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Physics of Respiratory Infections: do we understand it?

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- Infection transmission modes:
  - By close contact: in the range of larger droplets or touching surfaces where they were deposited (direct)
  - Inhaling small airborne droplets somewhere in the room (indirect)
- Today talking about indirect/airborne transmission
- Extreme debate around COVID whether it is aerosol or droplet…
  - Aerosol science defines an aerosol as an assembly of liquid or solid particles regardless of size
  - But medical science defines aerosols as small and droplets as large
  - Don't worry about the difference in today's talk! It's all semantics in this discussion
- Particle atomization in expiratory activities
  - Results from the passage of an air-stream at a sufficiently high speed over the surface of a liquid
    - Similar to an old fashioned perfume bottle
  - ..But not quite that simple because our respiratory track is much more complex
  - Multiple processes of particle atomization:
    - Fluid blockages form in bronchioles during exhalation
    - Fluid bathing the larynx is aerosolized due to vocal fold vibrations
    - Saliva in the mouth is aerosolized during interaction of tongue, teeth, during speech
  - Bronchiole fluid film burst (BFFB)
    - We can model and simulate this process, but cannot measure directly
- Detection of respiratory particles
  - Instrumental techniques:
    - Her group designed a flow tunnel a person speaks into and droplets are measured by particle analyzers
    - Other group designed an open bench cough model with a laser diffraction system
    - Extension of flow tunnel technique: person blows into a rotator
      - Achieves higher concentrations of particles
      - Can test how long pathogens stay viable/infectious
      - But still not suitable for fast changing processes
- **Size distributions and concentrations**
  - Results from flow tunnel experiments show that majority of the particles are smaller than ~10 um; stay suspended longer in the air
    - See several modes: BFFB (linked to H5N1), LV, and OSAM (linked to H1N1)
    - These results required 10 data processing steps to acquire
  - A very different size distribution was measured by the laser diffraction system
    - Found mostly droplets that are too small to carry the virus
  - Concentrations:
    - Results show that concentration is very dependent on the activity (i.e. sound made)
    - Other group found similar results – speech results in higher concentration than breath
- **Virus-laden particles from respiratory activities**
  - Size of naked virus = ~0.12 um

    - Size of virus-laden particles = >0.12 um because the virus is contained in a droplet with other mucus, water, salts, etc.
    - Particles <1 um contain higher loads of the virus
    - Mass size distributions – mixed acuity covid-19 rooms:
        - Used a dynamic particle sizer to measure the particle size distribution
        - Measures all respiratory activities and background with several data processing steps
        - Found highest viral load in the smallest sized particles (<1 um)
- **Summary:**
    - Particle size and emissions:
        - Majority of particles are < 1 um (vast majority are < 10 um)
        - Such small particles are light so can stay suspended in the air for a long time
        - All respiratory activities (including breathing) generate particles, but vocalization results in higher emissions than other activities
    - Virus in the particles:
        - Smaller particles contain higher loads of the virus
        - Smaller particles -> from deeper parts of the respiratory tract -> location of the virus
        - Larger particles -> less virus (because they originate from the mouth)
        - Therefore breathing/speaking is the main source of small, virus-laden particles
- **Particle dynamics in the air:**
    - Evaporation dynamics:
        - Looked at time of evaporation for salt solution droplets of size 1 um and 10 um
        - Vast majority of the particles evaporate very fast! (fraction of a second)
    - Particle fate in the air:
        - Our particles of interest fall 1 m in 30,000 seconds
        - So we need to examine the gravitation dependence of large particles and flow dynamics of small particles, and removal by ventilation
- **What happens when the particles are inhaled?**
    - For small particles, diffusion is the most relevant process
    - For large particles, impaction/interception is most relevant process
    - Particles of our interest are closer to impaction/interception
    - Factors influencing particle deposition include the physio-chemistry of the aerosol, the anatomy of the respiratory tract, and the physiology of the respiratory track
        - Experiment (on environmental tobacco smoke) shows a huge variation between individuals
            - One individual has ~100% deposition! Noted that this person felt uncomfortable during the experiment, repeated and still had the same deposition!
            - Highlights the complexity of this process and the difficulties of only being able to measure indirectly and model
- **Lessons from this outbreak:**
    - Performed modeling on Skagit Valley choir outbreak (53 out of 61 participants got infected)
        - Modelled results agreed well with the outbreak data
    - Comparison of infection risk between models and evidence in 12 outbreaks showed agreement in 9 cases
    - Conclusions: large numbers of outbreaks were reported – airborne transmission is the most commonly reported cause

- **Mitigation:**
    - Building engineering controls:
        - Avoiding overcrowding
        - Avoiding air recirculation
        - Particle filtration
        - Sufficient and effective ventilation
            - Need *enough* of it AND need it *everywhere*
            - Can we use current ventilation standards for CO2?
                - Not quite that simple because of infectious quanta
                - Emitted quanta depend on location in the respiratory tract, physiology, stage of disease, type of activity, etc.
            - Has been measured for influenza, tuberculosis, and rhinovirus
                - Now extended this study with modeling for this virus
                - Calculated risk for a customer entering a pharmacy 26 min after an infected individual and remaining for 10 min based on ventilation
                    - Assessing the requirements for sufficient ventilation is very easy for single cases! But difficult to generalize
            - Airflow distribution/direction and infection risk
                - Interesting case where large number of people in one side of a restaurant got infected, but not others
                    - The problem was poor ventilation and flow direction
            - Many misconceptions about flow directions…
                - Do we want to open windows/doors or not? Could create a flow for students to infect other students, but closing them will reduce ventilation… demonstrates the complexity of determining the best practice for each situation
- **Bigger Picture:**
    - Bush fires smoke!
    - Bush fire smoke triggered a fire alarm indoors, so the recommendation was to close up buildings and limit outside air and recirculate
        - Advice for COVID mitigation is totally opposite!
    - So our buildings need to be designed with the flexibility to adjust to changing situations
    - **Need a paradigm shift in engineering controls design!**
- **Summary:**
    - Physics plays a key role in:
        - Generation of virus-laden particles from human respiratory activities
        - Detection and measurements of these particles
        - What happens to the particles in the air – transport and removal dynamics
        - Deposition of the particles in the respiratory tract and upon inhalation
    - **Therefore, physics of transmission of respiratory infections matters, and it is important to understand it!**

Questions and Answers:

- If re-circulation of air is bad, what are the implications for airplane travel?

    - This is a unique environment where the air is filtered and disinfected upon recirculation
    - We should be more concerned about the unidirectional flow of the air
- Are masks effective if the important particles are smaller than 1 um?
    - The *material* is less important than the *fit* of the mask
    - If masks are wore properly, they are very efficient at protection, but wearing the mask improperly significantly reduces their effectiveness
- Is there a way to coagulate the small particles to get them to settle out and remove them from the air? Or are you aware of any other ways of dealing with the particles while they are still airborne?
    - Coagulation would be a much slower process than just removal by ventilation due to the concentration of the particles
    - UV treatment of the particles is also done and effectively, but must be done with caution to protect people from the UV radiation
- How do you know if the ventilation in the room is good enough? Can you measure this for yourself?
    - Guidelines for now are based on CO_2 and not on infection control
    - However, we can use the model her group created to check the risk reduction based on many factors for a particular room – need more tools developed like this
- How much do you think this pandemic will elevate the importance of modeling and data acquisition for good models?
    - The modeling is currently very advanced! Can model the flow, single particles, etc.
    - The problem is with generalization – can't be done for every room everywhere!
    - More modeling and simulations are needed in order to come up with more generalization and general advice / guidelines
- If only people with virus in their lungs can infect people, can asymptomatic people with only virus in their upper respiratory track still transmit it?
    - Yes, but it depends on the activity they do and the location of the virus in the respiratory track
        - Size distribution of the virus will depend on where the virus originates in the track
- Is there a tool outside of the lab for measuring aerosol composition in the air?
    - There is relatively high background of particles from other air pollution sources that make it usually impossible to distinguish the contribution to particle number concentration from human respiratory activities.
    - Biosamplers are used to collected samples for labs analysis for detection of pathogen content (virus or bacteria). Such analyses are costly.
    - This isn't really the right approach under most condition, as it would require a lot of (costly) sampling, which will not show anything if there are no infectious people in the indoor environment.
- How difficult has it been to bring these important messages to the public? Especially to change conventional wisdom or original thinking?
    - Not just convincing the general public, but also the public health authorities!
    - The concept is so obvious, why don't officials except that this infection is aerosol-based??
        - Likely due to some old (out of date) dogma in the training of the medical community
        - WHO is now moving toward a focus on ventilation (without, however, considering airborne transmission as a significant most of transmissions in shared indoor spaces)
        - Has a lot to do with the politics of all this and the size/complexity/difficulty of the solutions
            - Easier to tell people to wash their hands and wear a mask than to rethink all building code guidelines

- **It is important for scientists to speak up and be persistent!**