Covid Transmission and Infection Control

Update in Hospital Medicine

October 4, 2021

Michael Klompas MD, MPH, FIDSA, FSHEA
Hospital Epidemiologist, Brigham and Women's Hospital, Boston, MA
Professor, Harvard Medical School & Harvard Pilgrim Health Care Institute

Michael Klompas MD, MPH

Hospital Epidemiologist, Brigham and Women's Hospital
Professor of Population Medicine, Harvard Medical School

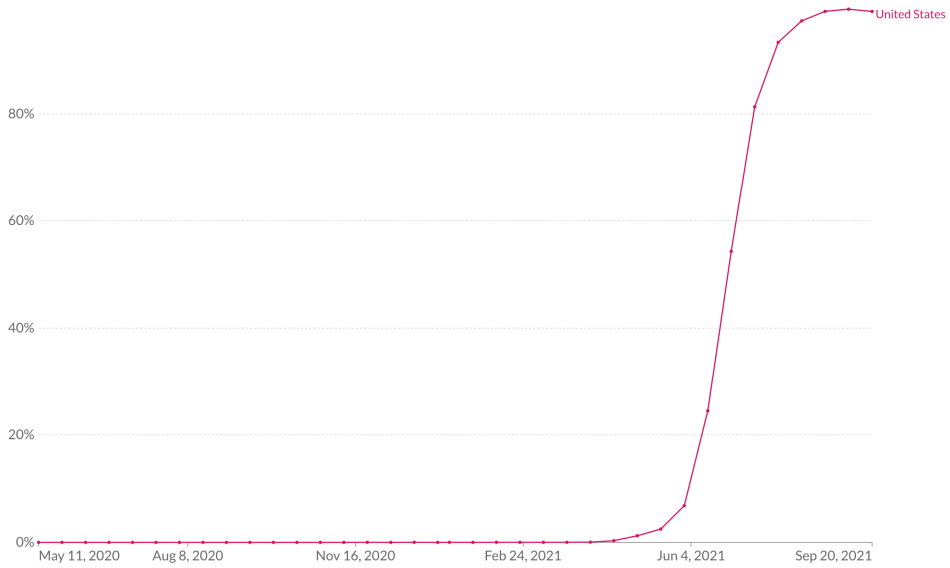
Disclosures

- **Grant funding**
  - Centers for Disease Control and Prevention
  - Massachusetts Department of Public Health
  - Agency for Healthcare Research and Quality
- **Royalties**
  - UpToDate Inc.

Covid in the World

Ourworldindata.org

Rise of Delta in the USA



99% of sequenced isolates

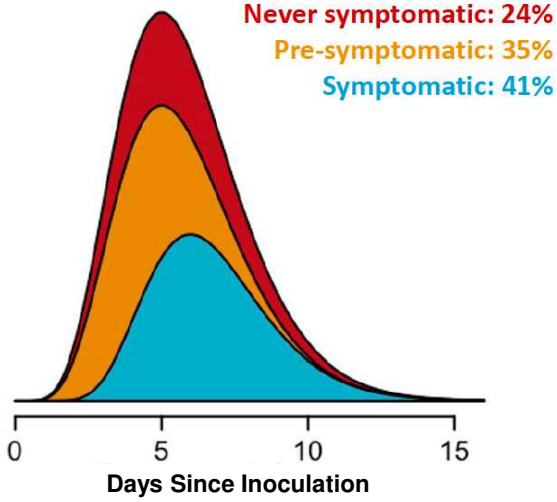
Delta: The Most Contagious Variant to Date

Average number of people infected by each case (unvaccinated population)

BBC, Imperial College London

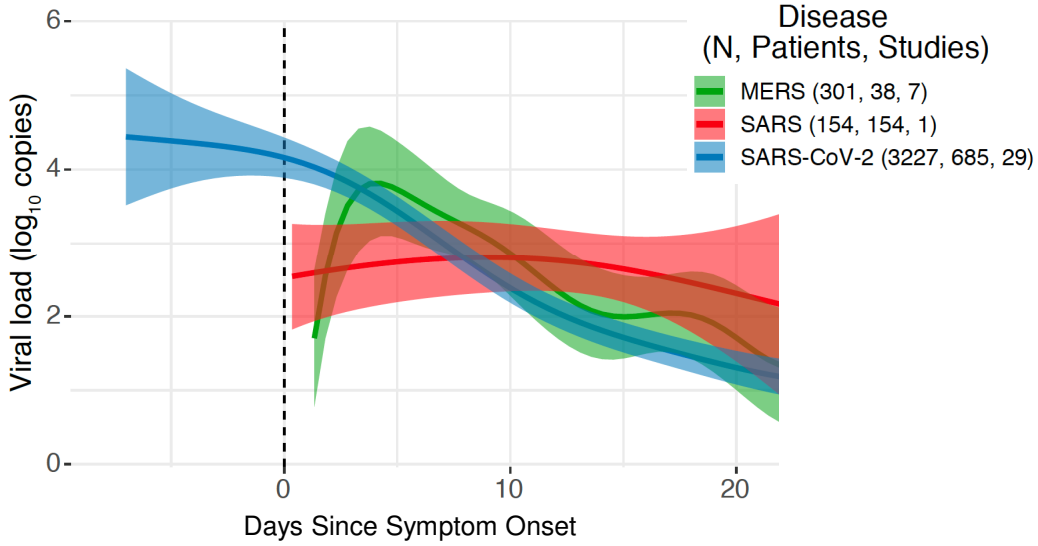
Most Infections Are Spread by People without Symptoms

percent of all infections by symptom status of the source individual



Johansson, JAMA Network Open 2021;4(1):e2035057

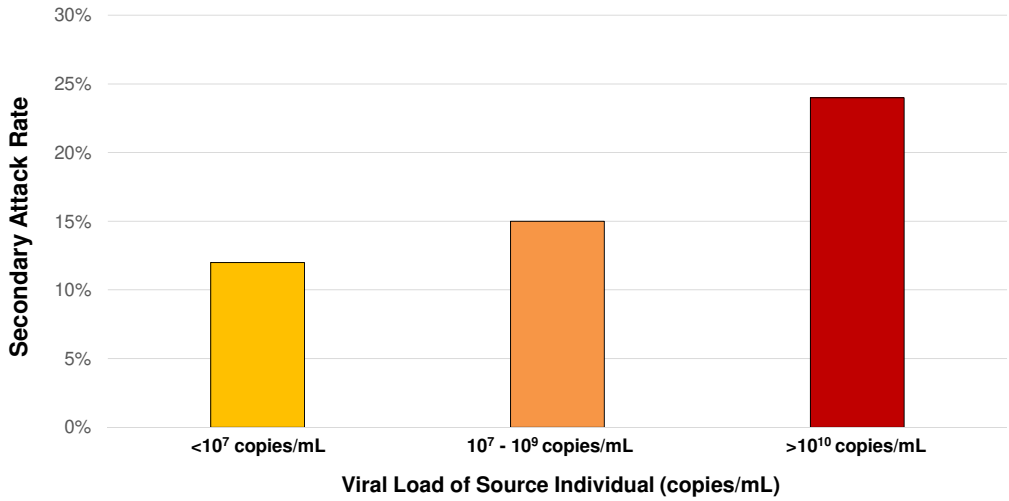
Viral Load Relative to Symptom Onset



Benefield 2020, medRxiv doi 10.1101/2020.09.28.20202028

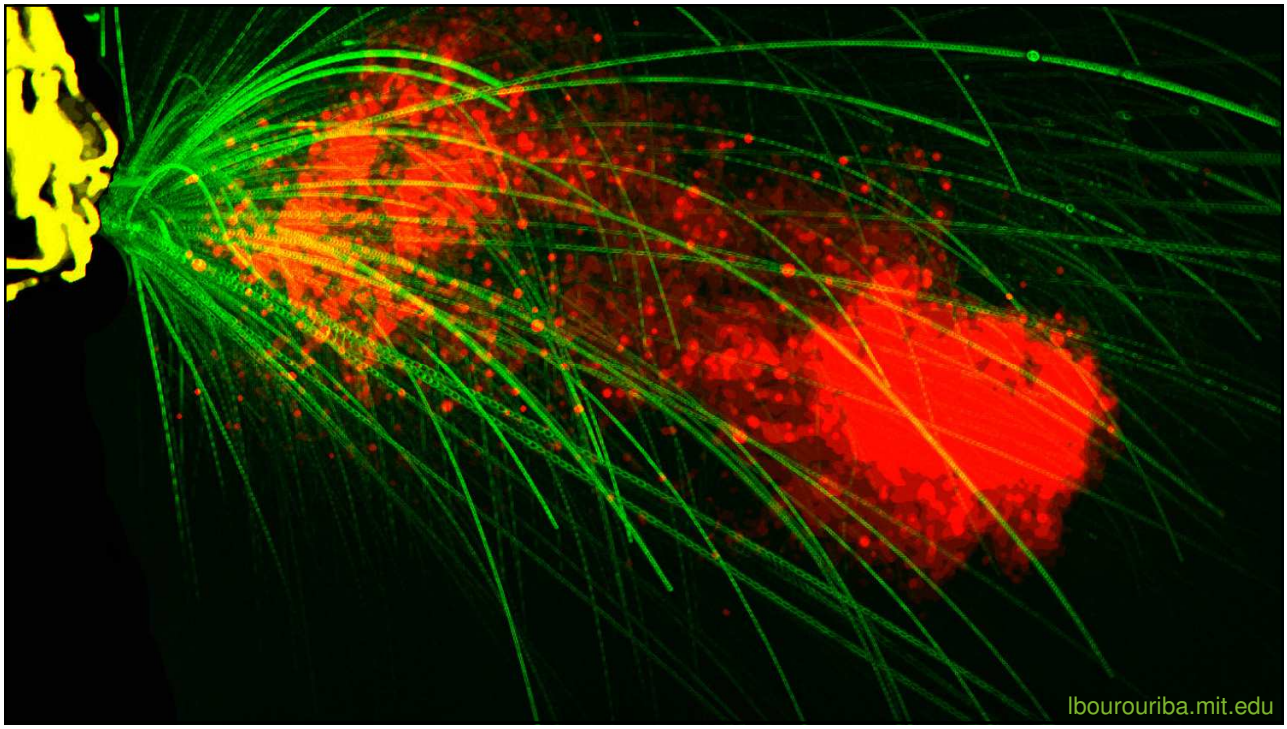
Viral Load Determines Infectiousness

Secondary infection rates amongst 753 contacts of 314 adults with mild Covid-19

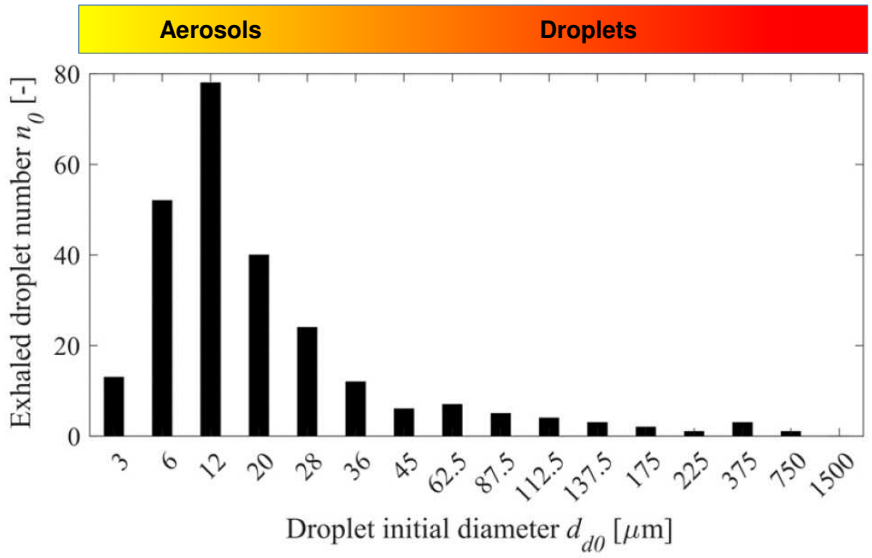


Marks, *Lancet Infect Dis* 2021; doi.org/10.1016/ S1473-3099(20)30985-3

Is Covid spread by droplets or aerosols?

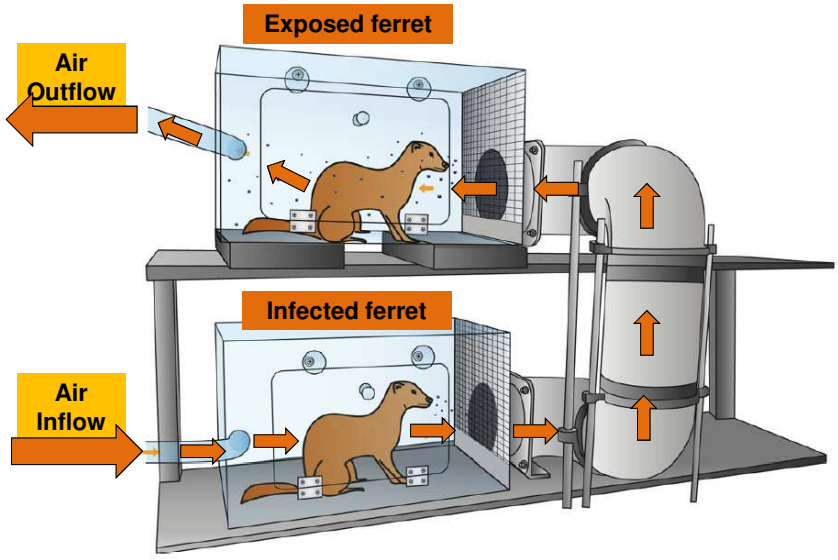


People Produce Respiratory Particles in a Range of Sizes



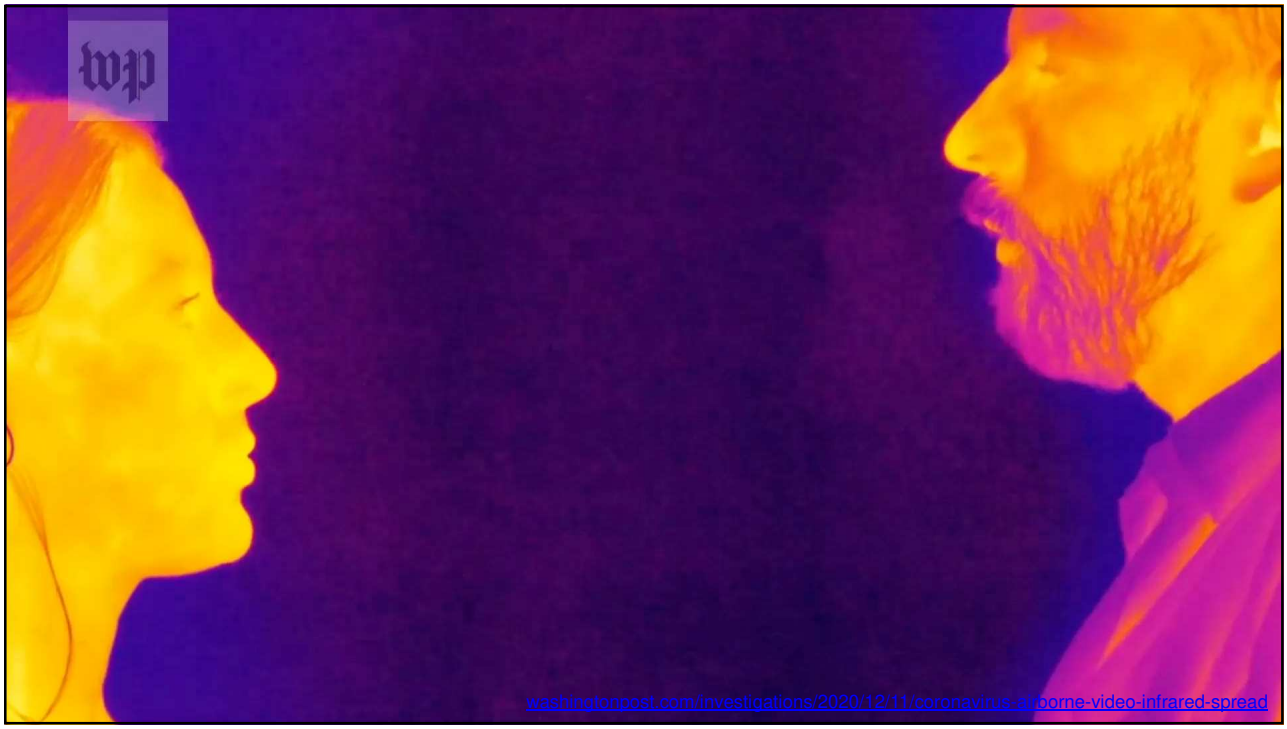
Chen, *Building and Environment* 2020:176:106859

Transmission via Aerosols

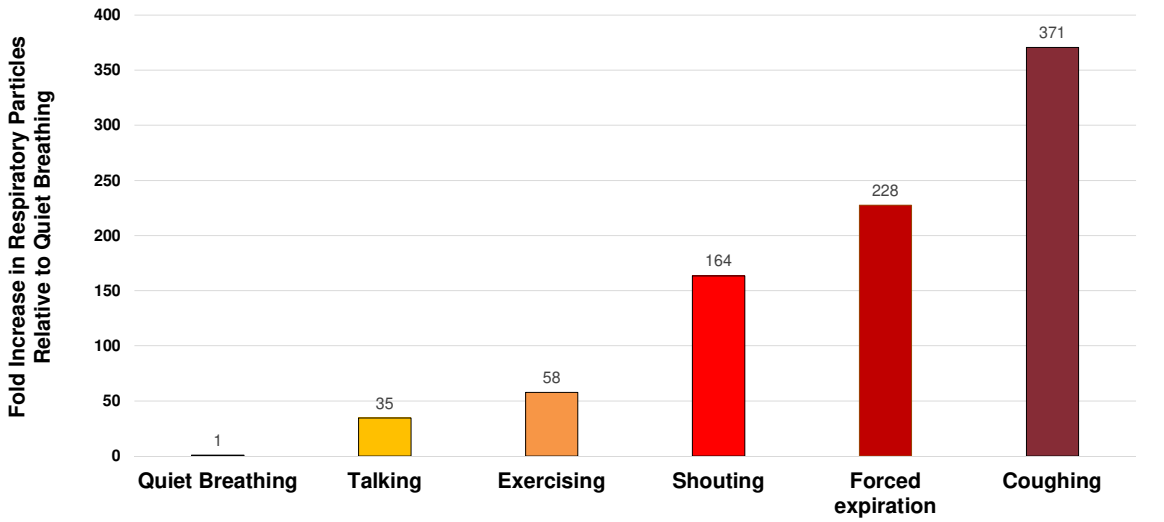


- Ferret model used to assess treatment via aerosols
- 4 uninfected ferrets exposed to infected ferret
- Airflow between cages via closed pipe, 1.1m long, 4 right-angle turns
- 2/4 exposed ferrets were infected

Kutter, *Nature Communications* 2021;12:1653



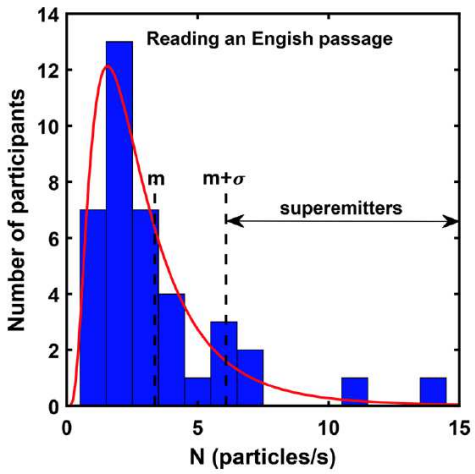
Variation in Respiratory Emissions by Activity



Wilson 2021, medRxiv, doi: 10.1101/2021.02.07.21251309

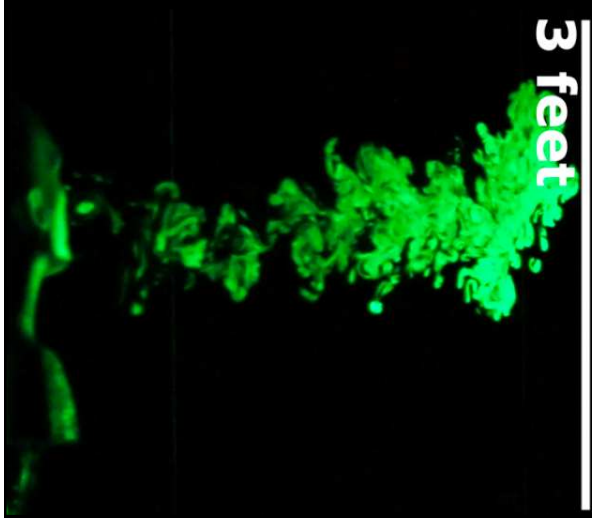
Variation in Respiratory Emissions by Person

Some people emit much more than others

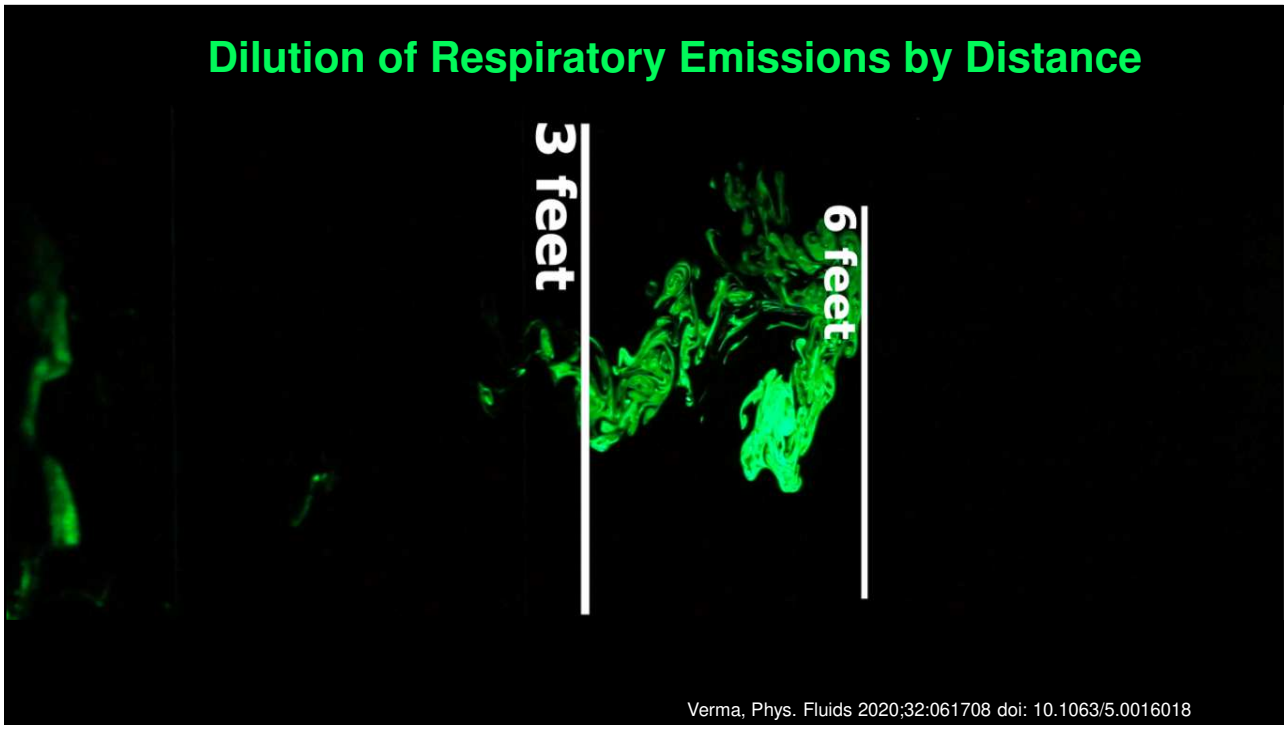


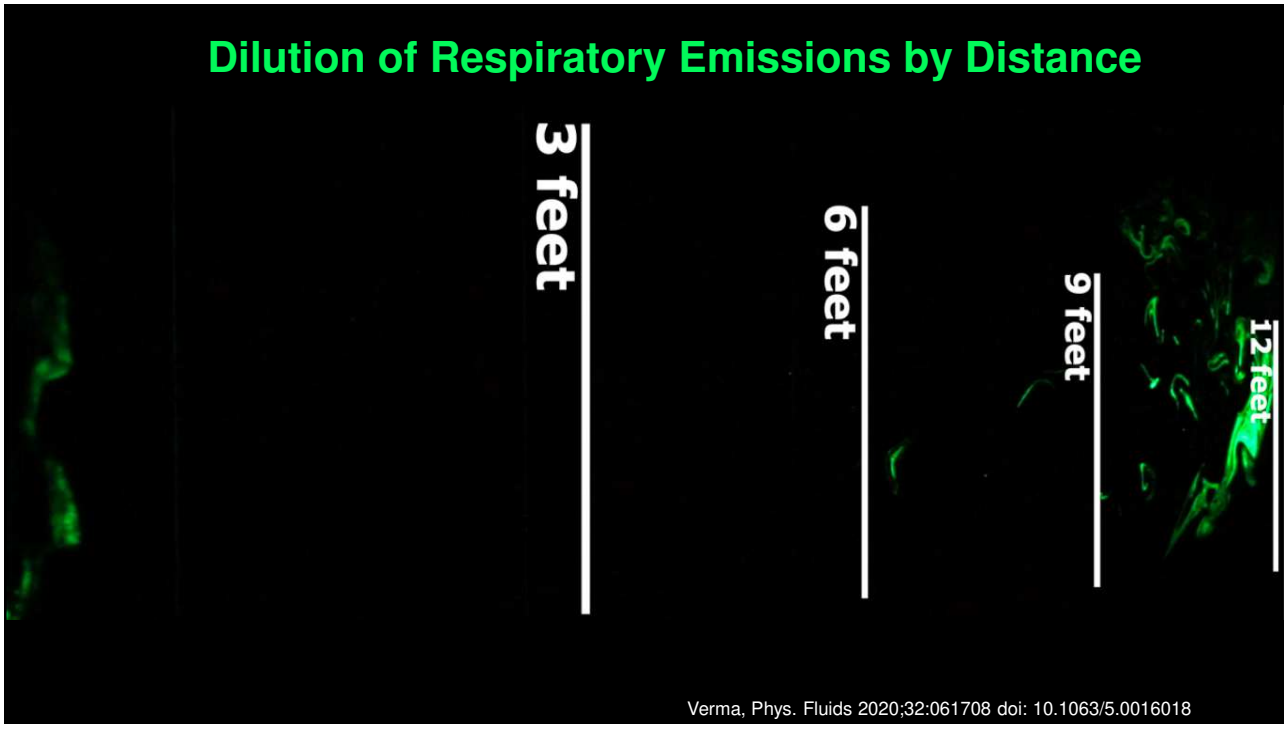
Asadi, *Scientific Reports* 2019;9:2348

Dilution of Respiratory Emissions by Distance



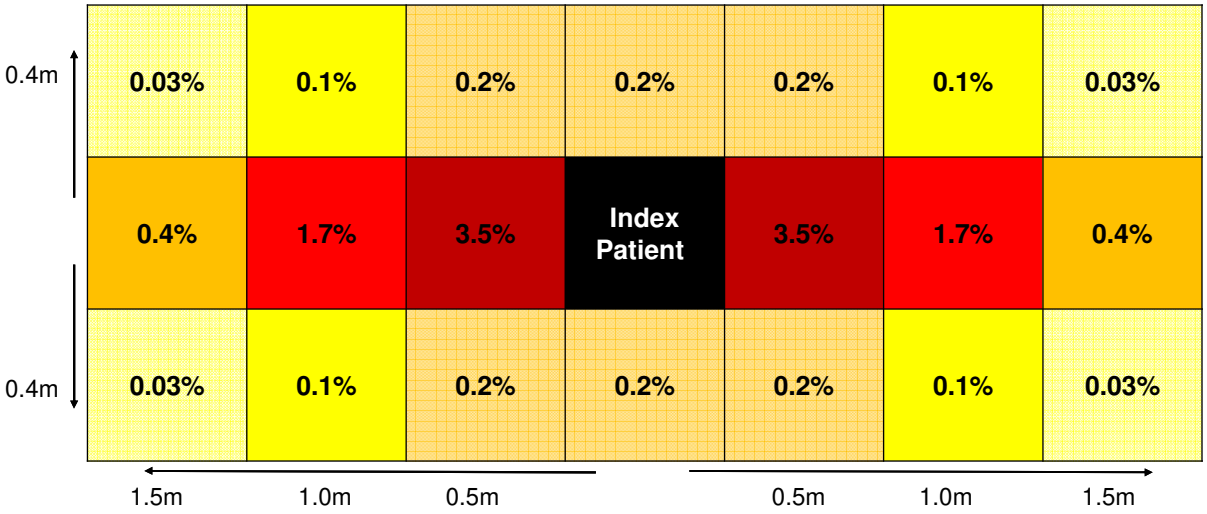
Verma, Phys. Fluids 2020;32:061708 doi: 10.1063/5.0016018


Dilution of Respiratory Emissions by Distance
3 feet
6 feet
Verma, Phys. Fluids 2020;32:061708 doi: 10.1063/5.0016018


Dilution of Respiratory Emissions by Distance
3 feet
6 feet
9 feet
12 feet
Verma, Phys. Fluids 2020;32:061708 doi: 10.1063/5.0016018

Transmission Risk Decreases with Distance

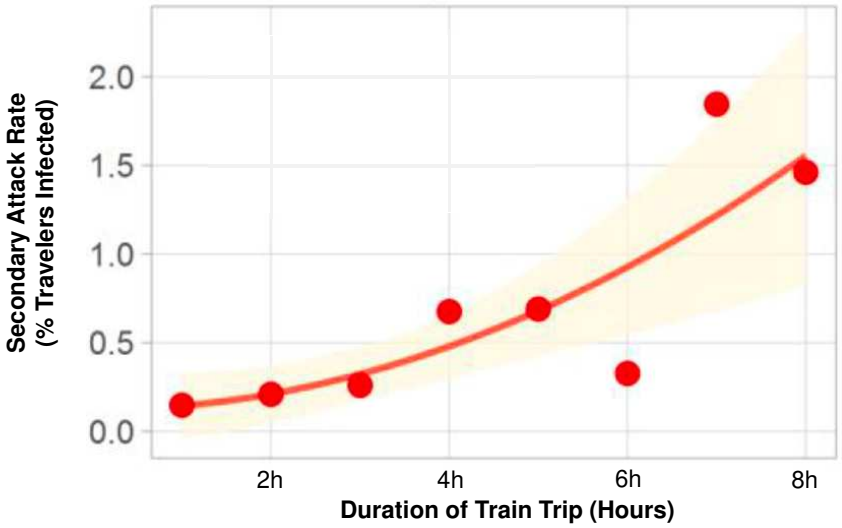
Spatial analysis of 2,334 Covid patients and 72,093 close contacts who rode high-speed trains in China



Hu, *Clin Infect Dis* 2021;72(4):604-610

Transmission Risk Increases with Time

Temporal analysis of 2,334 Covid patients and 72,093 close contacts who rode high-speed trains in China



Hu, *Clin Infect Dis* 2021;72(4):604-610

Skagit Valley Choir Outbreak

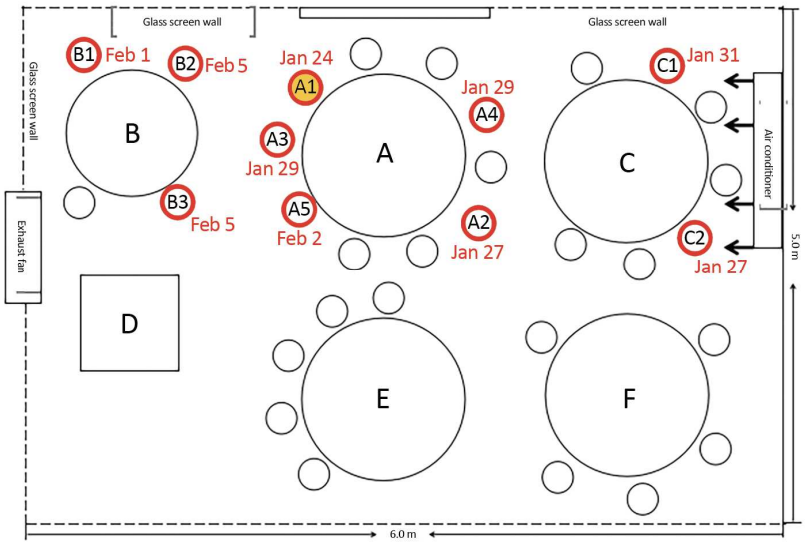
Skagit Valley CHORALE

- **61 members of the choir attended practice together (March 10, 2020)**
  - 53 developed Covid-19 (87% attack)
  - 3 hospitalized, 2 died

- **Investigation**
  - One member tested positive for SARS-CoV-2
  - 2.5 hour practice; no masking
  - Participants sat in chairs 6-10 inches apart
  - Cases spread broadly throughout the room, no clustering by seating location
  - Air change rate estimated to have been 0.7 changes per hour

Hamner, *MMWR* 2020;69:606-610
Miller, *Indoor Air.* 2021;31(2):314-323

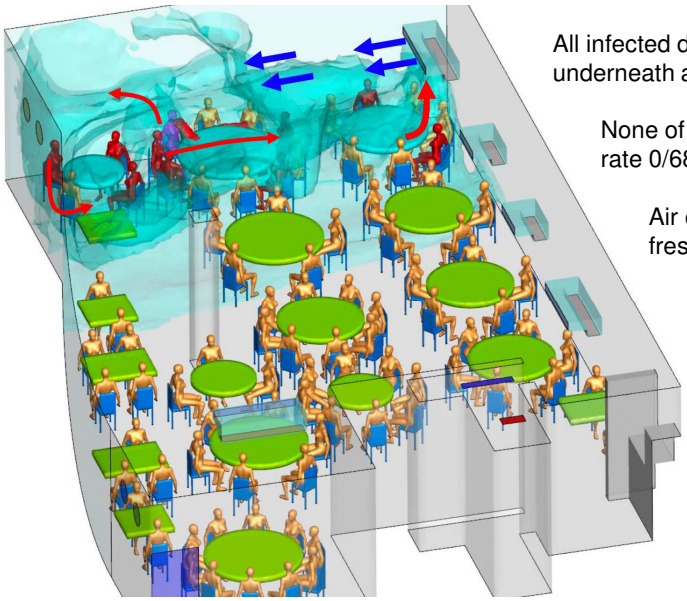
Restaurant Cluster Associated with Air Conditioning, Guangzhou, China



- **Well documented cluster in a restaurant in Guangzhou**
- **One pre-symptomatic diner infected 9 other diners (4 at own table, 5 at other tables)**
- **Some of the infected diners up to 4 meters (12 feet) away from the index case**
- **Air conditioner and lack of ventilation potentially contributory**

Lu, *Emerging Infectious Dis* 2020;26:1628-31

Air Flow Modeling



All infected diners were in one area of the restaurant underneath an air conditioner (attack rate 9/20, 45%)

None of the 68 diners in other areas were infected (attack rate 0/68). None of the 8 waiters infected.

Air conditioner was recirculating "old" air rather than fresh (exhaust vents were closed)

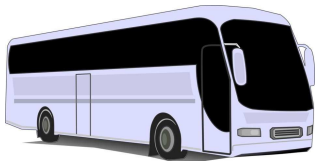
Tracer gas studies confirmed VERY poor ventilation in the affected area of the restaurant (0.7 air changes/hour; hospital standard is ≥6 air changes/hour)

Take home: poor ventilation facilitates longer range aerosol transmission

Li 2020, medRxiv preprint, doi: 10.1101/2020.04.16.20067728
and Li, *Build Environ.* 2021;196:107788

Cluster of Infections on Poorly Ventilated Bus

- Cluster of 31 infections amongst 300 people who attended an outdoor Buddhist ceremony and lunch in Eastern China. Traced to one pre-symptomatic attendee.
- Two groups traveled to the ceremony by bus. Others travelled via private transport
- 100 mins travel time. 150 mins ceremony time. Ceremony Outdoors.

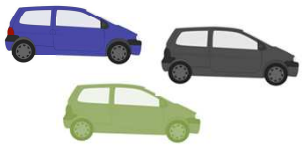


Bus #1 (indoor exposure)
- Pre-symptomatic patient onboard
- 24/68 people on bus infected

35% infected

Bus #2 (outdoor exposure)
- 0/60 infected despite attending the same ceremony as passengers on Bus #1

0% infected



Private transport
- 7/172 infected.
- All 7 had close contact with the index patient at ceremony

4% infected

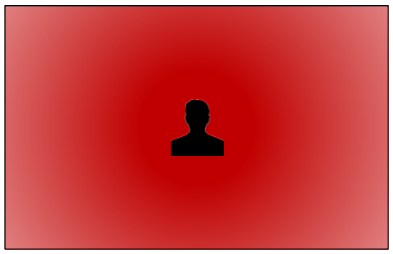
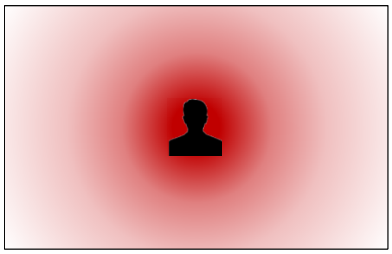
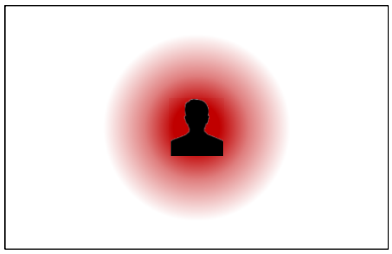
Shen, *JAMA Intern Med* 2020;180(12):1665-1671

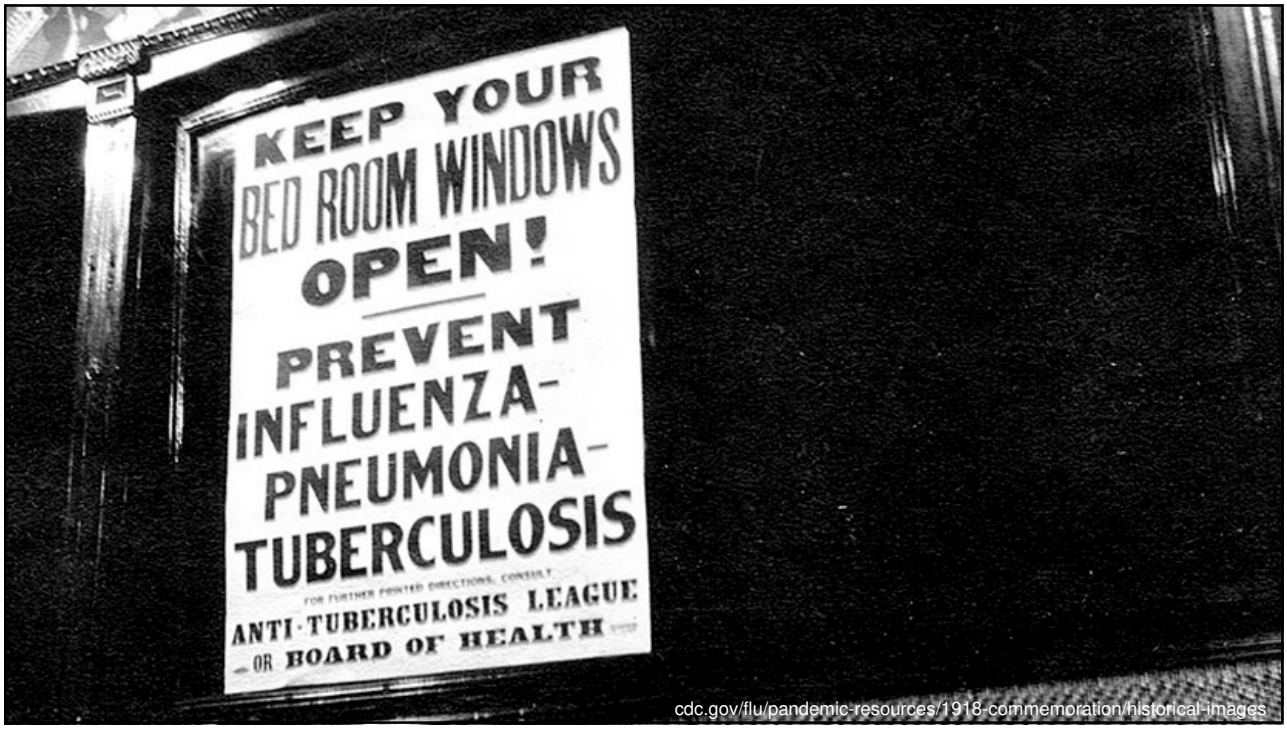
Transmission Risk in Shared Hospital Rooms

- Brigham & Women's Hospital, Sept 2020-April 2021
- 25 patients diagnosed with SARS-CoV-2 after admission to a shared room
- 31potentially exposed roommates
- Roommates ~7 feet apart and separated by a curtain
- ≥6 air changes per hour
- Median duration of exposure 18 hours (IQR 12-47 hours)
- 12/31 (39%) roommates tested positive

Karan, *Clinical Infectious Diseases* 2021; doi: 10.1093/cid/ciab564

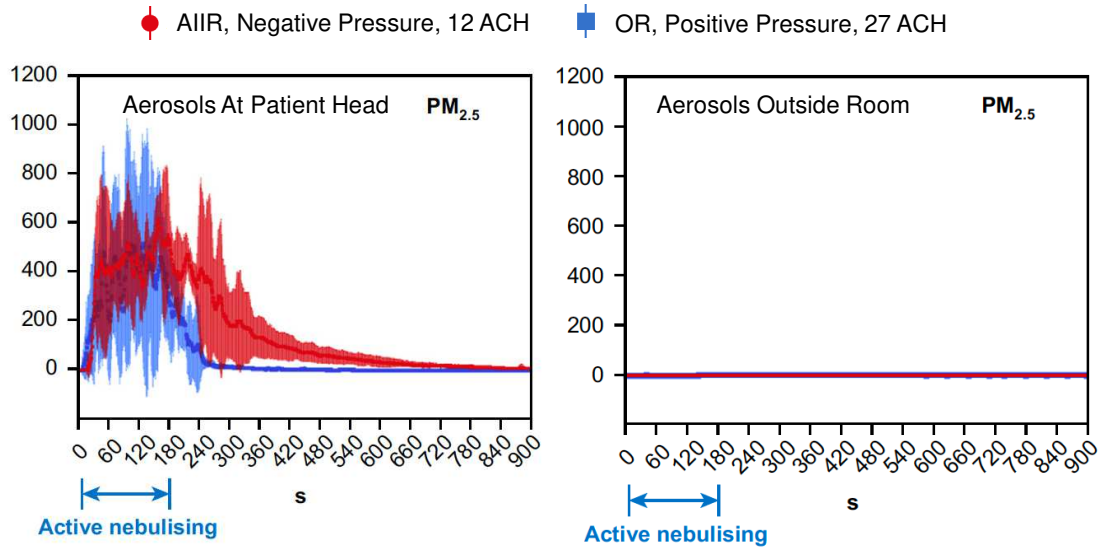
Impact of Ventilation on Viral Exposure

Poorly ventilated indoor area	Moderately ventilated indoor area	Well ventilated outdoor area
		
Dense viral cloud throughout the room	*Dense viral plume at source, gradual dilution with distance*	*Dense viral plume at source, rapidly dilutes with distance*



cdc.gov/flu/pandemic-resources/1918-commemoration/historical-images

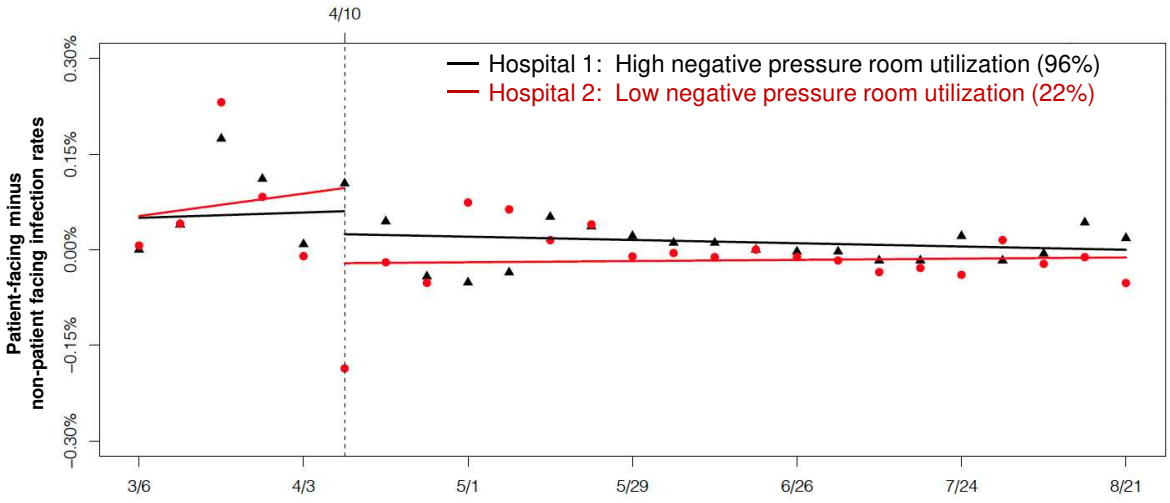
Aerosol Clearance in Operating Room (positive pressure, 27 air changes per hour) vs Airborne Infection Isolation Room (negative pressure, 12 air changes per hour)



Tsui, *Br J Anaesthesia* 2020; doi: 10.1016/j.bja.2020.09.011

Impact of High vs Low Negative Pressure Room Utilization on Healthcare Worker Infections

Excess infections in patient-facing vs non-patient-facing employees in a hospital with high negative pressure room utilization (96% of Covid patient-days) vs a hospital with low negative pressure room utilization (22% of Covid patient-days)



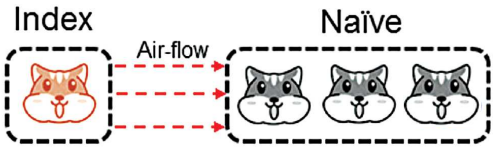
Klompas, *Clinical Infectious Diseases* 2021

So, what about masks?

Medical Masks are Good! … But Not Perfect

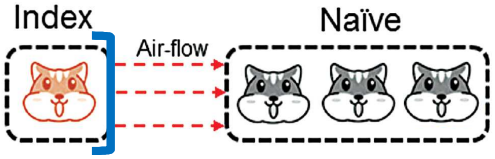
Transmission study using Golden Syrian Hamsters in adjacent cages with and without tightly fixed surgical masks between cages

No Mask



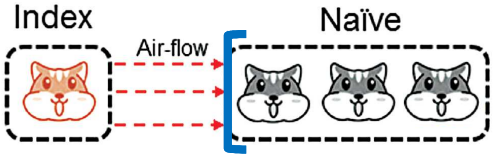
67%
(10/15) Infected

Mask on Source



17%
(2/12) Infected

Mask on Exposed

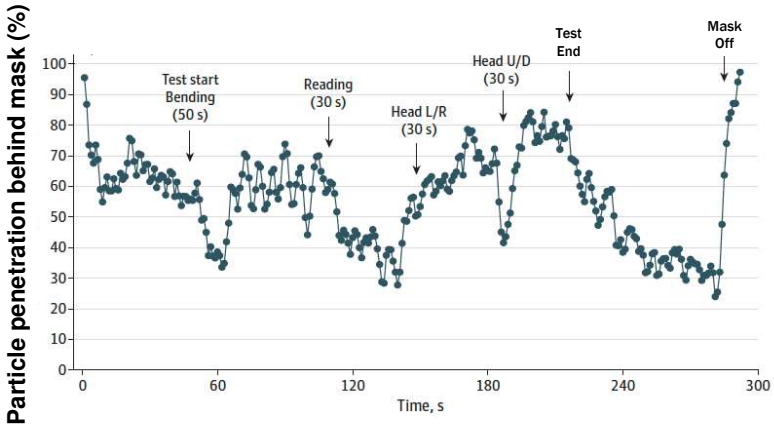


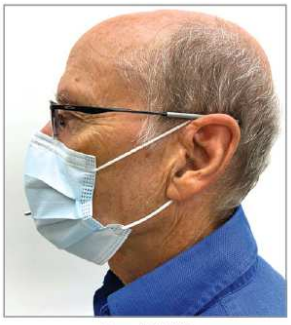
33%
(4/12) Infected

Chan, Clin Infect Dis 2020;71:2139-2149

Mask Filtration Efficiency in Practice

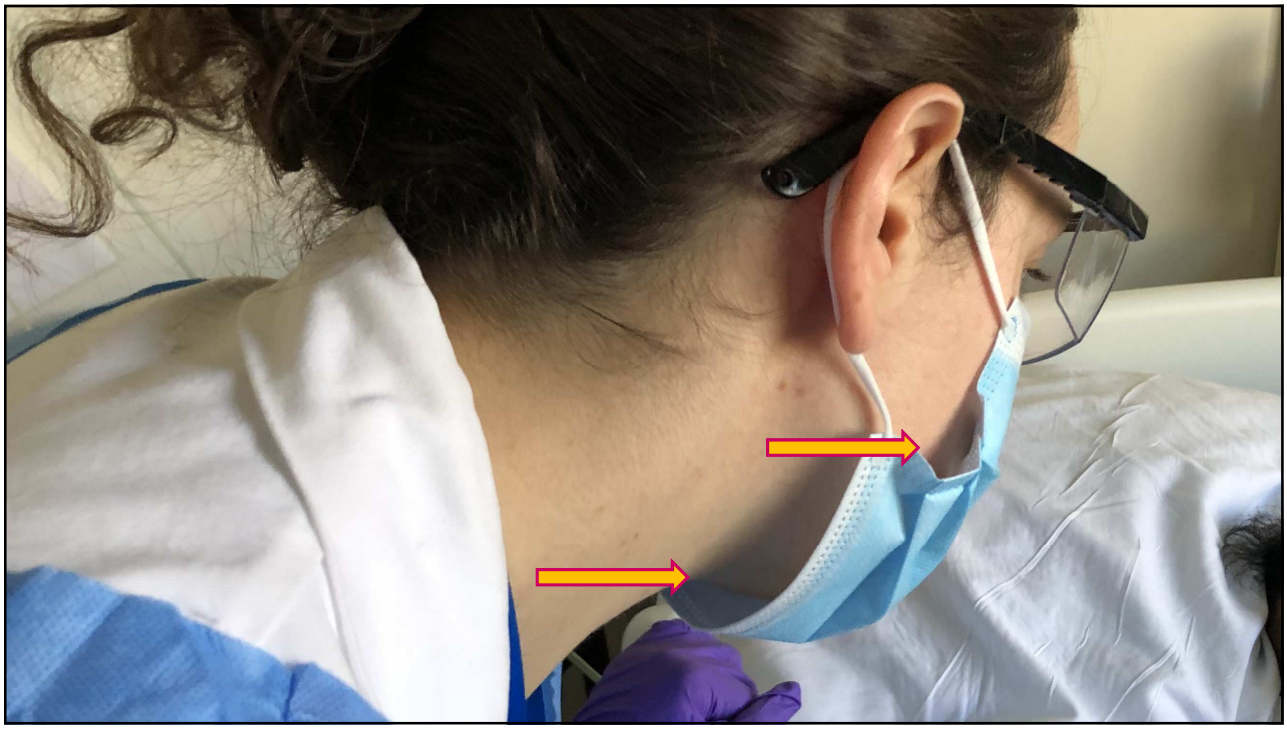
Medical Masks' Overall Efficiency: 38%



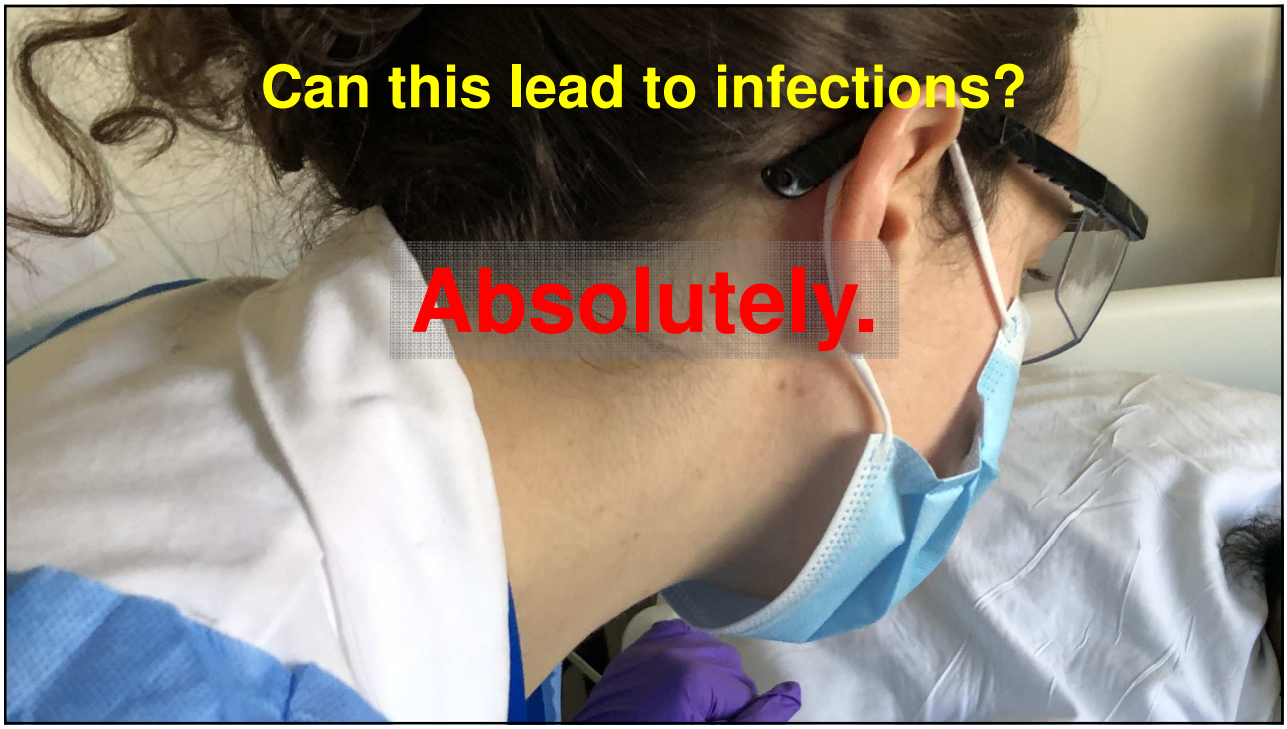


Overall % FFE
Mean (SD) over all tests,
38.5% (11.2%)

Clapp, *JAMA Intern Med* 2020; doi: 10.1001/jamainternmed.2020.8168




wp
washingtonpost.com/investigations/2020/12/11/coronavirus-airborne-video-infrared-spread



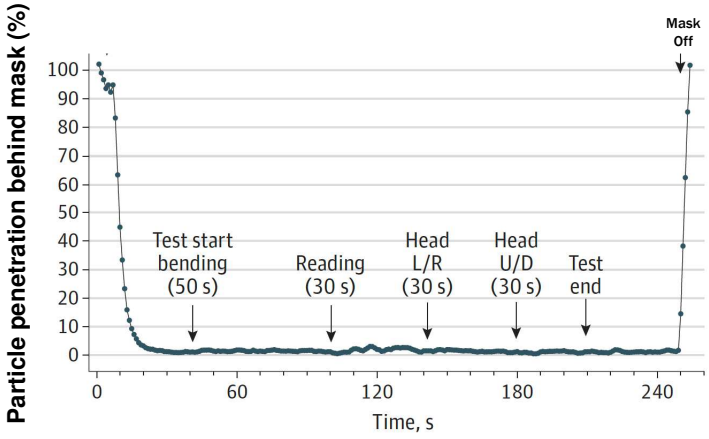
Transmission To and From HCWs Despite Masks

- We have documented multiple instances of transmission to healthcare workers despite masks & eye protection
- All transmissions confirmed by whole genome sequencing (0 SNP differences)
  - Patient to CT tech (10 min interaction)
  - Patient to video swallow technician (45 mins)
  - Asymptomatic inpatient to two patient care assistants (4-8 hours)
  - Presymptomatic nurse to patient (2 shifts)
  - Presymptomatic outpatient to physician (45 mins, both parties masked)

Klompas, *Ann Intern Med* 2021; doi.org/10.7326/M20-7567
Klompas, *Clin Infect Dis* 2021; doi.org/10.1093/cid/ciab218

We Have the Solution!

N95 Respirators' Overall Efficiency: 98%



3M 1860 N95 Respirator

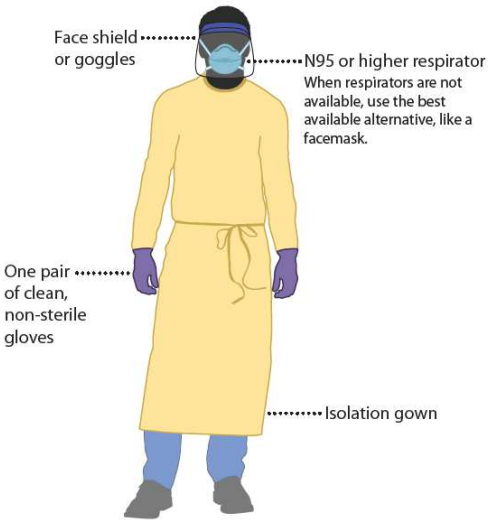
% FFE
(mean [SD] over all tests):
98.5% (0.4%)

Sickbert-Bennett, *JAMA Intern Med* 2020; doi: 10.1001/jamainternmed.2020.4221.

PPE for Patients with Suspected or Confirmed Covid-19

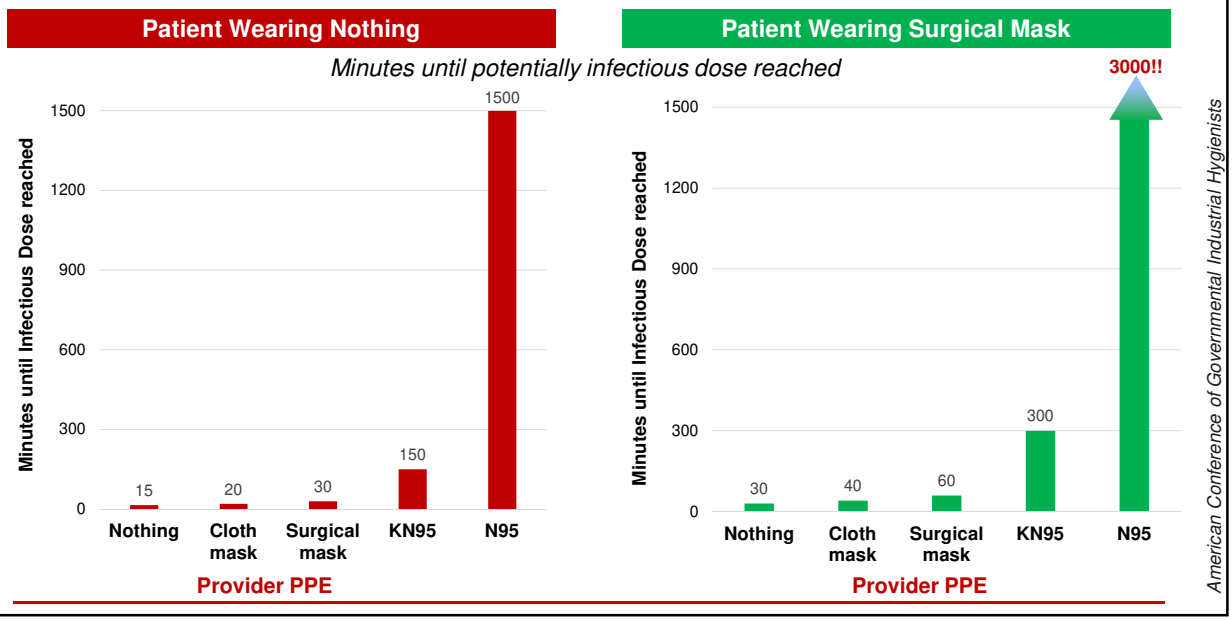
CDC
Centers for Disease Control and Prevention

"HCP who enter the room of a patient with suspected or confirmed SARS-CoV-2 infection ***should*** *…* ***use a NIOSH-approved N95 or equivalent or higher-level respirator****, gown, gloves, and eye protection."*



cdc.gov/covid19

Association between Mask Type and Protection

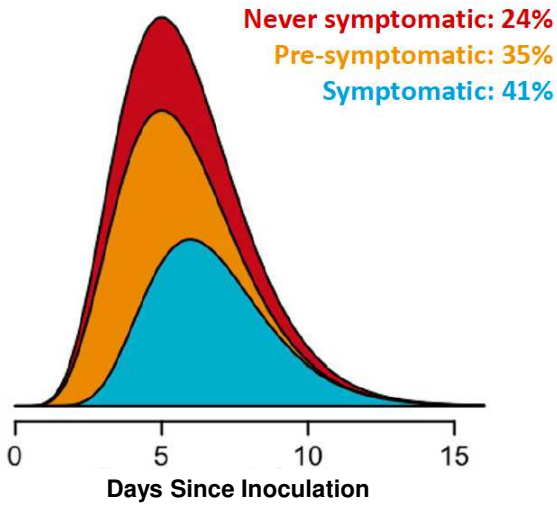


American Conference of Governmental Industrial Hygienists

Should we be using N95s for non-Covid care as well when Covid rates are high?

Most Infections Are Spread by People without Symptoms

percent of all infections by symptom status of the source individual



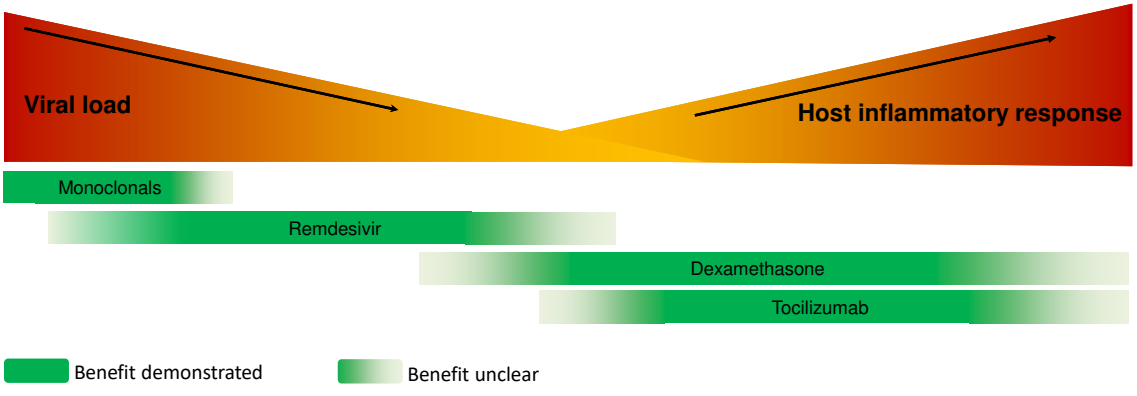
Johansson, JAMA Network Open 2021;4(1):e2035057

The Sickest are Sometimes the Least Contagious

Early Infection
Fever, myalgia, fatigue

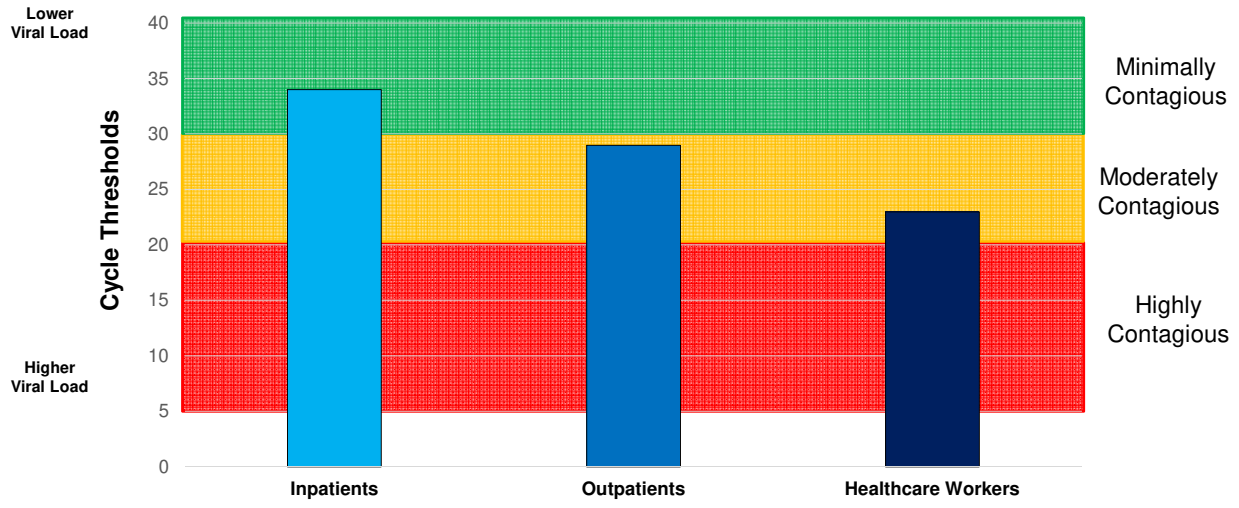
Pulmonary Phase
Shortness of breath, cough, hypoxia

Hyperinflammatory Phase
ARDS, myocarditis, renal failure, neuro syndromes



Inspired by Paul Sax MD

Average CT counts in Known Covid+ Inpatients vs Others

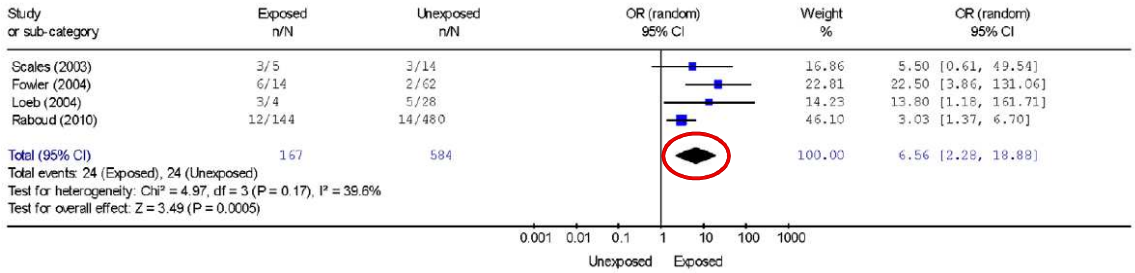


McEllistrem, *PLoS ONE* 2021; 16(3): e0248347

What is an aerosol generating procedure?

Tracheal Intubation Associated with Increased Risk of SARS

Risk of SARS-CoV-1 in HCWs Exposed to Tracheal Intubation



Tracheal intubation associated with a 6-fold increase in SARS-CoV-1!

Other procedures that have been associated with increased risk of HCW infections include non-invasive ventilation, manual ventilation before intubation, tracheotomy, cardiac resuscitation.

Tran 2012, *PLoS ONE* 2012;7(4):e35797

…but how many aerosols does intubation generate?

Continuous aerosol monitoring using an optical particle sizer in an operating room

Intubation

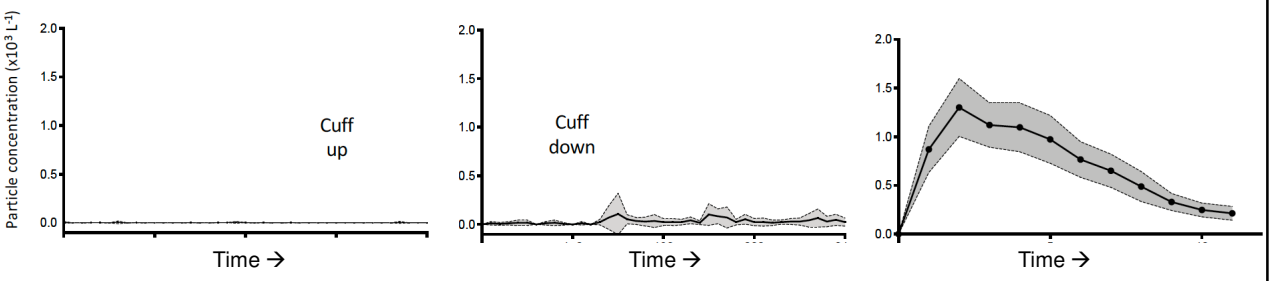
Mean 1.4 particles/L, N=14

Extubation

Mean 21 particles/L, N=10

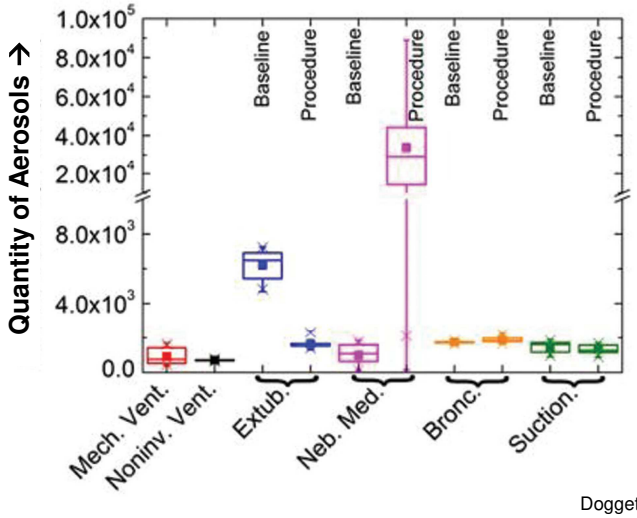
Cough

Mean 732 particles/L, N=38



Brown, *Anesthesia* 2021;76:174-181

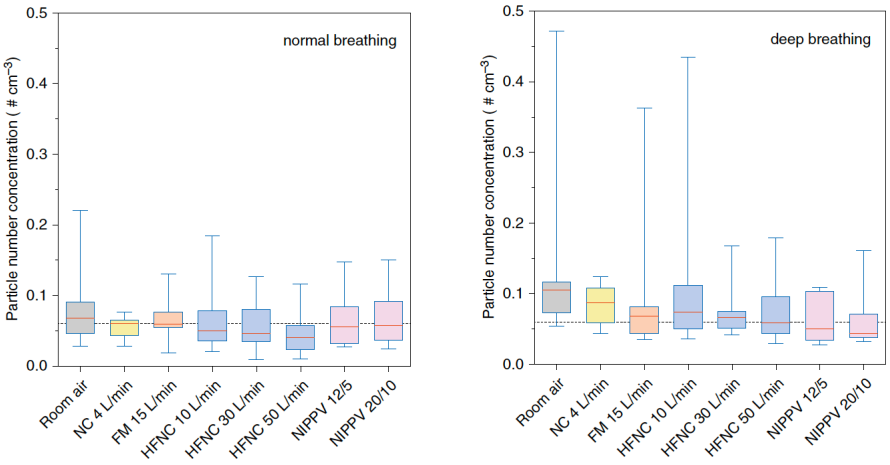
Most "Aerosol Generating Procedures" Generate Very Few Aerosols



Doggett, *Chest* 2020; 158:2467-2473
O'Neil, *Clin Infect Dis* 2017;65:1342-1348
Li, *Open Forum Infect Dis* 2017;4(Suppl 1):S34

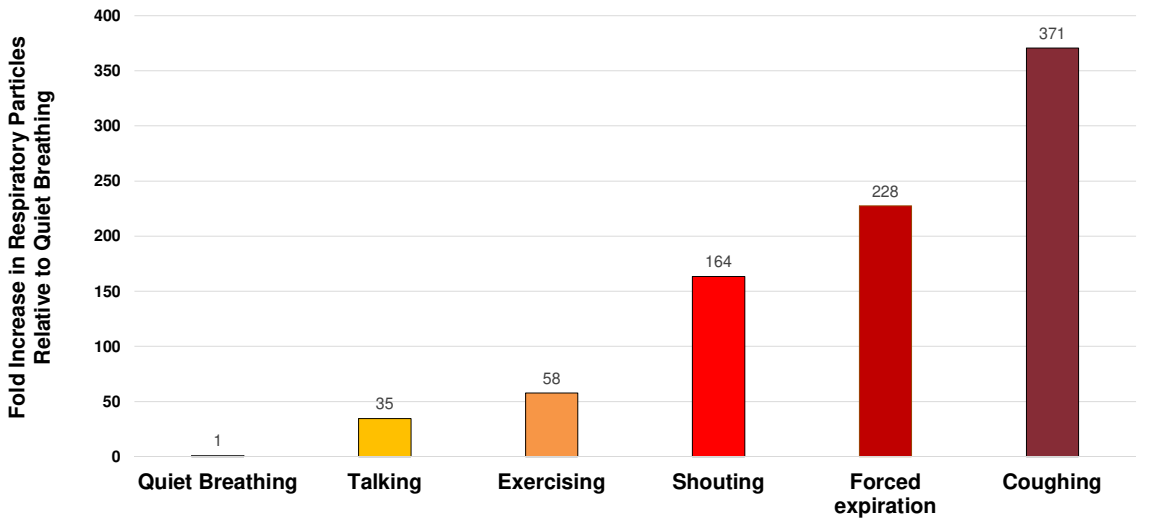
Aerosol Production with Supplementary Oxygen

Aerosol measurement with 10 healthy volunteers in a negative pressure room



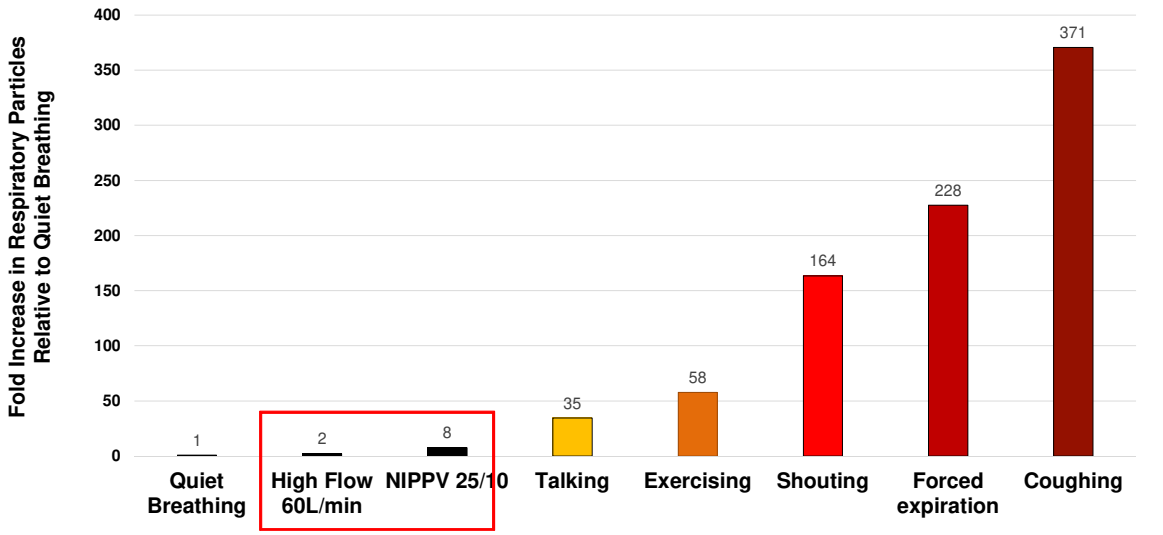
Gaeckle, AJRCCM 2021;ePub

Variation in Respiratory Emissions by Activity



Wilson 2021, medRxiv, doi: 10.1101/2021.02.07.21251309

Impact of High Flow O2 on Respiratory Emissions



Wilson 2021, medRxiv, doi: 10.1101/2021.02.07.21251309

The Intubation Paradox

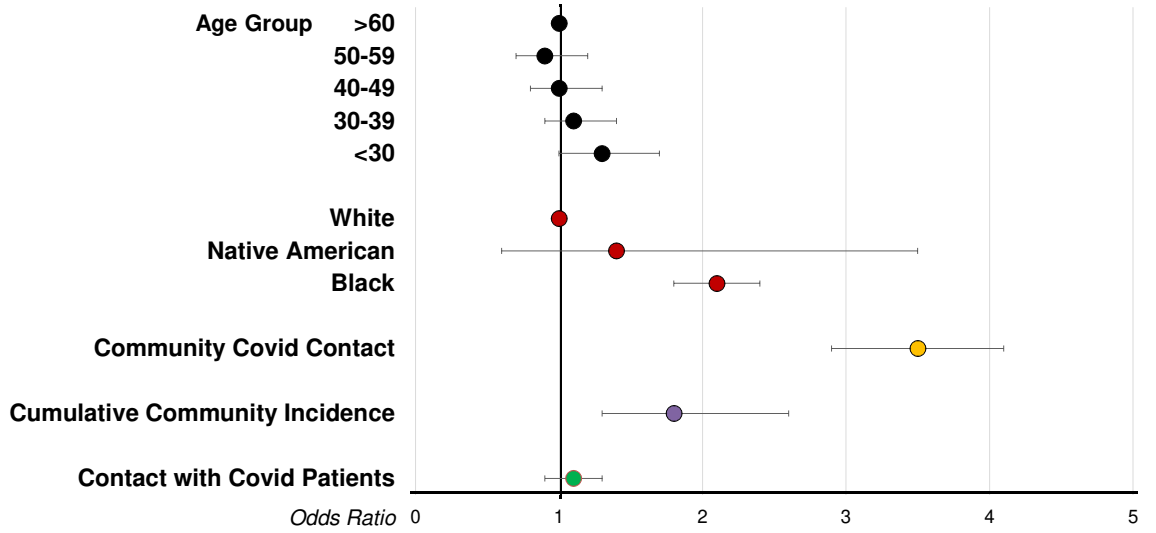
- **It's not the procedure, it's the patient!**
- **Associations between procedures and healthcare worker infections more likely due to the circumstances surrounding procedures rather than the procedures themselves**
  - Severe illness (high viral loads)
  - Significant symptoms (tachypnea, heavy breathing, coughing)
  - Profound proximity to the respiratory tract
  - Sustained exposure

Klompas, *JAMA Surgery* 2021;156:113-114

What is the risk to healthcare workers?

Risk Factors for Healthcare Worker Infections

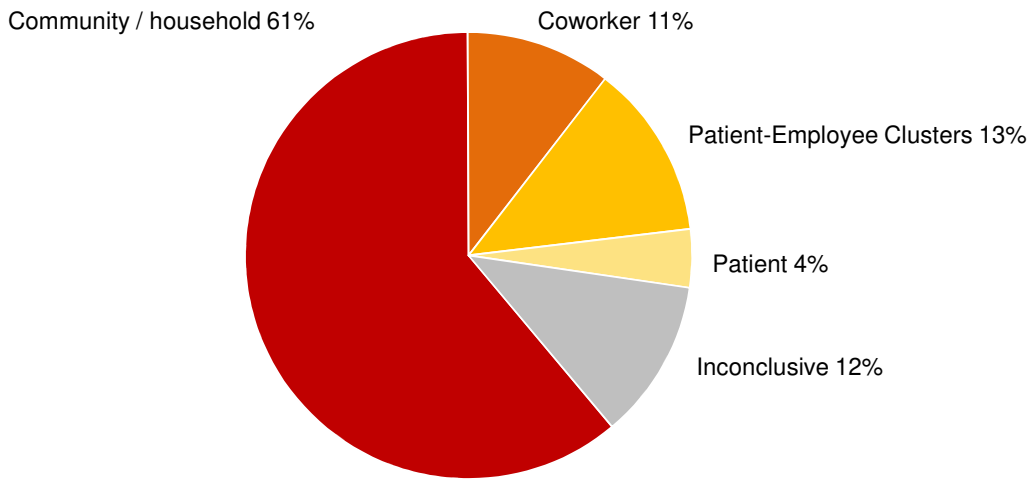
Seropositivity analysis amongst 24,749 healthcare workers, 4 U.S. healthcare systems in MD, GA, and IL



Jacob, *JAMA Network Open* 2021;4(3):e211283

Where Do Healthcare Workers Get Infected?

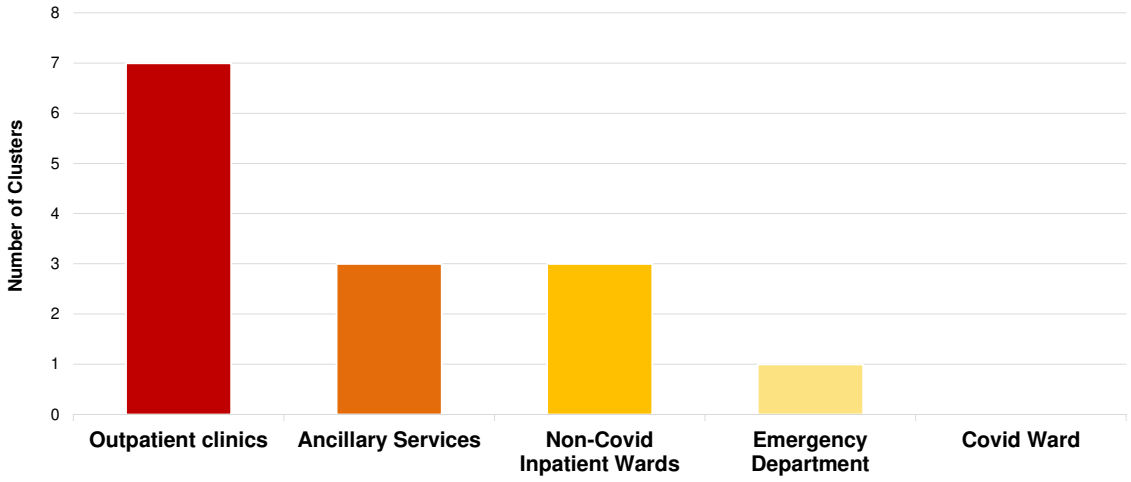
Sequencing of SARS-CoV-2 clusters, 95 HCWs & 137 possible patient contacts, University of Wisconsin



Braun, *Clin Infect Dis* 2021;ePub

Where do nosocomial clusters occur?

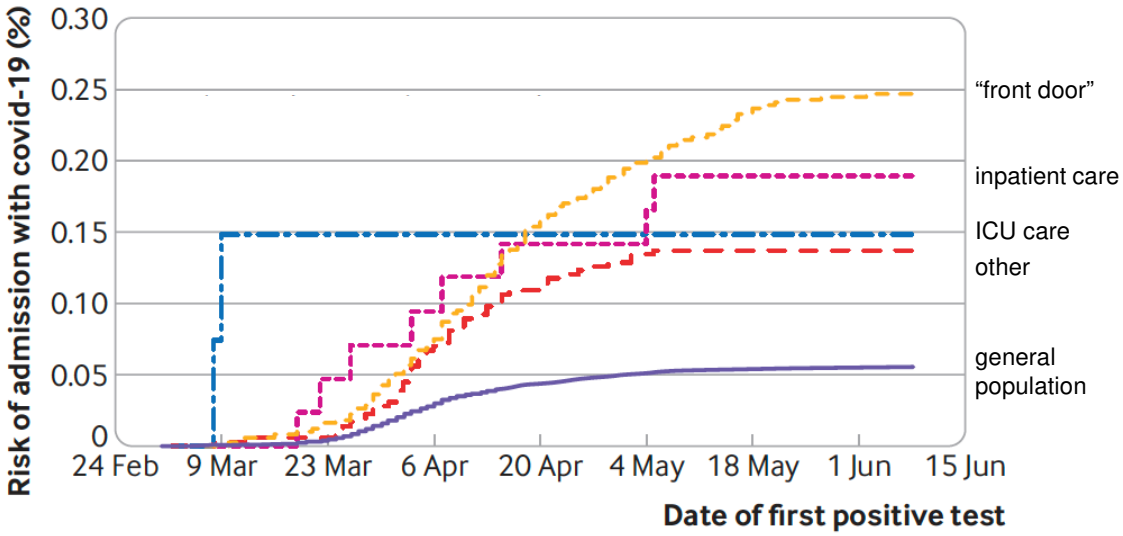
Whole genome sequencing analysis of 14 clusters, 117 infections (112 HCWs, 5 patients), VA Northeast Ohio
Cluster defined as ≥3 potentially-related infections



Jinadatha, *Open Forum Infect Dis* 2021; doi.org/10.1093/ofid/ofab328

Risk of Covid Admission for Healthcare Workers by Role

Risk of Covid admission amongst 158,445 healthcare workers in Scotland by role group

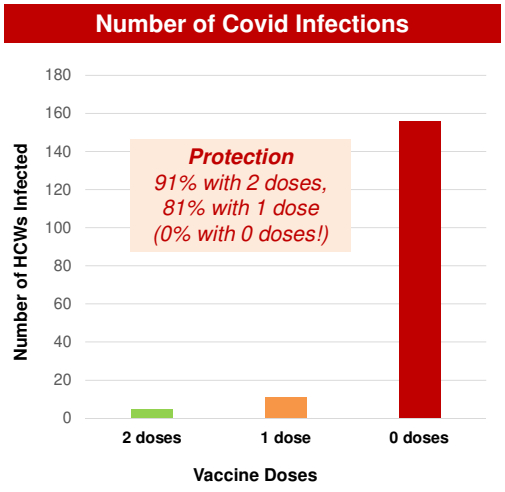


Shah, *BMJ* 2020;371:m3582

Can Vaccinated People Spread SARS-CoV-2?

Impact of Vaccination on Covid Infections in HCWs

Weekly SARS-CoV-2 surveillance via PCR in 3975 healthcare workers in 6 U.S. states, Dec 2020-April 2021



Mean Viral Load
- 40% lower if vaccinated
  (2.3 vs 3.8 $\log_{10}$ copies/ml)

Duration of viral RNA detection
- 6.2 fewer days if vaccinated
  (2.7 vs 8.9 days)

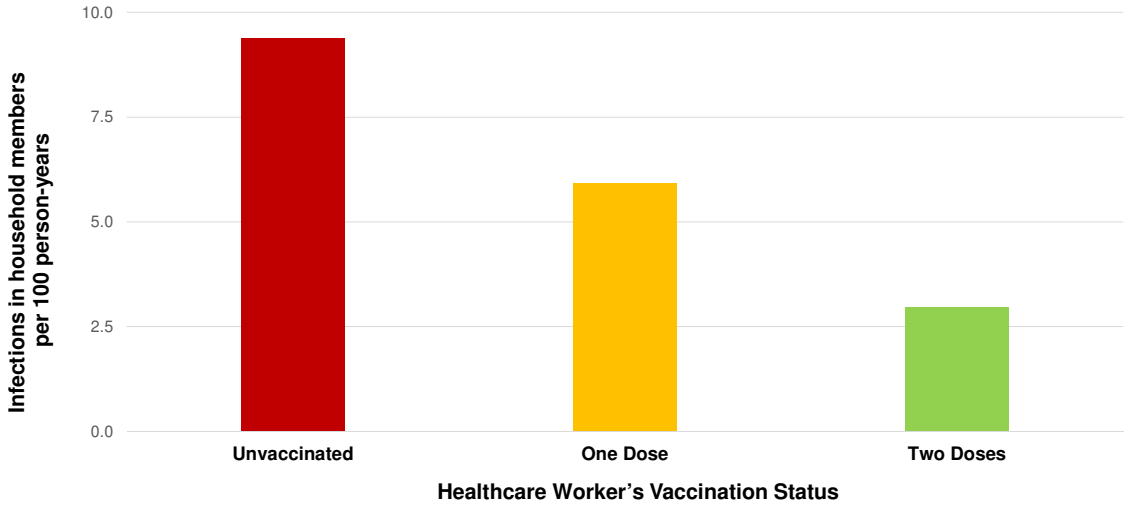
Risk of fever if infected
- 58% lower if vaccinated
  (25% had fever vs 63%)

Duration of illness if infected
- 2.3 fewer days in bed if vaccinated
  (1.5 vs 3.8 days)

Thompson, *NEJM* 2021;385:320-329

Impact of Vaccination on Transmission

Incidence of Covid-19 in 194,362 household members of 144,525 Scottish healthcare workers, Dec'20-Mar'21



Shah 2021, NEJM DOI: 10.1056/NEJMc2106757

Vaccinated People are 1/3 Less Likely to Carry Virus

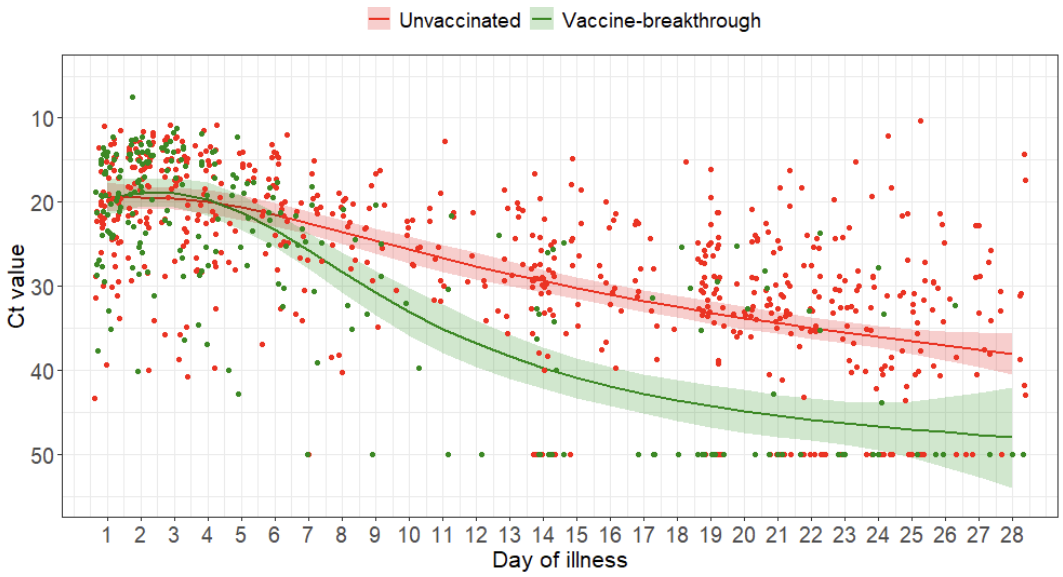
National random sample of 98,233 UK residents, June 24-July 12, 2021
(during the height of UK's Delta wave)

0.63%	**1.21%**	**0.40%**
of people overall tested positive	unvaccinated people tested positive	vaccinated people tested positive

Overall Vaccine Effectiveness: 49%

Elliott 2021, REACT-1 round 13 final report
https://spiral.imperial.ac.uk/handle/10044/1/90800

Delta Infection Viral Dynamics



Chia 2021, medRxiv, doi: 10.1101/2021.07.28.21261295

Risk & Protection Exists on a Continuum

Factors That Increase Risk

- High community incidence
- Higher viral load
- Symptoms
- Proximity
- Longer exposure
- Poor ventilation
- Lack of masking
- Lack of vaccination

Factors That Decrease Risk

- Low community incidence
- Lower viral load
- Lack of symptoms
- Distance
- Brevity
- Good ventilation
- Mask on patient
- Mask on provider
  - N95 > KN95 > facemask
- Vaccination

Summary

- SARS-CoV-2 transmitted by respiratory particles in a range of sizes including aerosols
- Risk of infection is associated with the amount of viral exposure
  - Determined by source patient's viral load, symptoms, proximity, duration of exposure, masking, ventilation, and vaccination status
- Masks decrease exposure but do not eliminate it
- Covid patients sick enough to be hospitalized may be less contagious than those with acute infection with or without symptoms. Should we be doing more to protect healthcare workers and patients in non-Covid units?
- Most "aerosol generating procedures" do not generate aerosols
- Vaccines prevent transmission. Vaccinated people less likely to carry virus & clear it more quickly.
- Stay humble.

mklompas@bwh.harvard.edu