Suspended viral dose
based on evaporation and settling of droplets from respiratory releases

Speaker: Dr Pedro Magalhães de Oliveira
Department of Engineering, Cambridge
RAMP Task 7 SG1/2
Motivation

- **Droplet transmission vs aerosol transmission problem**
  
  Dancer et al. 2020 "Putting a balance on the aerosolization debate around SARS-CoV-2" , Journal of Hospital Infection, 2020

- **Decay rates of the total amount of liquid/virus suspended in air?**

  **Evaporation/settling of single droplets:**
  from Wells (A. J. Epidemiology, 1934) to Xie et al. (Indoor Air, 2007)

  Wide range of droplet sizes!

  - droplet size/gas flow measurements:
    - Papineni & Rosenthal (J. Aerosol Medicine, 1997)
    - Morawska et al. (J. Aerosol Science, 2009)
    - Gupta et al. (Indoor Air, 2009 & 2010)

  Effect of droplet composition:
  Marr et al. (J. R. Soc. Interface Air, 2019)

  Time (s) vs droplet diameter
  Complete evaporation
  Settling at 2 m

  Droplet "equilibrium" diameter depends on the composition.
Motivation

• Droplet transmission vs aerosol transmission problem

• Decay rates of the total amount of liquid/virus suspended in air?

Evaporation and settling of droplet clouds emitted by coughing and speaking.

Evolution and life-time of suspended droplet cloud
Effects of droplet composition
Suspended viral dose
Impacts on physical distancing

MedRxiv preprint:
PM de Oliveira, LCC Mesquita, S Gkantonas, A Giusti, E Mastorakos
Evolution of spray and aerosol from respiratory releases: theoretical estimates for insight on viral transmission (24 July, 2020)
doi.org/10.1101/2020.07.23.20160648
Modelling approach

1-D Lagrangian approach (gravity, buoyancy, drag)

Evaporation model (mass, temperature)

Effect of composition on evaporation
Pruppacher & Klett (1996)

Droplet compositions as in Marr et al. (2019)

<table>
<thead>
<tr>
<th>Composition</th>
<th>pure water</th>
<th>h-p sputum</th>
<th>l-p sputum</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaCl salt</td>
<td>0</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>BSA protein</td>
<td>0</td>
<td>76</td>
<td>3</td>
</tr>
<tr>
<td>DPPC surfactant</td>
<td>0</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Initial droplet size distribution
Bronchiolar-Laryngeal-Oral model
Johnson et al. (J. Aerosol Sci., 2011)

Exponential viral decay
van Doremalen et al. (N. Engl. J. Med., 2020)

\[ \lambda = 0.636 \text{ h}^{-1} \]

Viral load
Wölfel et al. (Nature, 2020)
Pan et al. (The Lancet Infectious Diseases, 2020)
Jones et al. (medRxiv preprint)

10^4 to 10^{11} copies/ml
All suspended droplets
mass and # decay

~ similar mass decay
between speaking and
coughing

99% of liquid mass
In droplets between
100 μm - 1 mm
All suspended droplets
mass decay

By 10 s
3 orders of magnitude removal by gravity

Between 10 s and 1 min
Largest variations due to RH and mode
Further order-of-magnitude removal
Associated to droplets between 30 - 100μm
Aerosol

d<5μm

mass and # decay

After 1h
Virtually no removal

Speaking vs Coughing
Aerosol during speaking has much higher mass
Composition
Effect on evaporation and settling

Droplet "equilibrium" size between 20-50% of $d_0$
settling time varies ~100%

Composition
also influences modelling of short-term droplet transmission
(mid-sized 10-100 μm droplets)
Suspended viral dose

Initial viral load
- \(10^{11}\) copies/ml
- \(10^8\) copies/ml

Droplet composition
- high protein
- low protein

Relative humidity
- 80%
- 40%

Infection dose \(N^\text{IDP}_v\)
Viable viral dose associated with \(P\%\) risk of infection

(a) coughing
(b) speaking

Time, \(t\)
Implications for physical distancing and ventilation policies

Impact of such metrics in 3 canonical problems:

(i) uniform velocity

(ii) jet decay

(iii) mixing ventilation
Implications for physical distancing and ventilation policies

(i) uniform velocity assumptions:
- exhaled gas velocity ignored
- e.g., speaking, presence of strong background flow

\[ t = \frac{L}{U} \]

\[ N_{v,s} = 200 \text{ PFU} \] (at face height)

\[ N_{v,s} = 20 \text{ PFU} \] (at face height)

\[ t = 4 \text{ s} \]

Mean flow (m/s)
- +0.1
- 0
- -0.1

\[ t - t_{spk} \]

(a) speaking

\[ A \quad L = 2 \text{ m} \quad U = 0.5 \text{ m/s} \quad B \]
Implications
for physical distancing
and ventilation policies

(ii) jet decay

assumptions:
emission as continuous round jet in stagnant air
jet decays downstream from emission source
neglecting: buoyancy, dilution by entrainment

mean velocity (centreline)
\[
\frac{U}{U_0} = C \left( \frac{x}{D} \right)^{-1}
\]

following a fluid particle
\[
\frac{dL}{dt} = U \iff L^2 = 2 CD U_0 t_{fl}
\]

A \hspace{1cm} B

\begin{align*}
L &= 2 \text{ m} & \text{safe distance} \\
U_0 &= 20 \text{ m/s} & \text{cough initial velocity} \\
D &= 10 \text{ mm} & \text{mouth opening}
\end{align*}
Thank you.

Acknowledgements

Co-authors (Cambridge)
- Dr Leo C.C. Mesquita
- Mr Savvas Gkantonas
- Dr Andrea Giusti (Imperial)
- Professor Epaminondas Mastorakos

Thanks to
- Dr Philip Sitte (Siemens)
- Dr Adam Boies (Cambridge)
- Professor Catherine Noakes (Leeds)
- Dr Megan Davies Wykes (Cambridge)
- Dr Henry C. Burridge (Imperial)