Airborne transmission of the virus SARS-COV-2 and other respiratory infections

Lidia Morawska
Queensland University of Technology
This presentation

1. Introduction: airborne transmission
2. Generation of particles during respiratory activities
3. Characteristics of the particles
4. Dynamics of particles in the air
5. Evidence from the outbreaks – modelling
Epidemics and pandemics of the past

Spanish flu

What lessons have we learned?
Confusion: COVID-19

FACT CHECK: COVID-19 is NOT airborne

The virus that causes COVID-19 is mainly transmitted through droplets generated when an infected person coughs, sneezes, or speaks. These droplets are too heavy to hang in the air. They quickly fall on floors or surfaces.

You can be infected by breathing in the virus if you are within 1 metre of a person who has COVID-19, or by touching a contaminated surface and then touching your eyes, nose or mouth before washing your hands.

To protect yourself, keep at least 1 metre distance from others and disinfect surfaces that are touched frequently. Regularly clean your hands thoroughly and avoid touching your eyes, mouth, and nose.

March 28 2020

World Health Organization

#Coronavirus  #COVID19
Airborne transmission of SARS-CoV-2: The world should face the reality

Lidia Morawska\textsuperscript{a,*}, Junji Cao\textsuperscript{b}

\textsuperscript{a} International Laboratory for Air Quality, 4001, Australia
\textsuperscript{b} Key Lab of Aerosol Chemistry & Physics, \textit{Infectious Diseases Society of America}

\textbf{ARTICLE INFO}

Handling Editor: Adrian Covaci

Keywords:
Airborne transmission
Airborne infection spread

\textbf{Clinical Infectious Diseases}

\textbf{INVITED COMMENTARY}

\textbf{It Is Time to Address Airborne Transmission of Coronavirus Disease 2019 (COVID-19)}

\textbf{EDITORIALS}

\textbf{Covid-19 has redefined airborne transmission}

Improving indoor ventilation and air quality will help us all to stay safe

Julian W Tang, Linsey C Marr, Yuguo Li, Stephanie J Dancer

Over a year into the covid-19 pandemic, we are still debating the role and importance of airborne transmission for SARS-CoV-2, with cursory mention in some infection control guidelines.\textsuperscript{1, 2}

The confusion has emanated from the terminology introduced during the early days. It created poorly defined divisions between "airborne," and "droplet nuclei," leading to misunderstandings over the behaviour of these particles.\textsuperscript{3} Everyone inhales particles—regardless of their size—and are breathing in aerosols. Although at long range, it is more likely where the aerosols between two people are concentrated or concentrated at short range, rather than being breathed by someone who is smoking.\textsuperscript{4}

Ten scientific reasons in support of airborne transmission of SARS-CoV-2

Heneghan and colleagues’ systematic review, funded by WHO, published in March, 2021, as a preprint, states: "The lack of recoverable viral culture samples of SARS-CoV-2 prevents firm conclusions to be drawn about airborne transmission." This conclusion, and the widespread belief in long-range transmission and overdispersion of the basic reproduction number ($R\textsubscript{0}$), discussed below—consistent with airborne spread of SARS-CoV-2 that cannot be adequately explained by droplets or fomites.\textsuperscript{6} The high incidence of such events strongly suggests the dominance of airborne transmission.
"There is no specific evidence to suggest that the wearing of masks by the mass population has any potential benefit."

Dr. Mike Ryan, executive director of the WHO health emergencies program

CNN March 31, 2020
Definitions: is IT aerosol or droplet?

In aerosol science:

**Aerosol**: an assembly of liquid or solid particles suspended in a gaseous medium long enough to enable observation or measurement.

**Droplet**: a liquid particle.

In medical sciences:

**Aerosol**: smaller particles.

**Droplet**: larger particles.

Let’s don’t worry about these differences!

I will call them particles.

Definitions: short (close) or long range?

And also: where is the division?
- 1 m?
- 1.5 m
- 1 kangaroo apart?

There is no division, it is a continuum

Closer to the source → concentrations higher → shorter exposure time → infection

Away from the source → concentrations lower → longer exposure time → infection
Airborne transmission: inhalation of virus-laden particles


PARTICLE AEROSOLIZATION
Particle aerosolization in expiratory activities

...results from the passage of an air-stream at a sufficiently high speed over the surface of a liquid.
Multiple process of particle aerosolization

Saliva in the **mouth** is aerosolized during interaction of the tongue, teeth palate and lips during speech articulation.

Fluid bathing the larynx is aerosolized during voicing due to vocal fold vibrations.

Fluid blockages form in respiratory **bronchioles** during exhalation.

They burst during subsequent inhalation produce the particles.

**After formation**, the particles undergo processes in the respiratory tract before they are respired.

**Deposition** – changing initial size distribution.

Bronchiole fluid film burst (BFFB)

We cannot measure these processes directly, but model and simulate

CHARACTERISTICS OF THE PARTICLES
Number size distribution: speech + breathing

Bronchial Fluid Film Burst Mode (BFFB)

Laryngeal Vibration (LV) Mode

Oral Speech Articulation Movement (OSAM) Mode

Small particles - stay suspended longer in the air

Note: the scale

10 data processing steps

Concentration/emission rates of particles – respiratory activities

b – breathing
n – nose
m – mouth
c – counting
v – voice
w – whisper


Particle size and emissions:

- The majority of particles are $< 1 \mu m$ (and the vast majority are $< 10 \mu m$)
- Such small particles are light ⇒ can stay suspended in the air for a long time
- All respiratory activities (including breathing) generate particles, but vocalization ⇒ higher emissions than other activities
Virus-laden particles from respiratory activities

Virus in the particles

Size of a SARS-CoV-2 “naked virus”: ~ 0.12 µm

Size of the virus-laden particles: > 0.12 µm

Particles < 1 µm ⇒ contain higher loads of SARS-CoV-2

Majority within the mid sub-micrometre range and larger

Water
Mucus
Salts

Santarpia et al. The Infectious Nature of Patient-Generated SARS-CoV-2 Aerosol. medRxiv, 2020

Ma et al, COVID-19 patients in earlier stages exhaled millions of SARS-CoV-2 per hour. CID, Accepted 26 Aug, In Press.
Mass size distributions - mixed acuity COVID-19 rooms

Sample collection for virology: NIOSH BC251 sampler
3 stages, cut-off sizes - the red and blue lines

Particle size distribution: Aerodynamic Particle Sizer (TSI APS 3321)
0.542-20 µm, 52 size bins

Highest viral load

Several data processing steps

Note: the scale

Santarpia et al., 2020. The Infectious Nature of Patient-Generated SARS-CoV-2 Aerosol. *medRxiv*
Summary: virus-laden particles

Virus in the particles

- Overall, smaller particles ⇒ contain higher loads of SARS-CoV-2
- Smaller particles ⇒ from deeper parts of the respiratory tract ⇒ location of the virus
- To the contrary, larger particles ⇒ less virus, as they originate from the mouth
- Therefore, breathing/speaking ⇒ the main source of small, virus-laden particles
PARTICLE DYNAMICS IN THE AIR
Particle evaporation

What we measure is usually already a *droplet nuclei*

Respiratory liquids are water based

**Water droplet evaporation**

**Composition of respiratory particles:**
- Water
- Salts
- Mucus
- Pathogens

Evaporate very fast!

The process is much more complex than for salt solution

Evaporation to 20 - 40% of the initial size

**Droplet nuclei** (of 0.86% NaCl solutions)

Particle fate in the air

<table>
<thead>
<tr>
<th>Particle diameter [(\mu m])</th>
<th>“Falling” time height 1 m [s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>0.3</td>
</tr>
<tr>
<td>100</td>
<td>3</td>
</tr>
<tr>
<td>10</td>
<td>300</td>
</tr>
<tr>
<td>1</td>
<td>30,000</td>
</tr>
</tbody>
</table>

Wells 1934
How do particles from respiratory activities travel in the air?

Summary: particle dynamics in the air

- Gravitational deposition of large particles
- Flow dynamics of small particles
- Removal by ventilation (and other processes)

Level of understanding:
- Very good quantitative understanding
- Based on empirical studies and modelling
Q: How long will virus-laden particles stay in indoor air?
A: As long as the forces acting on them will keep them in the air.

Q: How far will virus-laden particles travel in indoor air?
A: As far as the air flow will take them.
Physics of respiratory infections

Quantitative evidence:

- Characteristics of particles / virus-laden particles from human respiratory activities
- What happens to the particles in the air – transport and removal dynamics
- Deposition of the particles in the respiratory tract upon inhalation

Is such evidence available for each outbreak?

No, because this is a complex process and we never have all the required parameters for real life scenarios
EVIDENCE FROM OUTBREAKS
Skagit Valley choir outbreak

Modelled results agreed with the outbreak data

ER\textsubscript{q} = 341 quanta h\textsuperscript{-1}

53 out of 61 participating infected


Estimates of contributions: transmission modes + viral sources

Comparison of infection risk between 12 modelled and documented outbreak data


Model assumption: all cases were caused by long-range transmission

PIRA: modelled
AR: documented

Agreement in 9 cases

Airborne transmission must be mitigated!
Why do we question evidence from these processes…

Should gravity be questioned?

…if we accept transport of other objects in the air, and its impact?

A *seed* hundreds of meters from a parent tree?

*Dust* particles thousands of km from a source causing air pollution episodes?

We don’t trace the *seed* or the *dust* grain, but rely on various models and other evidence to explain their journey.

In a similar way, physics-based evidence should be used to explain airborne transmission or respiratory infections.
Randomized control trials?

The Parachute

Parachute use to prevent death and major trauma related to gravitational challenge: systematic review of randomised controlled trials
Gordon C S Smith, Jill P Pell

Conclusions As with many interventions intended to prevent ill health, the effectiveness of parachutes has not been subjected to rigorous evaluation by using randomised controlled trials. Advocates of evidence based medicine have criticised the adoption of interventions evaluated by using only observational data. We think that everyone might benefit if the most radical protagonists of evidence based medicine organised and participated in a double blind, randomised, placebo controlled, crossover trial of the parachute.
MITIGATION
Building engineering controls

- Sufficient and effective ventilation
- Avoiding air recirculation
- Particle filtration and air disinfection
- Avoiding overcrowding

Ventilation: sufficient and effective


Enough of it

Everywhere

Air flow not from person to person
SUFFICIENT VENTILATION
What is sufficient ventilation in relation to infection transmission?

Can we use the existing ventilation guidelines for controlling infection transmission?

For example, guidelines for CO$_2$ exhaled by occupants?

To find out we need to use risk assessment models and tools!
A quantum is the dose of infectious airborne particles required to cause infection in 63% of susceptible persons.

Emitted quanta depend on:

- Location of the pathogen in the respiratory tract
- Physiology of the respiratory tract
- Stage of the disease
- Type of respiratory activity
- THE VIRUS
Risk of infection transmission

Traditional steady-state Wells-Riley model (W-R)

\[
Risk = 1 - e^{-\frac{Iqpt}{Q}}
\]

Where:

- \( I \) - the number of infectious source cases
- \( q \) - the number of infectious quanta produced per source case (quanta/h),
- \( p \) - the average respiratory ventilation rate of susceptible persons (m\(^3\)/h),
- \( t \) - the duration of exposure (h)
- \( Q \) - the volume of infection-free (i.e. outdoor) air supplied to the room (m\(^3\)/h)
Ventilation and infection risk

Quanta generation rates from literature (quanta/hour):
- Influenza - 67
- Tuberculosis - 12.7
- Rhinovirus - 5

The Prince Charles Hospital, Brisbane, Lung Function Laboratory: infection risk for 15 and 45 min occupancy
Risk assessment models and tools 1

Airborne Infection Risk Calculator (Version 3.0 Beta)


Stabile, L., Pacitto, A., Mikszewski, A., Morawska, L. and Buonanno, G. Ventilation procedures to minimize the airborne transmission of viruses at schools. Building and Environment, Accepted 7 June 2021 (medRxiv, https://doi.org/10.1101/2021.03.23.21254179)
Risk assessment models and tools 2

In summary, assessing the requirements for sufficient ventilation is relatively easy.

Assumption: uniform mixing of the air!

EFFECTIVE VENTILATION
Air flow distribution/direction and infection risk


The flow direction was a problem in this case (in addition to low fresh air supply)
Computation Fluid Dynamic (CFD) Modelling

Will CFD modelling answer all the questions about flow direction?
For specific indoor spaces - mostly

But we need general solutions

In summary, assessing the requirements for effective ventilation, which is based on air flow
still a challenge

How to generalise?
THE FUTURE
BEYOND COVID-19
A paradigm shift to combat indoor respiratory infection

Building ventilation systems must get much better


There is great disparity in the way we think about and address different sources of environmental infection. Governments have for decades promulgated a large amount of legislation and invested heavily in food safety, sanitation, and drinking water for public health purposes. By contrast, airborne pathogens and respiratory infections, whether seasonal influenza or COVID-19, are addressed fairly weakly, if at all, in terms of regulations, standards, and building design and operation. Pertaining to the air we breathe. We suggest that the rapid growth in our understanding of the mechanisms behind respiratory infection transmission should drive a paradigm shift to combat indoor respiratory infection.

"...healthy indoor environments with a substantially reduced pathogen count are essential for public health."

was on thermal comfort, odor control, perceived air quality, initial investment cost, energy use, and other performance issues, whereas infection control was neglected. This could in part be based on the lack of perceived risk or on the assumption that there are more important ways to control infectious disease, despite ample evidence that healthy indoor environments with a substantially reduced pathogen count are essential for public health.

It is now known that respiratory infections are caused by pathogens emitted through the nose or mouth of an infected person and transported to a susceptible host. The pathogens are enclosed in fluid-based particles aerosolized from sites in the respiratory tract during respiratory activities such as breathing, sneezing, and coughing. The particles encompass a wide size range, with most in the range of submicrometers to a few micrometers (1).

Although the highest exposure for an individual is when they are in close proximity, community outbreaks for COVID-19 infection in particular most frequently occur at larger distances through inhalation of airborne virus-laden particles in indoor spaces shared with infected individuals (2). Such airborne transmission is potentially the dominant mode of transmission of numerous respiratory infections. There is also strong evidence on disease transmission—for example, in restaurants, ships, and schools—suggesting that the way buildings are designed, operated, and maintained influences transmission.

Yet, before COVID-19, to the best of our

Paradigm shift: action

We need a “paradigm shift” in how:

➢ buildings are designed
➢ equipped, and
➢ operated

...to minimize all air hazards, including airborne infection transmission
Paradigm shift: perception

There must to be a shift in perception that we cannot afford new ventilation systems.

The economic costs of the impacts of indoor air pollution by far exceed all other costs.

Costs in Australia: $52-137 million (annual)

Cost of COVID: $1 trillion (monthly)

Cost of other transmissions in US: $50 billion (annual)
The solutions are here

Hershberger, S. The 1918 flu killed millions, then faded from our collective memory. Could the same happen with COVID-19? Scientific American, November 2020

It will happen to COVID-19, but we hope that the pandemic will influence the paradigm shift in combating indoor respiratory infections…

…on the scale of Chadwick’s Sanitary Report in 1842

Sir Edwin Chadwick led the British government to encourage cities to organise clean water supplies and centralised sewage systems
The Parachute

Parachute use to prevent death and major trauma when jumping from aircraft: randomized controlled trial

Robert W Yeh,1 Linda R Valsdottir,1 Michael W Yeh,2 Changyu Shen,1 Daniel B Kramer,1 Jordan B Strom,1 Eric A Secemsky,1 Joanne L Healy,1 Robert M Domeier,3 Dhruv S Kazi,1 Brahmajee K Nallamothu4 On behalf of the PARACHUTE Investigators

CONCLUSIONS
Parachute use did not reduce death or major traumatic injury when jumping from aircraft in the first randomized evaluation of this intervention. However,
Thank you!

l.morawska@qut.edu.au