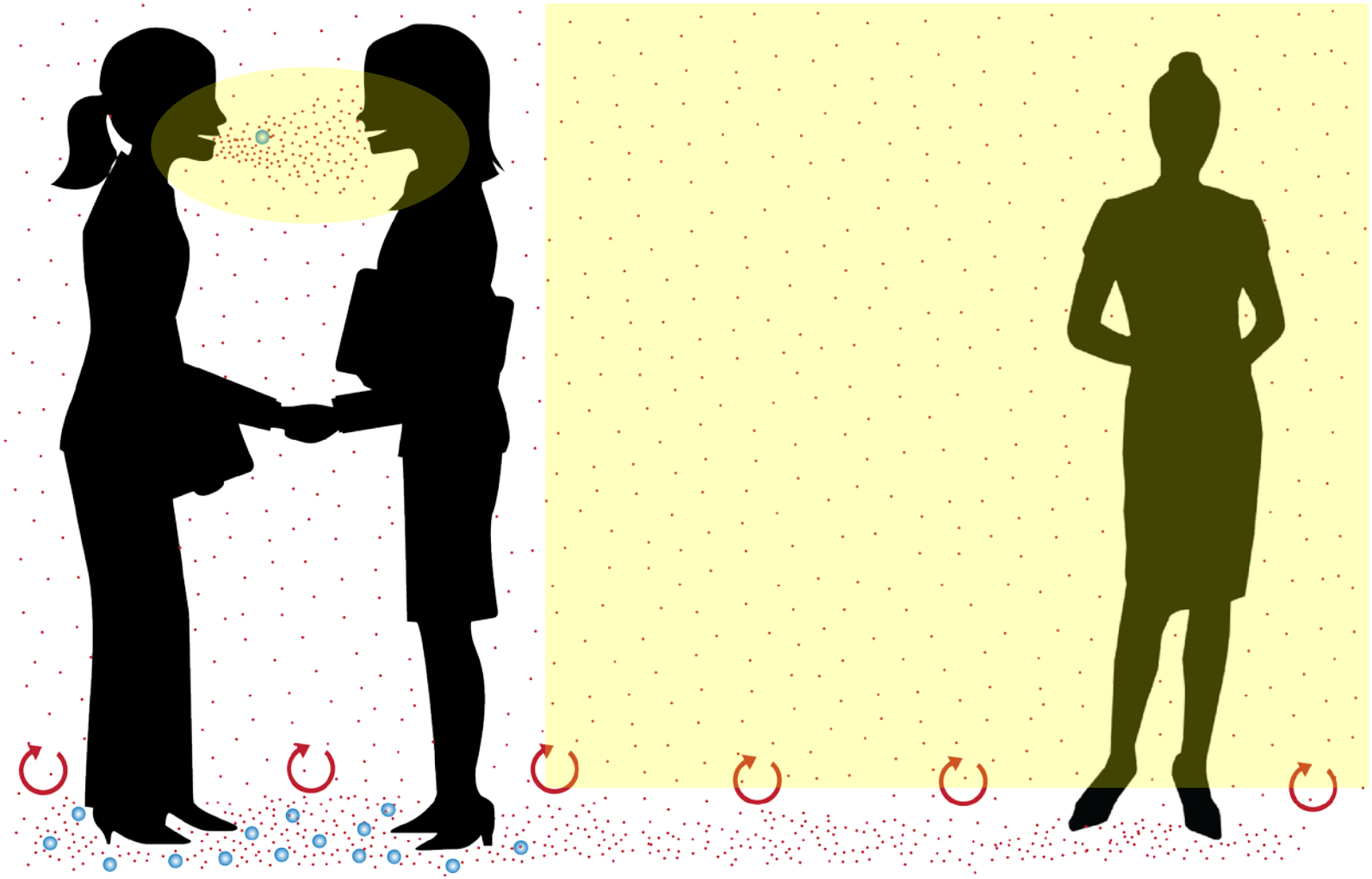
Physics-based model of large droplet spray and aerosols in jets produced by talking and coughing

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

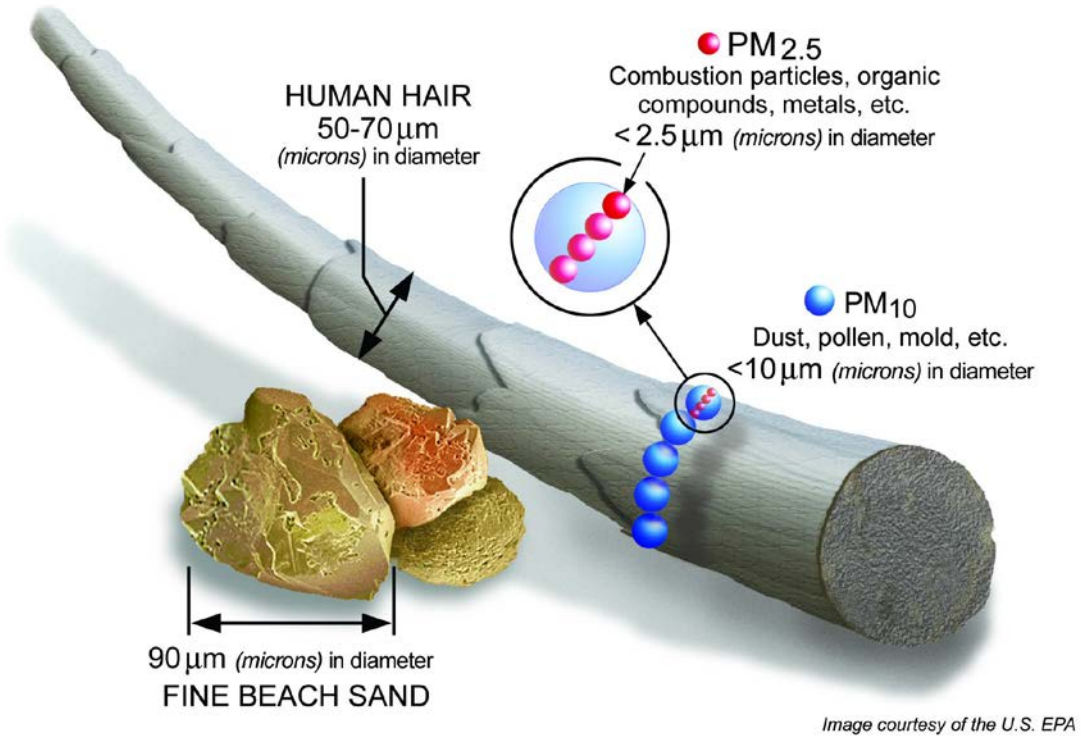


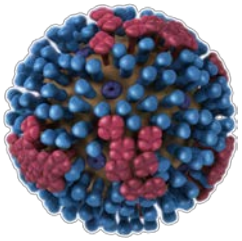
(1) Khare, P., Marr, L.C., 2015, Simulation of vertical concentration gradient of influenza viruses in dust resuspended by walking, *Indoor Air* (2) Asadi, S., Gaaloul ben Hnia, N., Barre, R.S., et al., 2020, Influenza A virus is transmissible via aerosolized fomites, *Nature Comm*

Transmission by inhalation of aerosols can happen at short and long range.

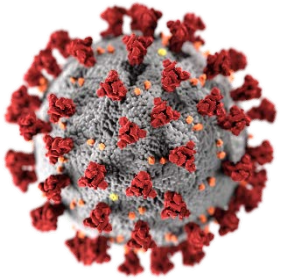
Why is size so important?

Virus Size

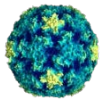




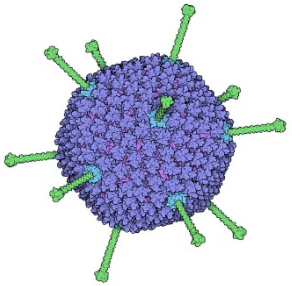
influenza
0.1 µm



SARS-CoV-2
0.12 µm



rhinovirus
0.03 µm

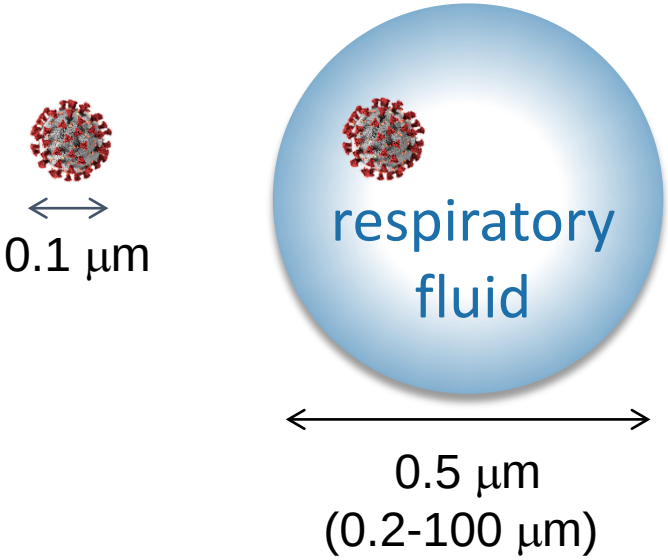


adenovirus
0.1 µm

https://www.cdc.gov/flu/resource-center/freeresources/graphics/images.htm, http://solutionsdesignedforhealthcare.com/rhinovirus, https://phil.cdc.gov/Details.aspx?pid=23312, https://pdb101.rcsb.org/motm/132

Size of Droplet/Aerosol is Critical

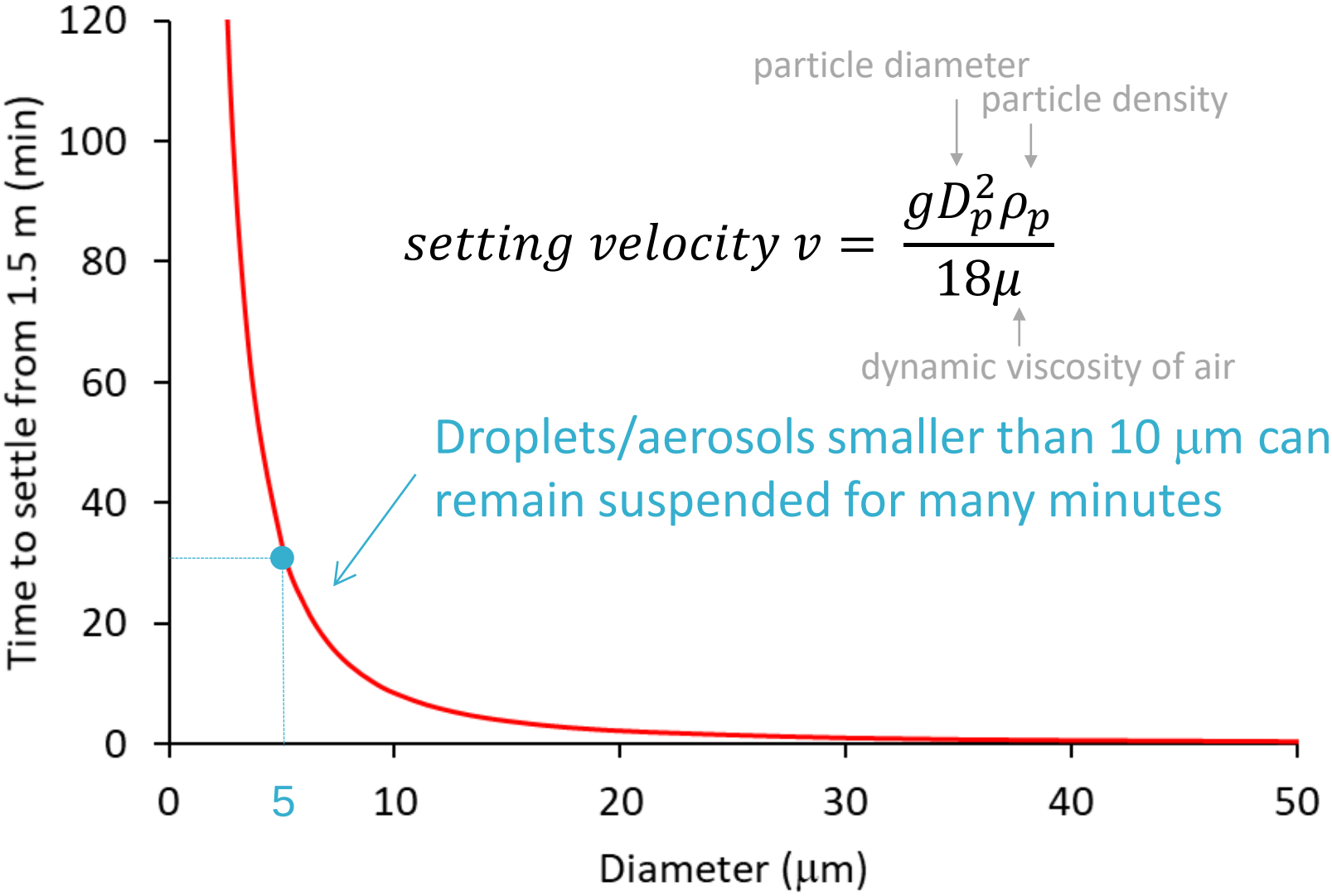
1. Airborne virus is not naked
2. Size of carrier droplet/aerosol defines transport



- 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

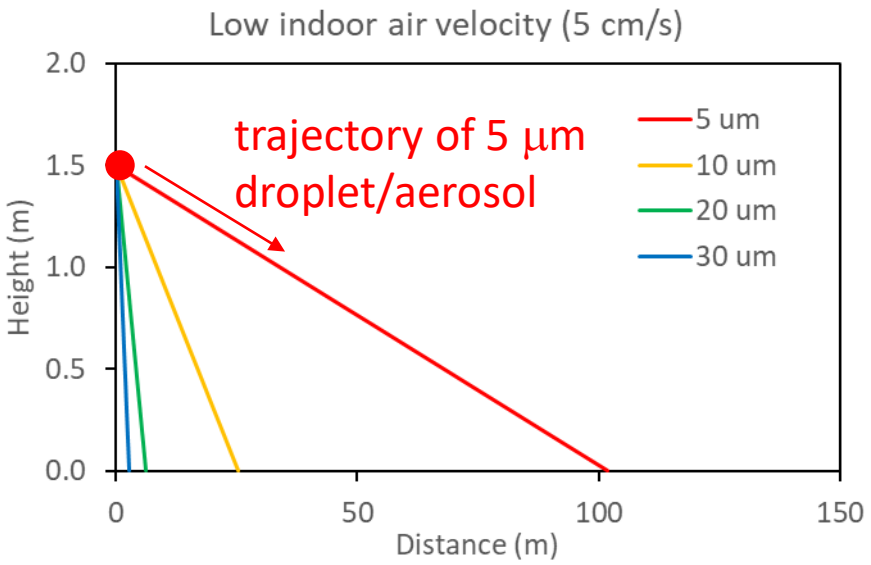
3. SARS-CoV-2 vs. measles vs. other viruses: (1) viral load in different size droplets/aerosols, (2) inactivation rate in droplets/aerosols, (3) location and dose to initiate infection

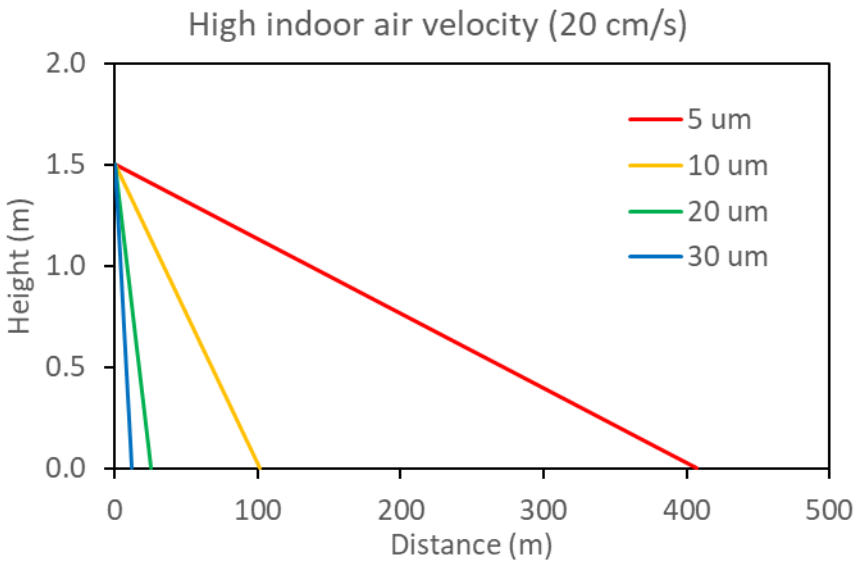
Settling Velocity and Time



They Can Travel More Than 2 m

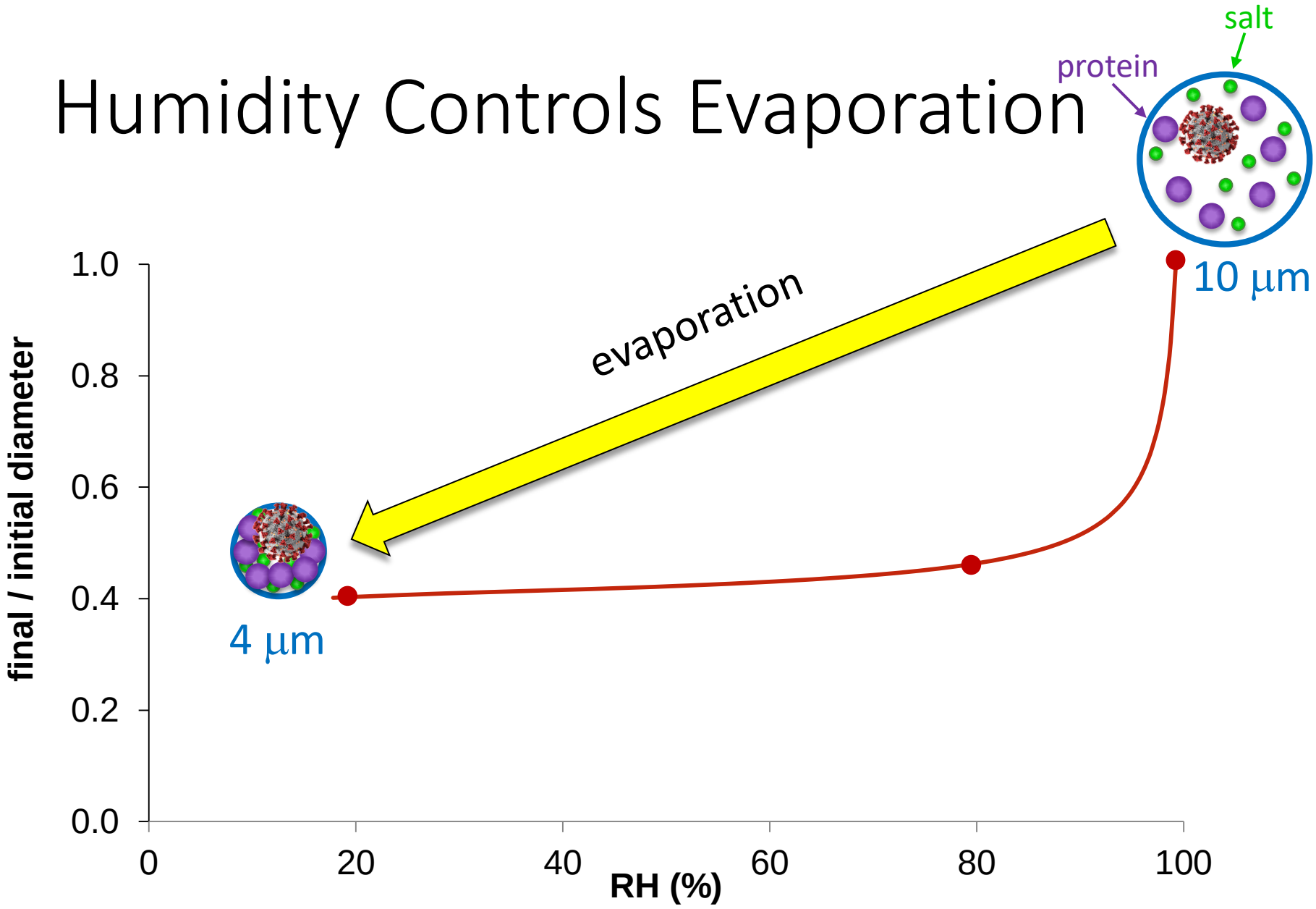
Position of droplets/aerosols released from a height of 1.5 m





(1) Nazaroff, 2020, personal communication (2) Matthews, T.G., Thompson, C.V., Wilson, D.L., et al., 1989, Air velocities inside domestic environments: An important parameter in the study of indoor air quality and climate, *Environ Internat* (3) Baldwin, P.E., Maynard, A.D., 1998, A survey of wind speeds in indoor workplaces, *Ann Occup Hyg*

Humidity Controls Evaporation

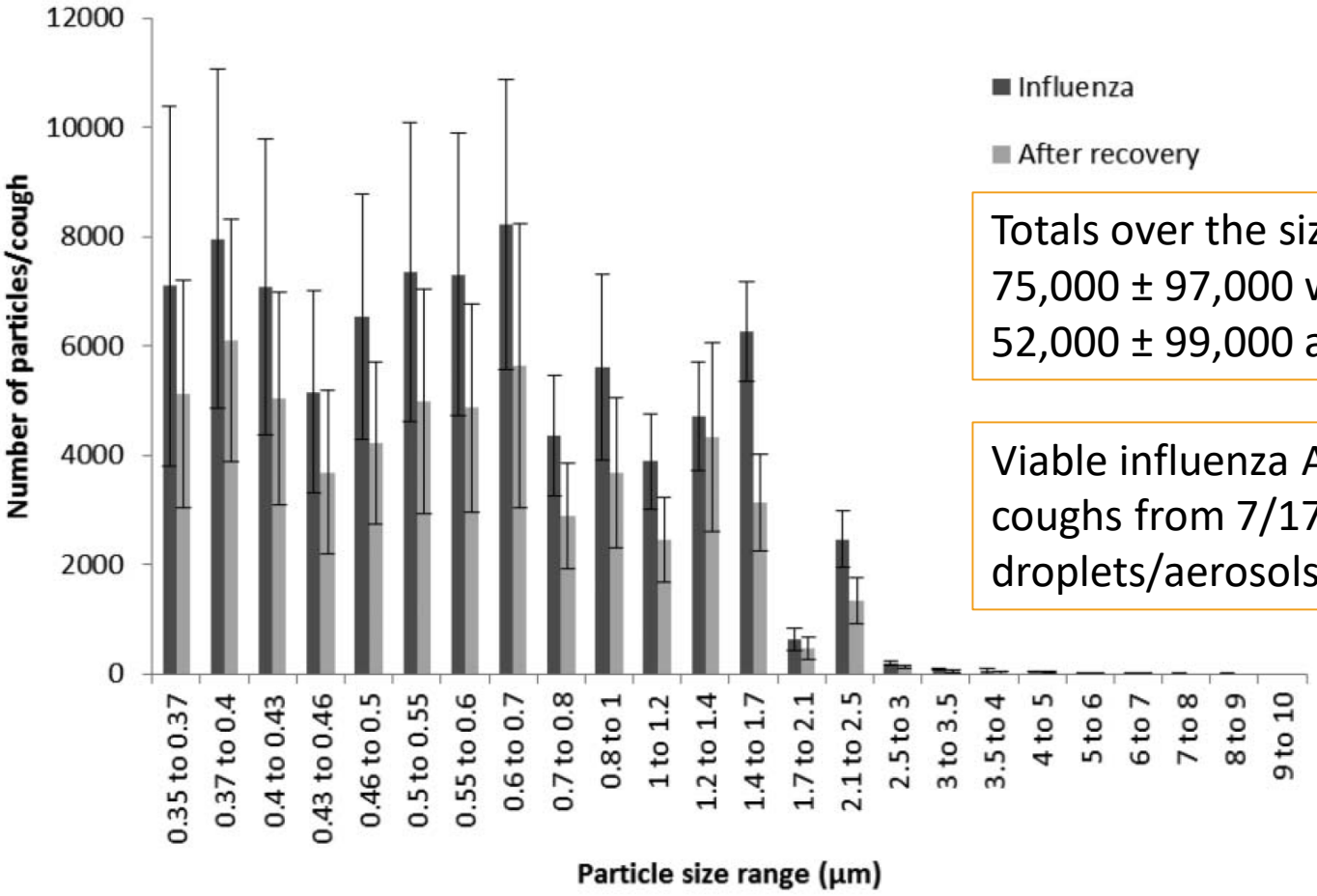


(1) Mikhailov, E., Vlasenko, S., Niessner, R., et al., 2004, Interaction of aerosol particles composed of protein and salts with water vapor: hygroscopic growth and microstructural rearrangement, *Atmos Chem Phys* (2) Marr, L.C., Tang, J.W., Van Mullekom, J., et al., 2019, Mechanistic insights into the effect of humidity on airborne influenza virus survival, transmission and incidence, *J Roy Soc Interface*

Droplet/aerosol size is really important!

How do they get into the air in the first place?

Coughing Produces Aerosols

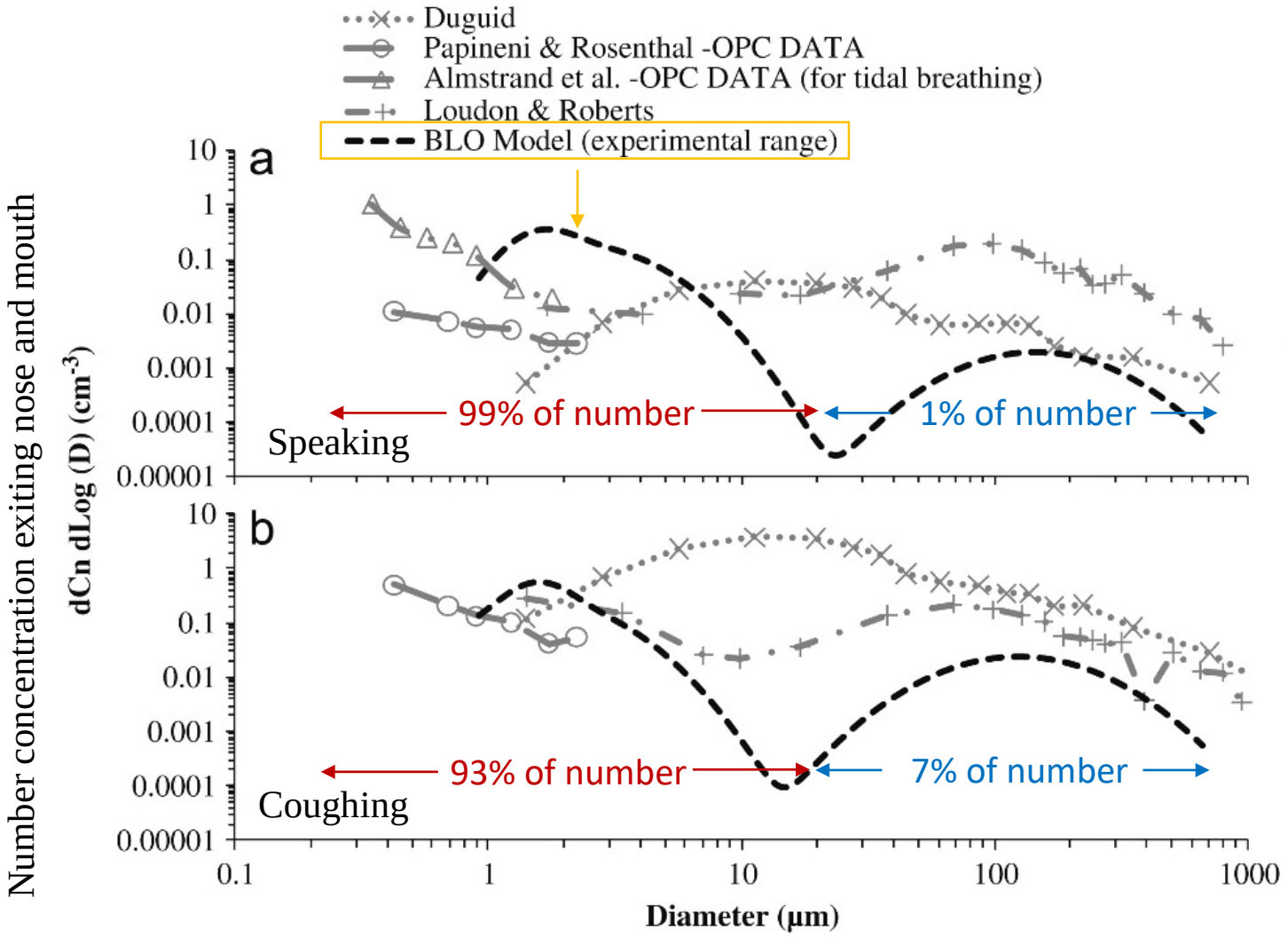


Totals over the size range 0.35-10 µm:
75,000 ± 97,000 when sick
52,000 ± 99,000 after recovery

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

(1) Lindsley, W.G., Pearce, T.A., Hudnall, J.B., et al., 2012, Quantity and size distribution of cough-generated aerosol particles produced by influenza patients during and after illness, *J Occup Environ Hyg* (2) Lindsley, W.G., Noti, J.D., Blachere, F.M., et al., 2015, Viable influenza A virus in airborne particles from human coughs, *J Occup Environ Hyg*

Speaking Produces Aerosols

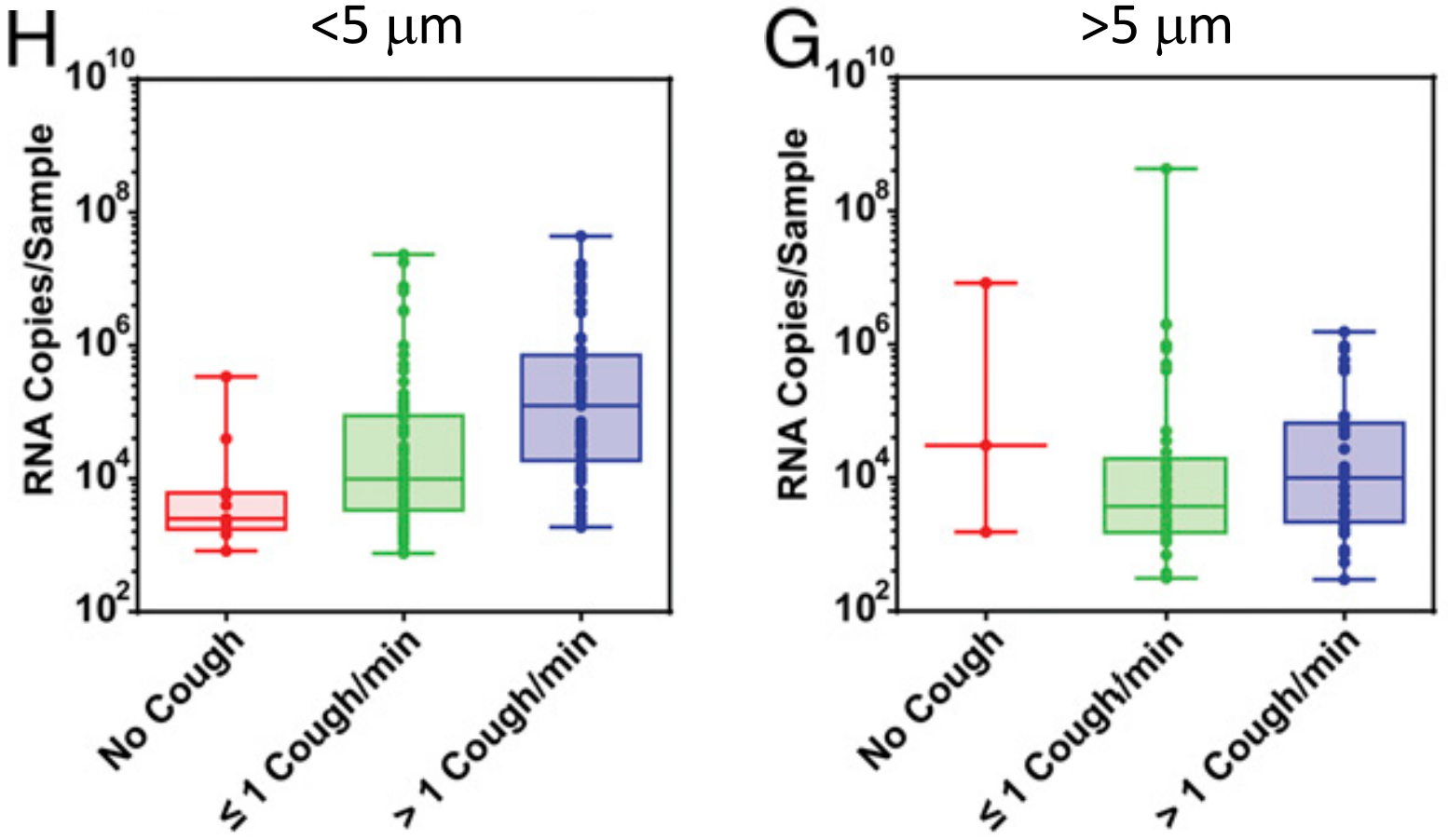


5 nl and 30 viral RNA copies from saying "Hello, World!"

125 nl and 900 viral RNA copies from one cough

(1) Johnson, G.R., Morawska, L., Ristovski, Z.D., et al., 2011, Modality of human expired aerosol size distributions, *J Aerosol Sci*, 42, 839-851 (2) Wölfel, R., Corman, V.M., Guggemos, W., et al., 2020, Virological assessment of hospitalized patients with COVID-2019, *Nature*

Flu Virus in Exhaled Breath



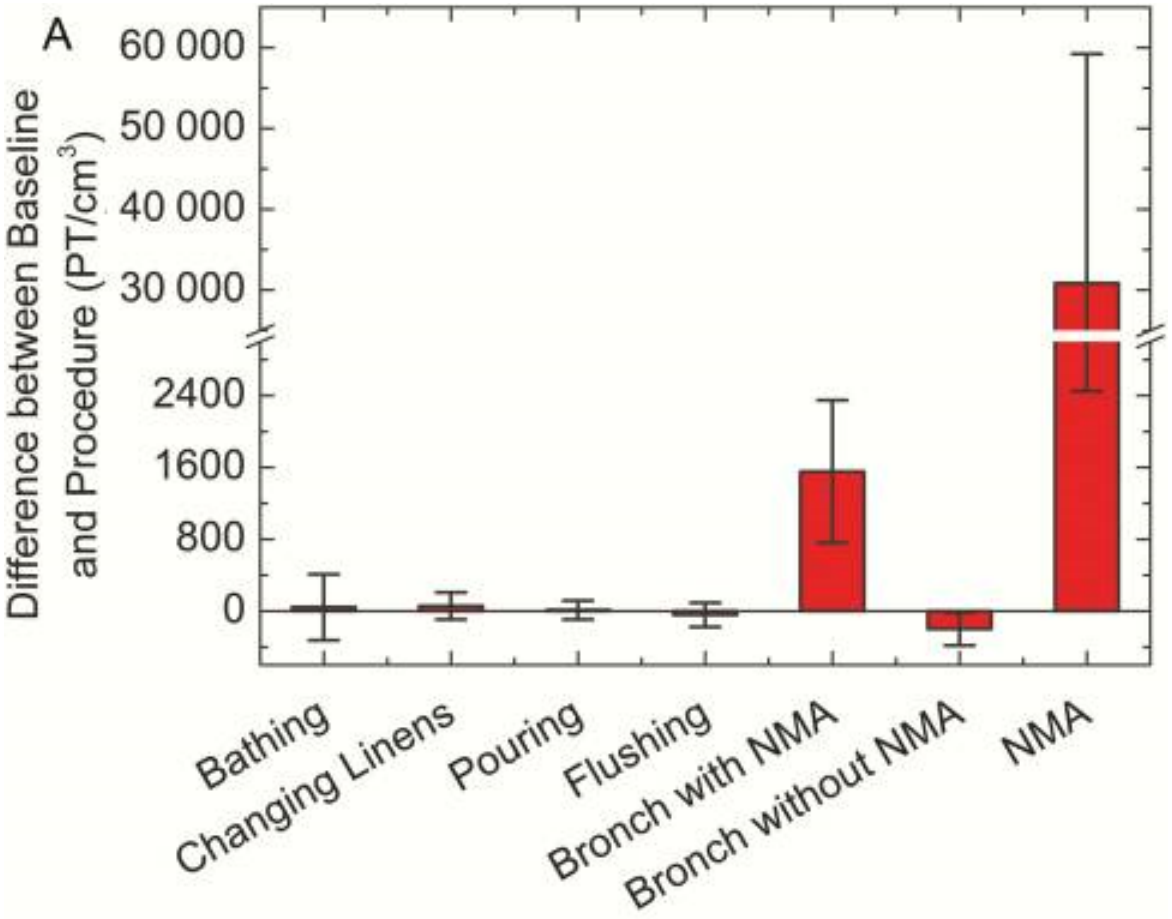
More virus in aerosols <5 μm than >5 μm, detected with no cough.

(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

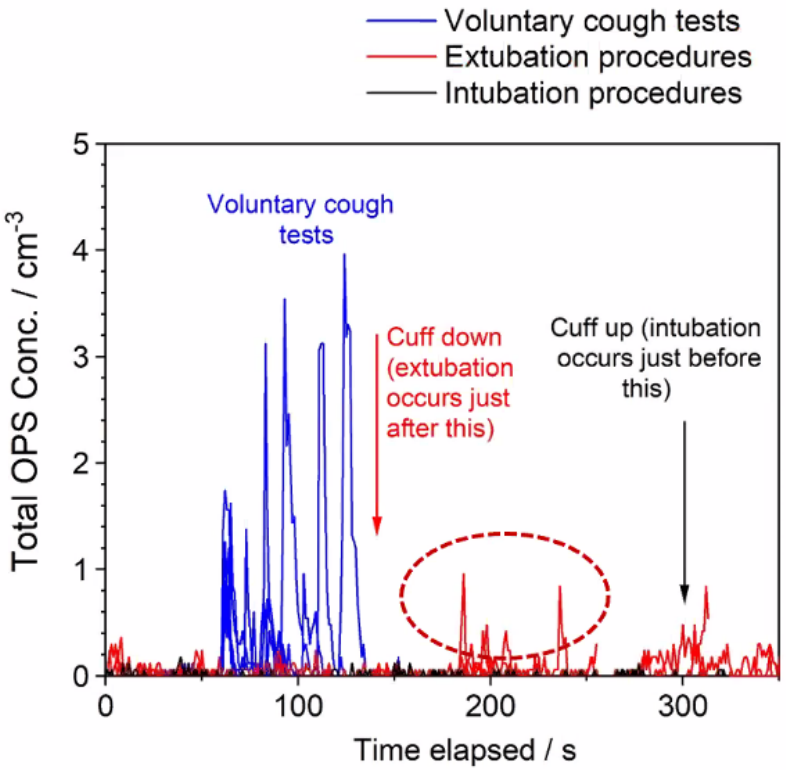


Nebulized medication administration (NMA) produced aerosols, but bronchoscopy alone did not.

(1) O'Neil, C.A>, Li, J., Leavey, A., et al., 2017, Characterization of Aerosols Generated During Patient Care Activities, *Clin Infect Dis*

Dr. Jose Jimenez, University of Colorado; Dr. Jonathan Reid, University of Bristol

Intubation and Extubation



Average particle concentration sampled in a 10 s window: (± standard error)

Intubation procedure	**0.012** ± 0.003
Extubations with no coughs	**0.15** ± 0.01
Cough detected in an extubation	**1.7** ± 0.1
Single voluntary cough	**8.2** ± 0.8
Background during theatre operational hours	**0.052**

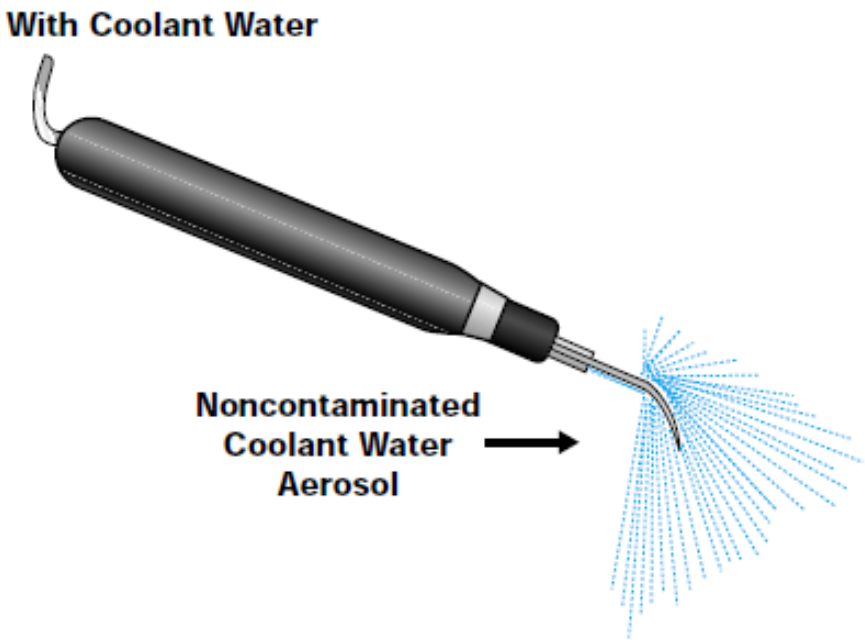
Currently classified as "Aerosol Generating Procedure" – Full PPE

Not classed as an AGP

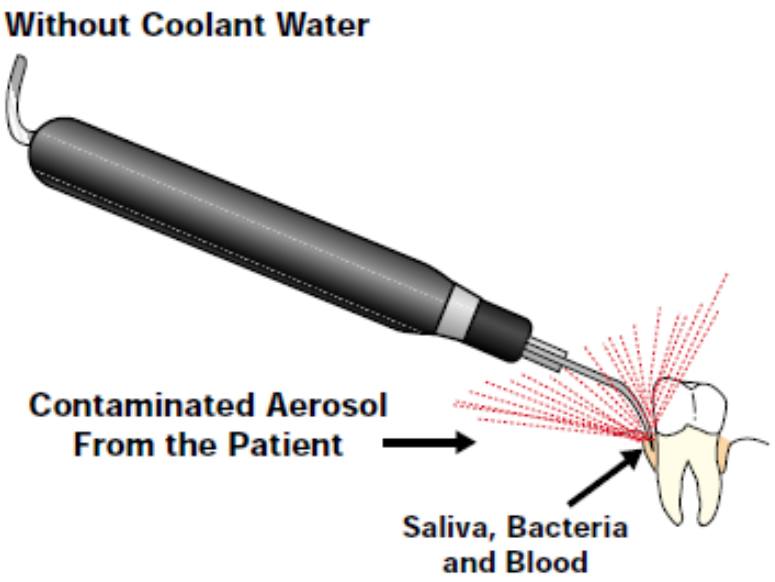
Extubation generated more aerosols than intubation, especially when patient coughed, but coughing alone generated at least 35x more aerosols.

(1) Brown, J., Gregson, F.K.A., Shrimpton, A., et al., 2020, A quantitative evaluation of aerosol generation during tracheal intubation and extubation, *Anaesthesia*

Dental Procedures



**EQUIPMENT—
SOURCE OF AEROSOL**



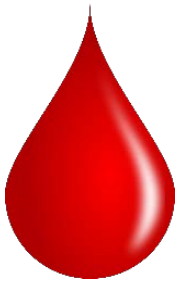
**PATIENT—
SOURCE OF AEROSOL**

(1) Harrel, S.K., Barnes, J.B., Rivera-Hidalgo, F., 1998, Aerosol and splatter contamination from the operative site during ultrasonic scaling, *JADA*
(2) Zemouri, C., de Soet, H., Crielaard, W., et al., 2017, A scoping review on bio-aerosols in healthcare and the dental environment, *PLoS One*

Dental AGPs

Mainly on the basis of culturable bacterial counts:

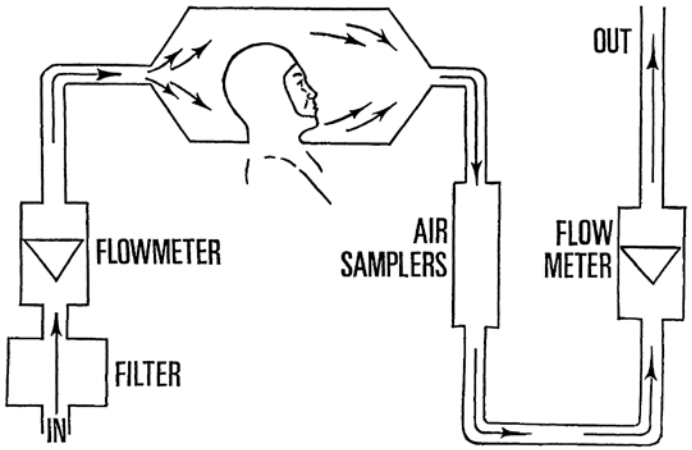
- Ultrasonic scaler
- Air-driven high-speed handpiece
- Air polisher
- Air/water syringe
- Drills, wet and dry
- Air abrasion



0.003-2.2 μl/min
0.06-13 μm

(1) Harrel, S.K., Molinari, J., 2004, Aerosols and splatter in dentistry, *JADA* (2) Miller, R.L., 1995, Characteristics of blood-containing aerosols generated by common powered dental instruments, *Am Indust Hyg Assoc J*

Bacterial Aerosols

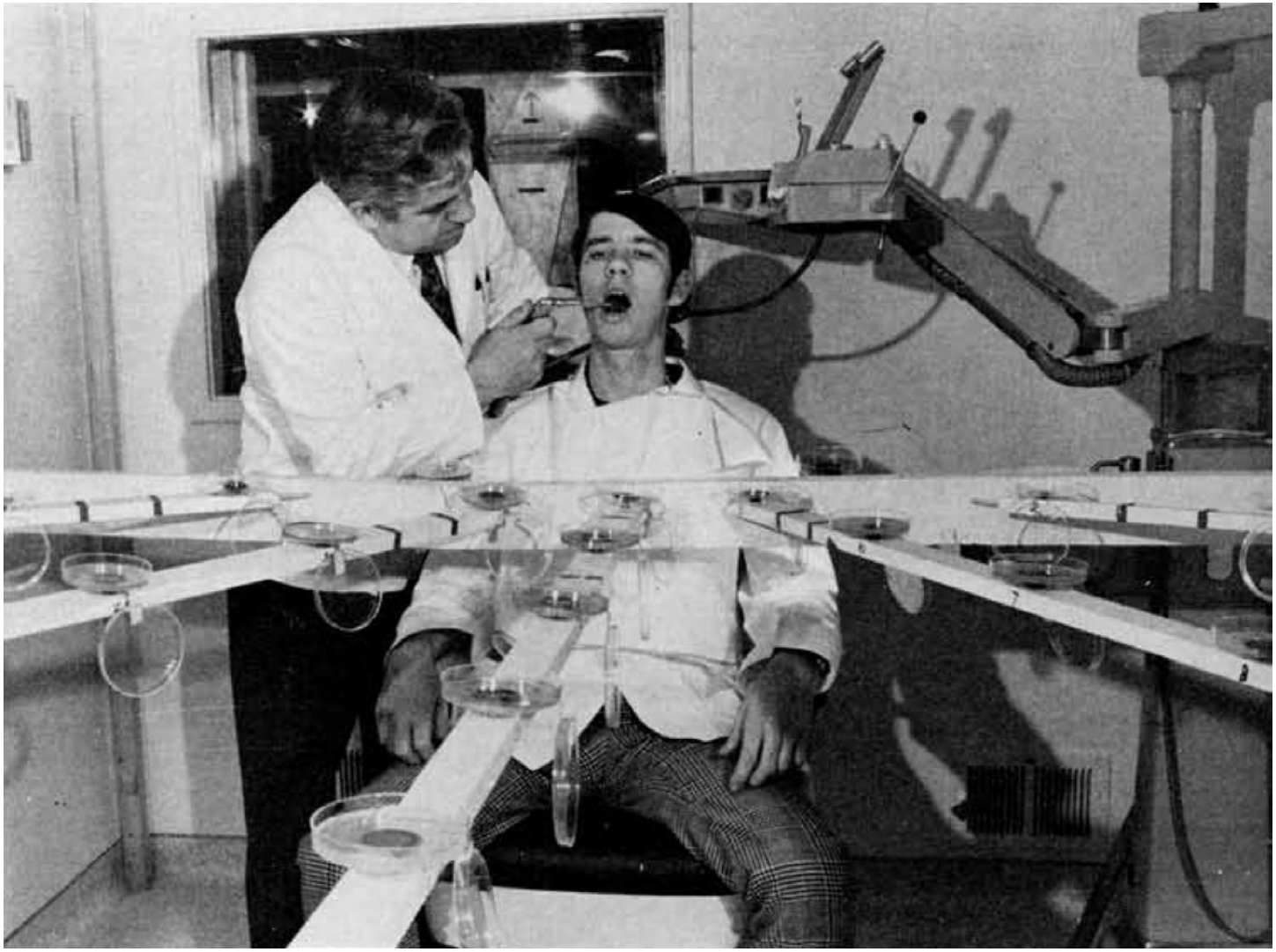


Activity	Median emissions (CFU/min)
Speaking	3
Coughing	36
Manual scaling	1
Prophylaxis (pumice)	42
Air turbine handpiece (air coolant)	58
Air turbine handpiece (water coolant)	1000
Drying with air spray	72
Washing with water spray	37,000

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

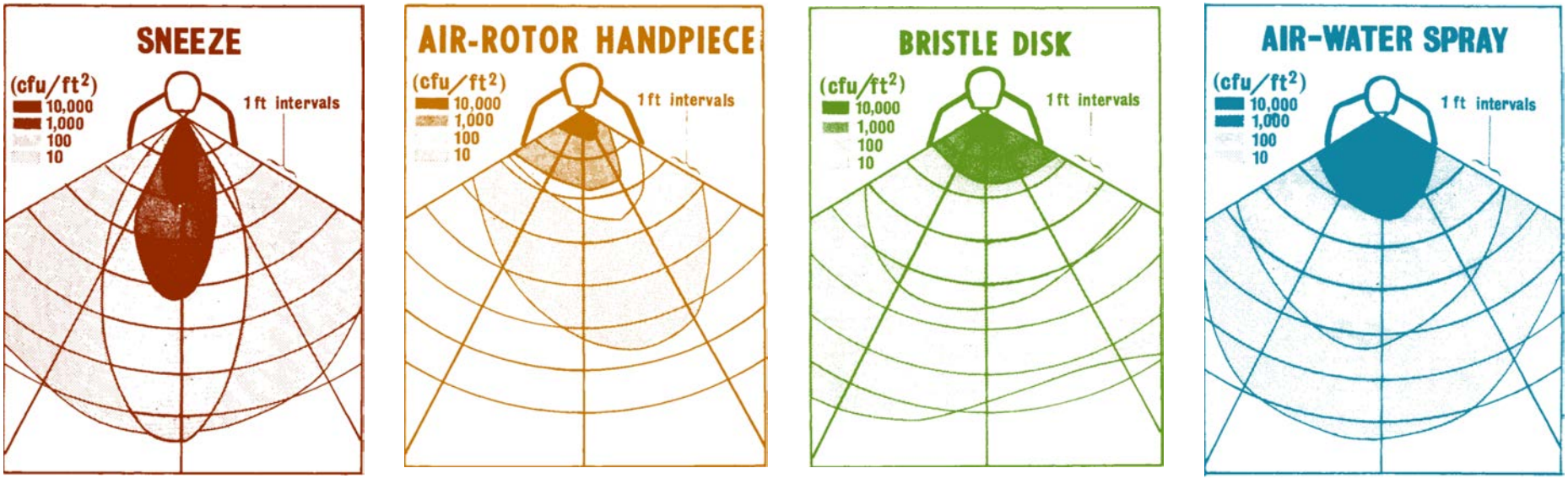
(1) Micik, R.E., Miller, R.L., Mazarella, M., et al., 1969, Studies on Dental Aerobiology: I. Bacterial Aerosols Generated During Dental Procedures, *J Dental Res*

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*

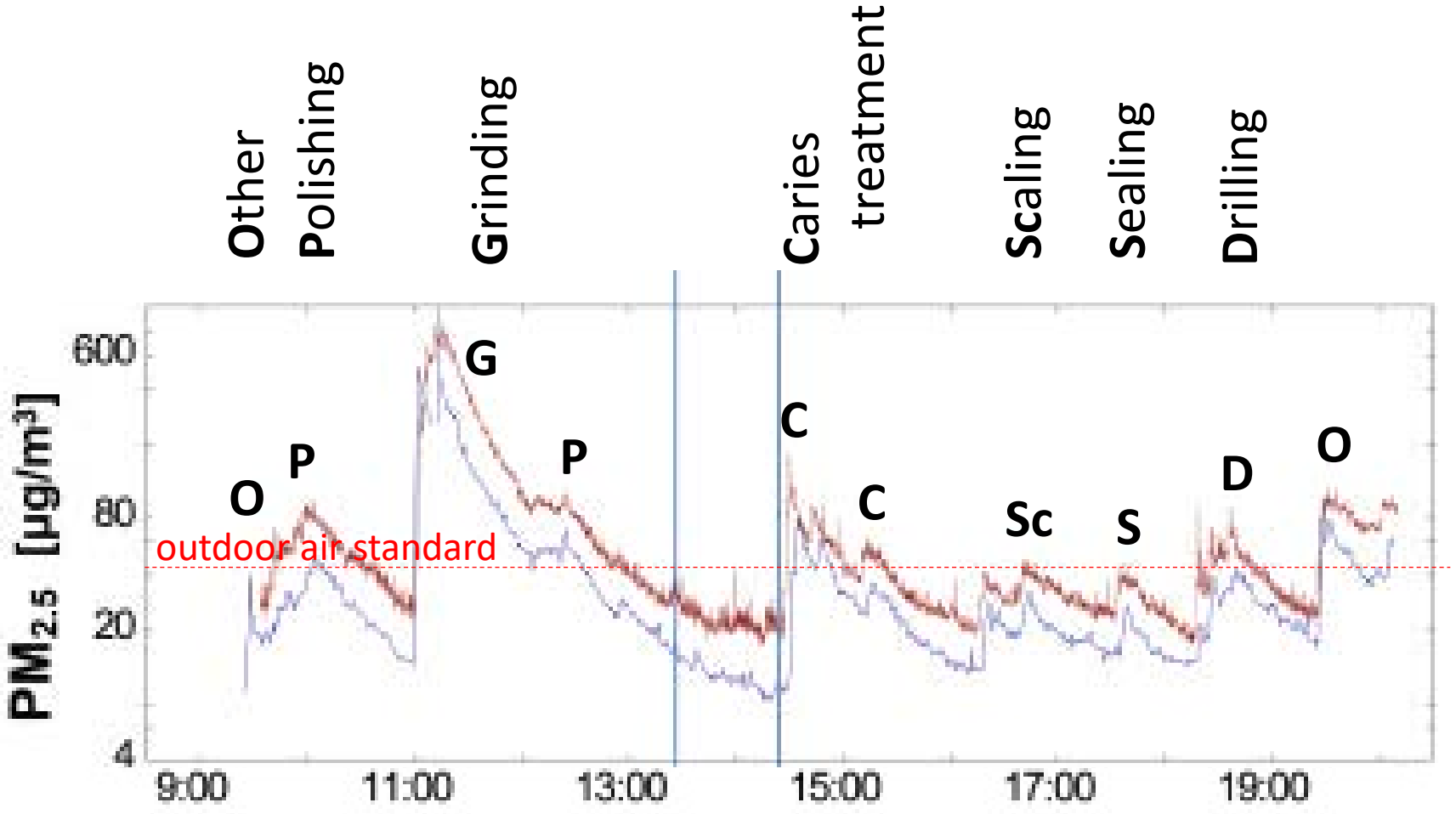
Bacteria Settled Many Feet Away



"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*

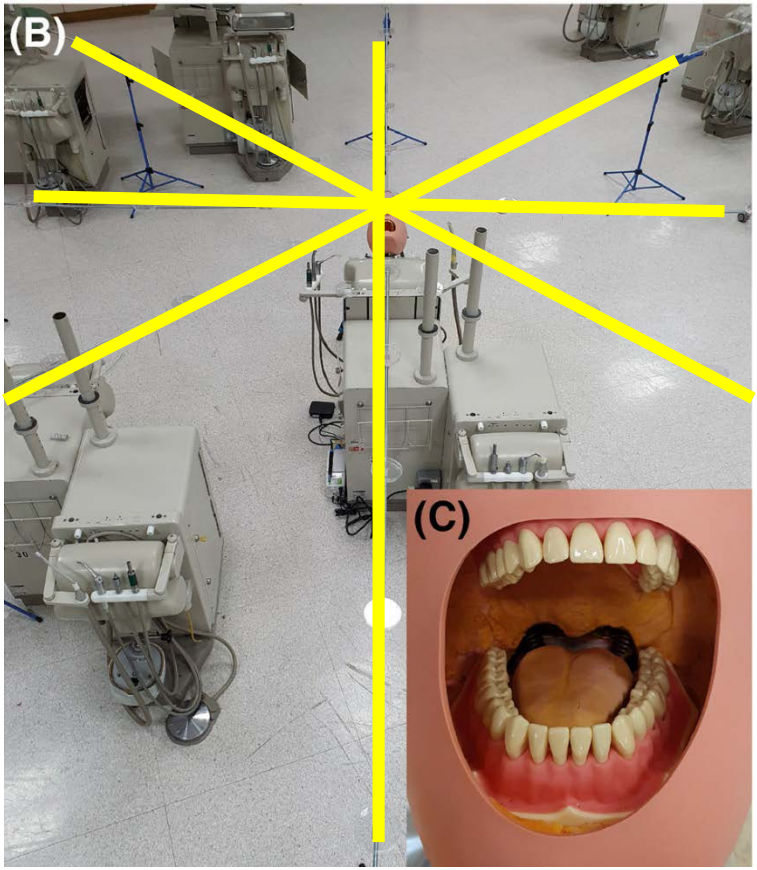
Many Activities Produce Aerosols



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

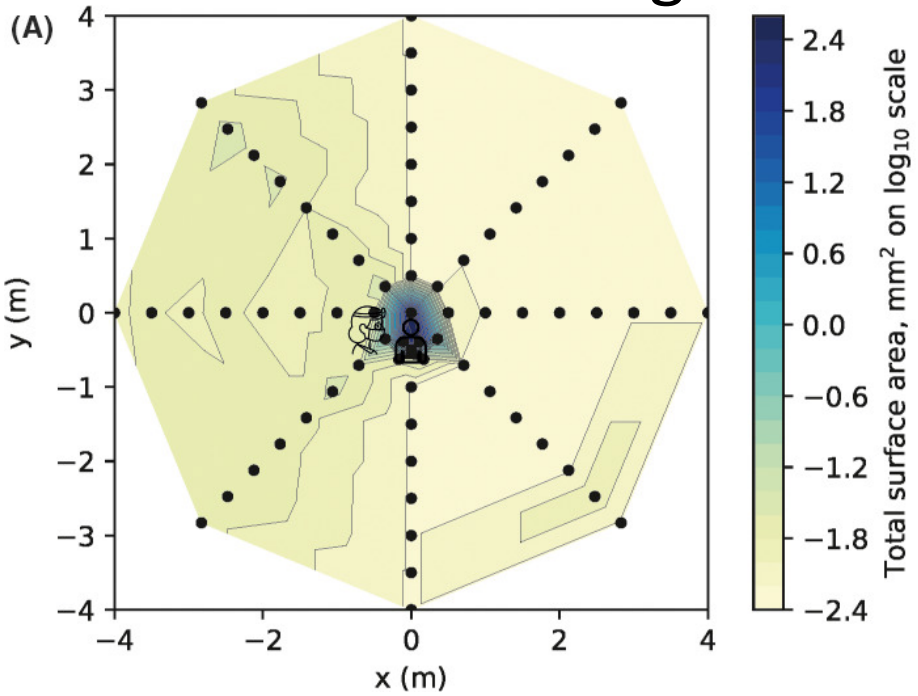


- ❑ Add fluorescein to irrigation reservoirs
- ❑ Detect fluorescence on filter paper
- ❑ This method is sensitive to large droplets that settle quickly, but is blind to aerosols
- ❑ Where there are droplets, there are usually aerosols

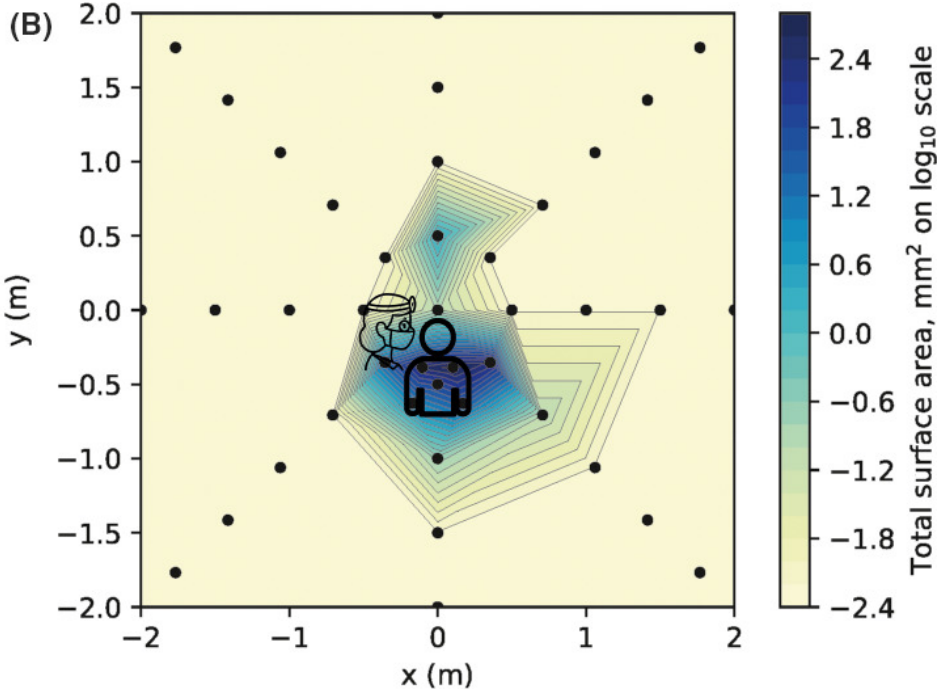
(1) Allison, J..R., Currie, C.C., Edwards, D.C., et al., 2020, Evaluating aerosol and splatter following dental procedures: Addressing new challenges for oral health care and rehabilitation, *J Oral Rehabilitation* (2) Veena, H.R., Mahantesha, S., Joseph, P.A., et al., 2015, Dissemination of aerosol and splatter during ultrasonic scaling: A pilot study, *J Infect Public Health*

Contaminated Area

Ultrasonic scaling



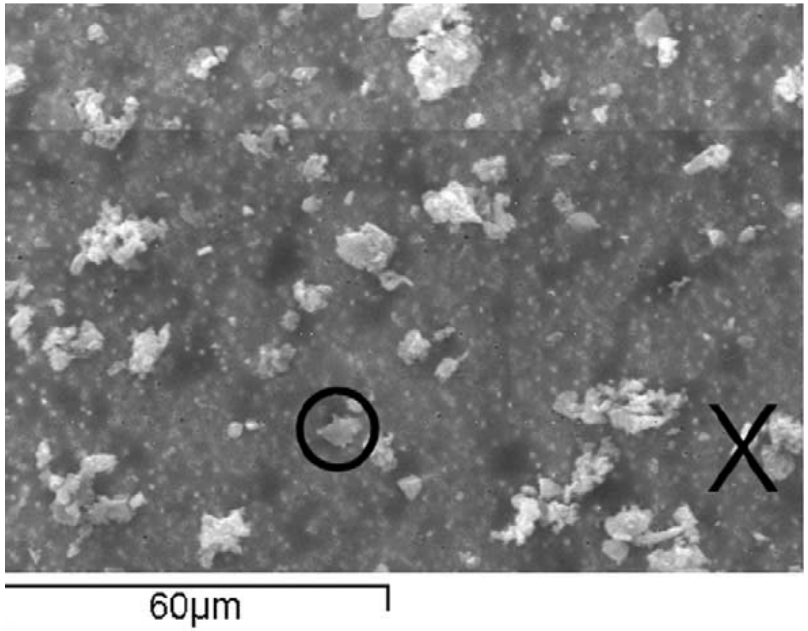
3-in-1 spray



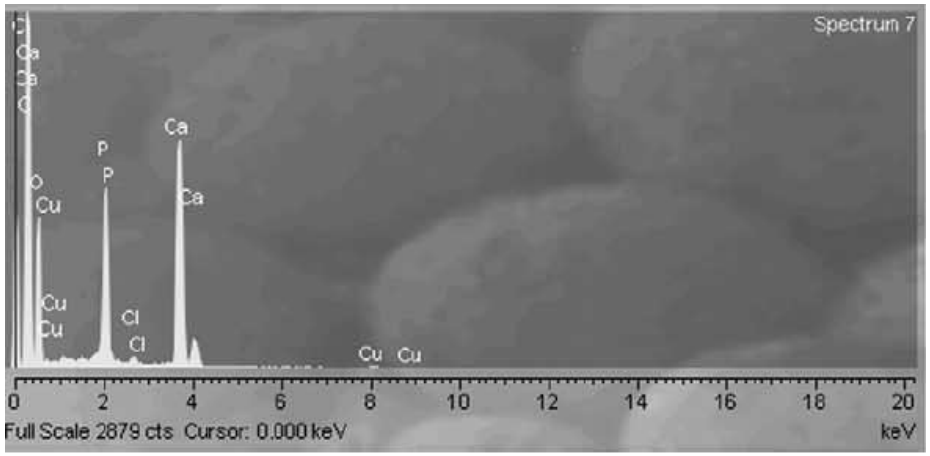
Suction reduced contamination by 67-75% at 0.5-1.5 m.

(1) Allison, J..R., Currie, C.C., Edwards, D.C., et al., 2020, Evaluating aerosol and splatter following dental procedures: Addressing new challenges for oral health care and rehabilitation, *J Oral Rehabilitation*

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

(1Ireland, A.J., Moreno, T., Price, R., 2003, Airborne particles produced during enamel cleanup after removal of orthodontic appliances, *Am J Orthodontics Dentofacial Orthopedics*

Opportunities

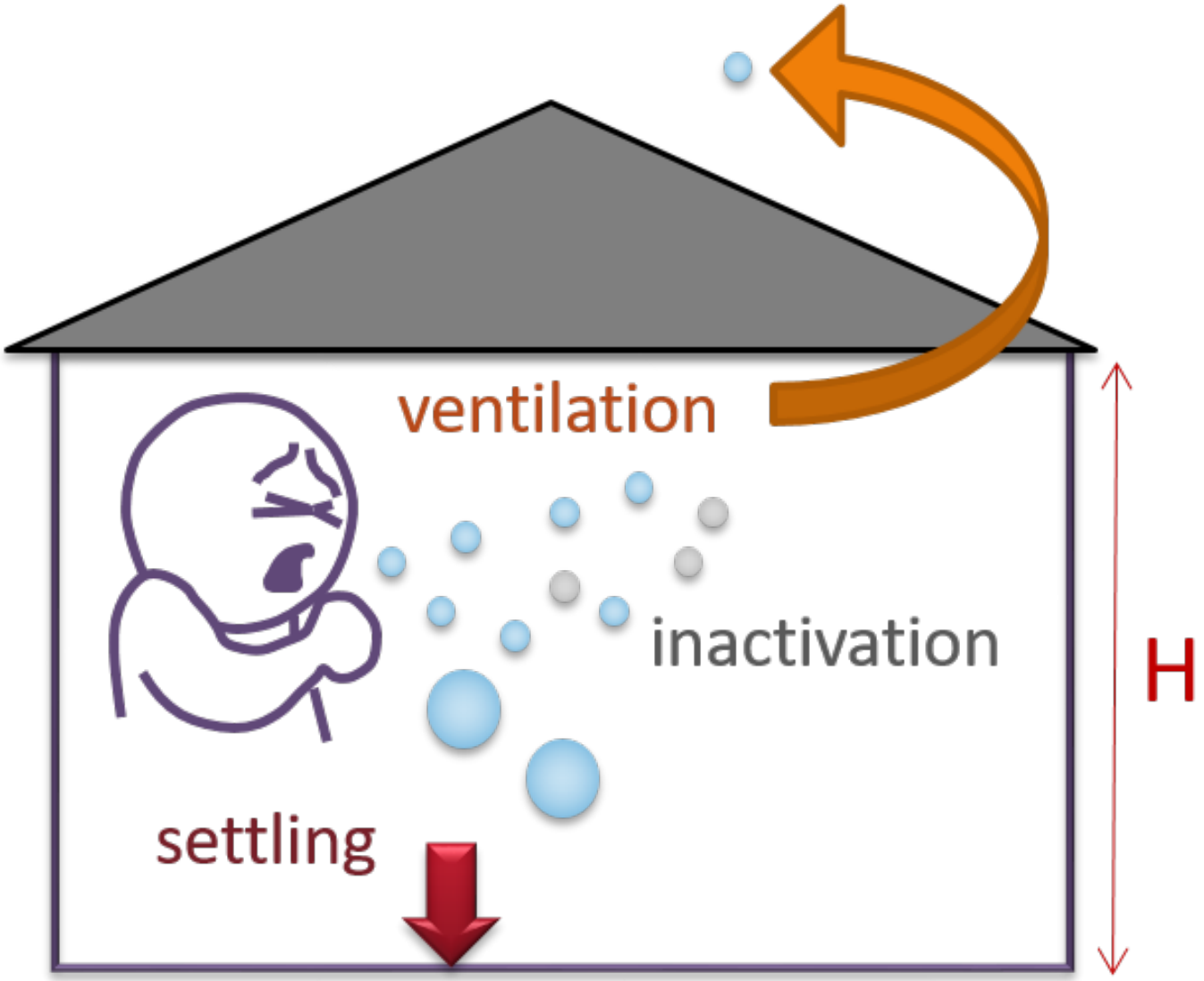
- Majority of studies looked at settled particles $\Rightarrow$ bias toward larger ones
- Modernize methods
  - Particle counters and sizers (optical particle counter, aerodynamic particle sizer)
  - Sensitive genomic techniques (qPCR, high-throughput sequencing)
  - Characterization of morphology and chemistry of particles
- Need to account for background aerosols

https://czo-archive.criticalzone.org/national/blogs/post/who-does-critical-zone-science/

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

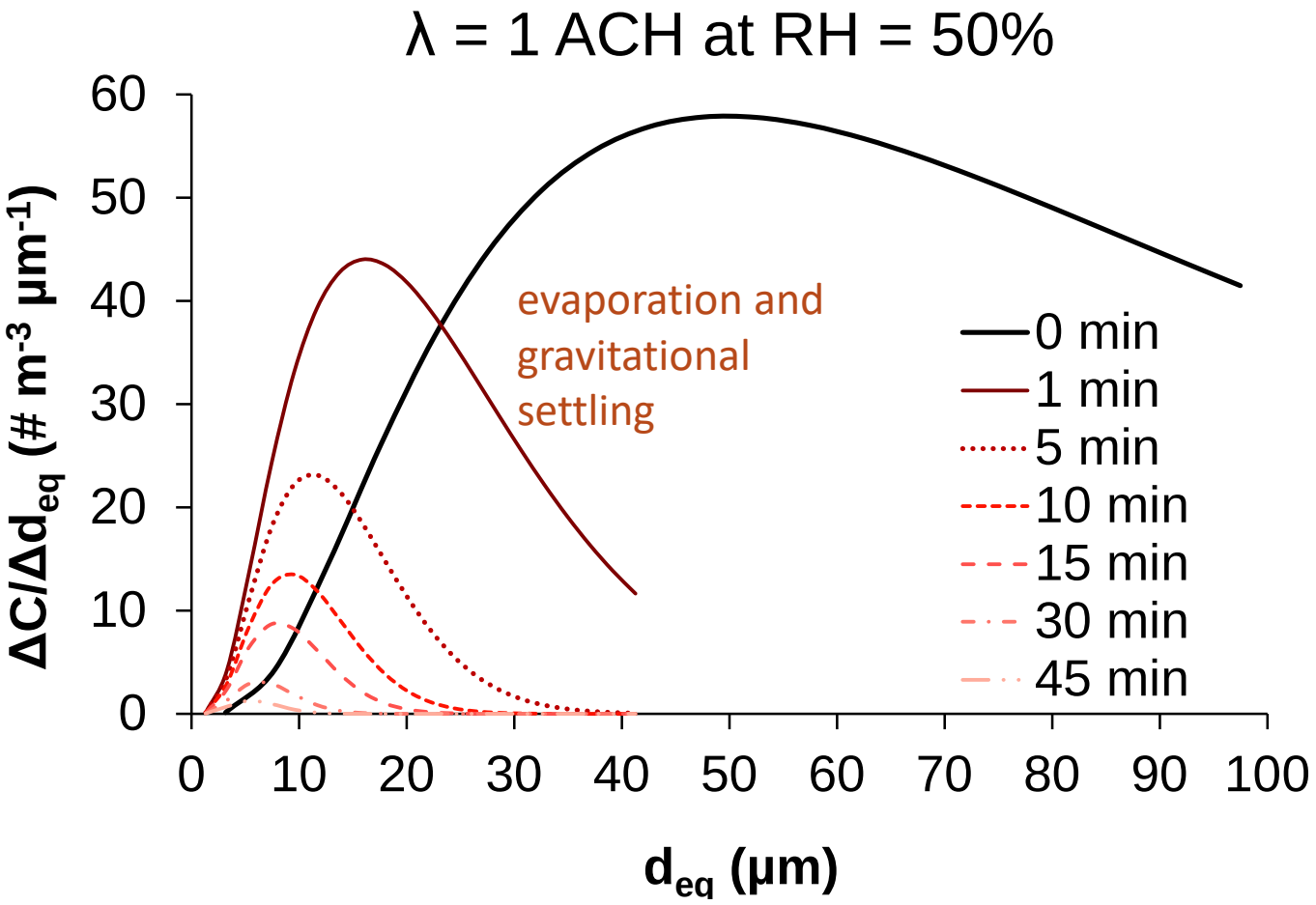
What happens to them in the air?

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

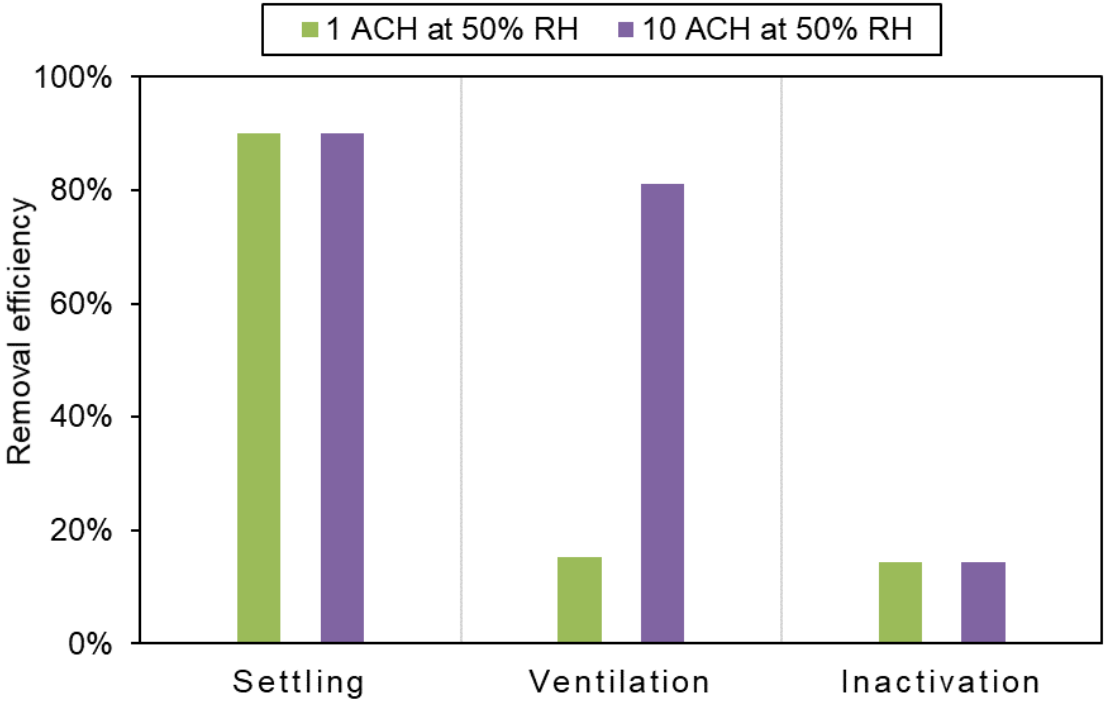


There is a size shift due to loss of larger droplets by gravitational settling.

(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 (2) Kormuth, K.A., Lin, K., Prussin II, A.J., et al., 2018, Influenza virus infectivity is retained in aerosols and droplets independent of relative humidity, *J Infect Dis* (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

https://www.dailykos.com/stories/2019/11/16/1899711/-The-Smoke-Filled-Room-Unsolicited-Advice-as-Who-Should-Be-Vice

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

Which interventions are effective?

Fogging (Chemical Disinfection)

Disinfectants
Hydrogen peroxide (H_2O_2)
Hypochlorous acid (HOCl)

H_2O_2 + virus → dead virus

H_2O_2 + you → airway irritation

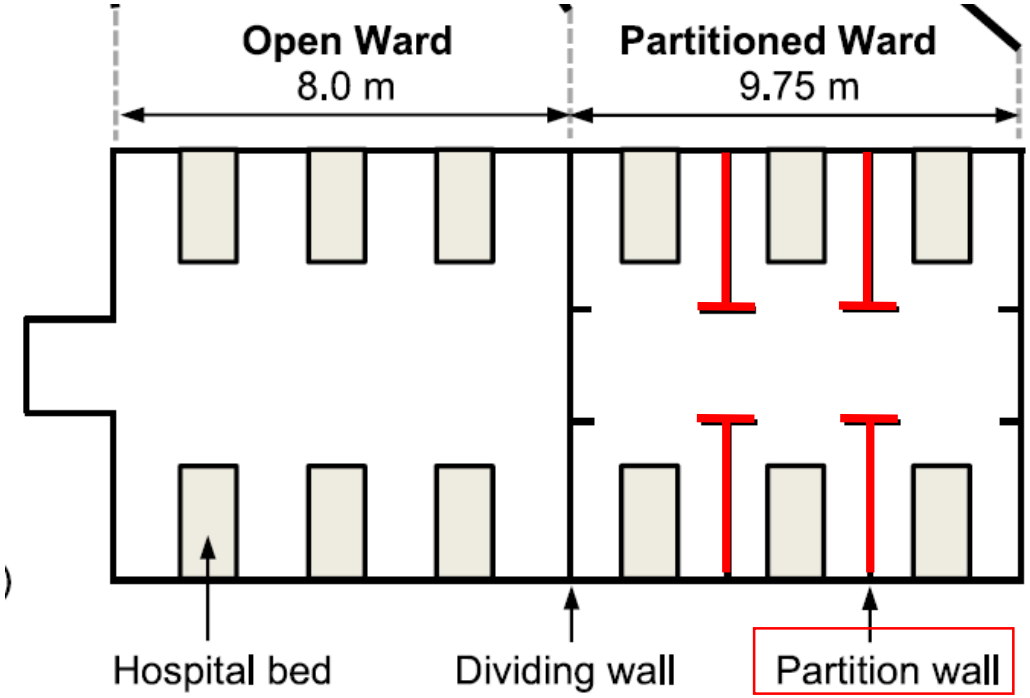
H_2O_2 + other chemicals → byproducts

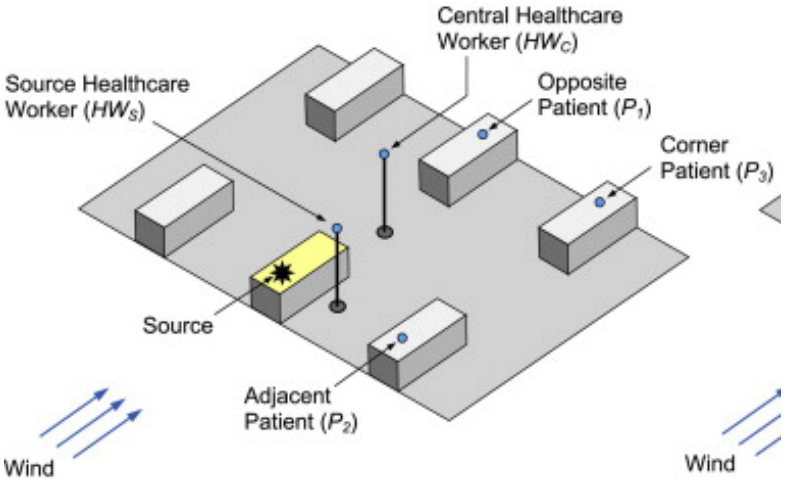
- More effective to wipe surfaces instead of fog
- Should ventilate after fogging, and ventilation will remove virus from the air anyway

Fogging is not recommended by CDC or EPA.

https://www.cdc.gov/infectioncontrol/guidelines/disinfection/updates.html; https://www.epa.gov/coronavirus/can-i-use-fogging-fumigation-or-electrostatic-spraying-or-drones-help-control-covid-19; https://www.westhawaiitoday.com/2020/04/19/hawaii-news/fogging-out-the-virus-county-deploying-disinfectant-equipment-to-health-care-facilities/

Barriers and Partitions





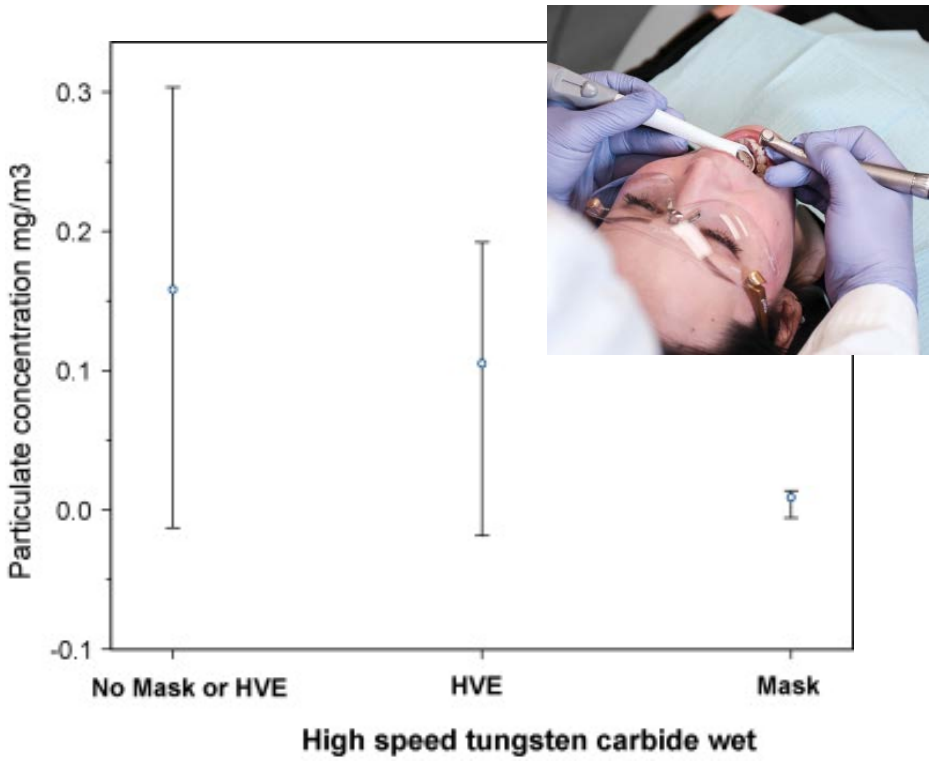
Partitions in hospital ward lead to increased airborne infection risk in some locations and decreased risk in others.

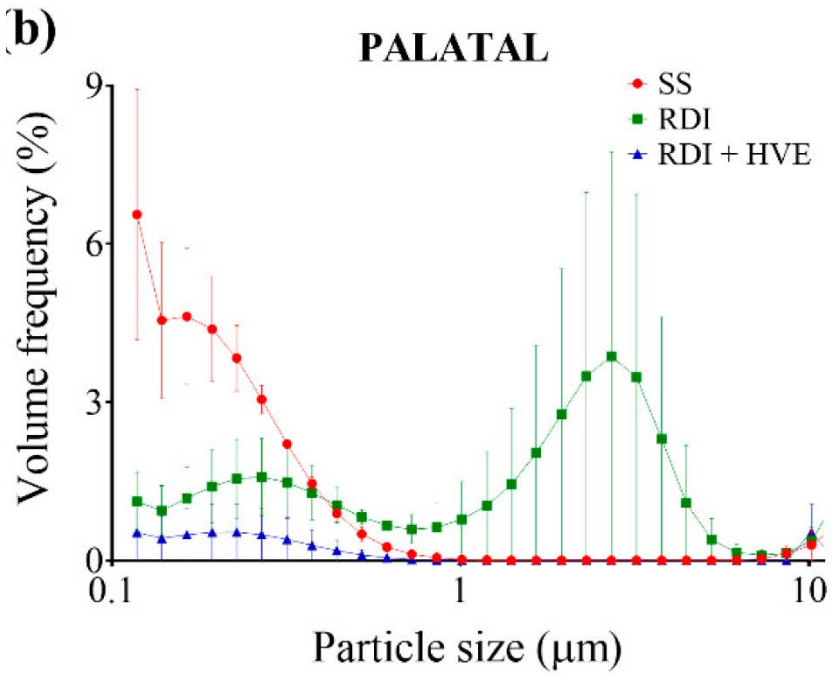
(1) Gilkeson, C.A., Cmargo-Valero, M.A., Pickin, L.E., et al., 2013, Measurement of ventilation and airborne infection risk in large naturally ventilated hospital wards, *Building and Environment*

Suction at the Source

(1) Froum, S.H., Froum, S.J., 2020, Incidence of COVID-19 Virus Transmission in Three Dental Offices: A 6-Month Retrospective Study, *Int J Periodontics Restorative Dent*

High-Volume Evacuator





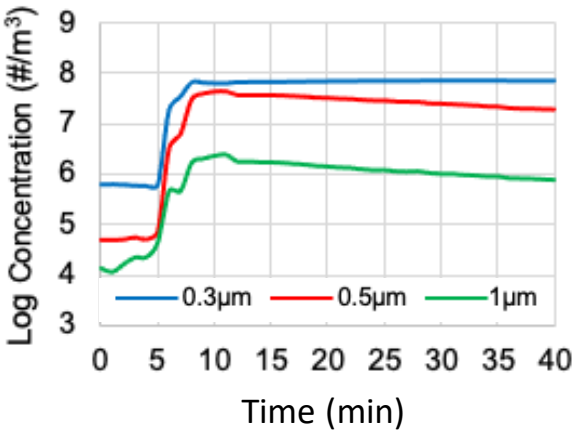
HVE reduced particles by 25-44%, while a surgical mask reduced them by up to 96%.

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

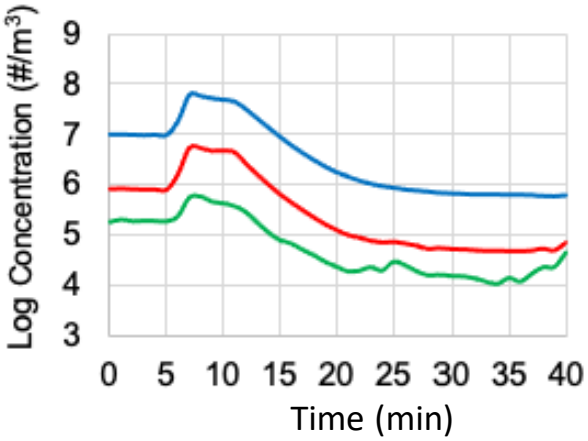
(1) Johnston, N.J., Price, R., Day, C.J., et al., 2009, Quantitative and qualitative analysis of particulate production during simulated clinical orthodontic debonds, *Dental Materials* (2) Balanta-Melo, J., Gutierrez, A., Sinisterra, G., 2020, Rubber Dam Isolation and High-Volume Suction Reduce Ultrafine Dental Aerosol Particles: An Experiment in a Simulated Patient, *Appl Sci*

Ventilation, Filtration, UV

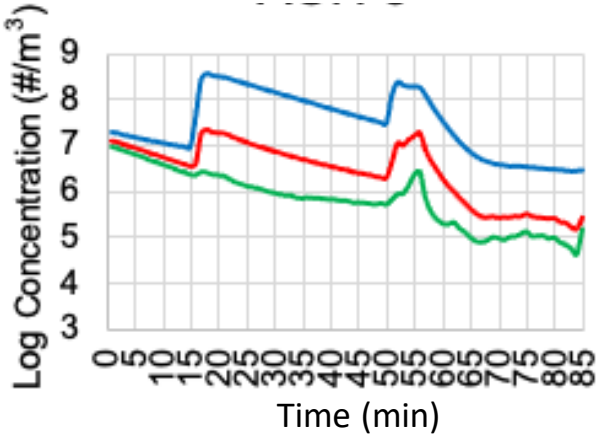
No ventilation



HEPA portable air cleaner



Mechanical ventilation 3 ACH + HEPA



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

(1) Ren, Y., Huang, Q., Marzouk, T., et al., 2020, Effects of mechanical ventilation and portable air cleaner on aerosol removal from dental treatment rooms, *J Dentistry*; https://shellym80304.com/projects/improving-air-handling-unit-performance-and-indoor-air-quality-using-ultraviolet-germicidal-irradiation-2/

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

(1) Allen, J.G., Marr, L.C., 2020, Recognizing and controlling airborne transmission of SARS-CoV-2 in indoor environments, *Indoor Air* (2) Fennelly, K.P., 2020, Particle sizes of infectious aerosols: implications for infection control, *Lancet Resp Med* (3) Morawska, L., Milton, D.K., 2020, It is time to address airborne transmission of COVID-19, *Clin Infect Dis* (4) Prather, K.A., Wang, C.C., Schooley, R.T., 2020, Reducing transmission of SARS-CoV-2, *Science* (5) Wilson, N., Corbett, S., Tovey, E., 2020, Airborne transmission of covid-19, *BMJ*