Office of the Chief
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Bureau du conseiller
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THE ROLE OF BIOAEROSOLS AND INDOOR VENTILATION IN COVID-19 TRANSMISSION

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REPORT FROM THE COVID-19 EXPERT PANEL OF THE CHIEF SCIENCE ADVISOR OF CANADA

CONTEXT

The Chief Science Advisor Expert Panel on COVID-19 is providing input on the current available evidence regarding indoor air quality and SARS-CoV-2 bioaerosol transmission. The list of participating experts is provided at the end of the document. This report reflects discussions from two meetings held virtually on August 28th and September 4th, 2020.

ISSUE

Circumstantial evidence on the role of aerosols in COVID-19 transmission is accumulating and some experts have pointed to aerosol transmission as a potentially significant route for SARS-CoV-2 spread. As workplaces and schools reopen this fall, it is important to review the available scientific evidence on airborne SARS-CoV-2, and to assess whether *additional* measures need to be considered to minimize the transmission of SARS-CoV-2 in indoor spaces.

KEY MESSAGES

- Close and prolonged contact is the most common route of SARS-CoV-2 transmission, which includes short-range inhalable particle transmission. While aerosol transmission over longer distances is possible, there are currently many unknowns about the conditions under which it could occur.

- Increasing ventilation through building controls (air changes per hour with outside air or filtered internal air) could be a method of mitigating indoor SARS-CoV-2 transmission, but should be part of a layered approach that includes practising effective public health measures to limit exposure such as physical distancing, face masks, surface cleaning, and hand hygiene. Public communications should not infer that crowded indoor spaces are safe as long as there is adequate ventilation.

- Common standards for ventilation in buildings have been developed to reduce airborne contaminants and to provide acceptable air quality to building occupants. In addition, there is a robust body of research that can be drawn from regarding the use of portable air filtration units to reduce disease transmission.

- Targeted studies can fill knowledge gaps. For example, prospective and retrospective epidemiological studies to systematically characterize school and residential (e.g. long-term care) environments would contribute to understanding the association between building characteristics, measurements of indoor air contaminants, and indicators of health.

SUMMARY OF OBSERVATIONS

Experts generally agree that the majority of SARS-CoV-2 transmission occurs through close contact via infected respiratory droplets or aerosols, but that aerosol transmission over longer distances is possible in certain circumstances. The conditions under which long range aerosol transmission of this virus occur, particularly in non-healthcare community settings, are not well understood. A growing number of environmental sampling studies have captured SARS-CoV-2 in air samples[1,2], though few studies have detected live, infectious virus in the air[3] .

Part of the issue is that SARS-CoV-2 is a membrane-bound virus, which presents challenges for preserving virus viability using the typical filtration-based air sampling methods[4]; some researchers have proposed using proxy indicators (e.g. CO_2) to measure overall air quality and airflow in closed or crowded indoor spaces, but these options are still under investigation. There are a number of key research questions, including the viability and infective dose of aerosol SARS-CoV-2, that if addressed, would provide much better understanding of the dynamics and risks of indoor transmission.

Decades of research in occupational hygiene have demonstrated that ventilation is very effective in assisting with controlling indoor air contaminants[5]. Ventilation, along with air filtration, could be important measures for mitigating indoor SARS-CoV-2 transmission; however, there are inherent practical challenges. Even with a recommended air change rate based on existing building ventilation standards, many older buildings, including schools and long-term care facilities, have poorly maintained ventilation systems that would be difficult to improve in a short period.

In circumstances where ventilation cannot be improved through the building heating, ventilation, and air conditioning (HVAC) system, other options like opening windows to promote outdoor air exchange (weather-permitting) and portable air filtration devices[6,7] to reduce airborne aerosols could be helpful. Notably, the quality of ventilation and filtration is just as important as the amount of airflow; therefore, if improved ventilation or filtration are to be listed as a measure for reducing indoor transmission of SARS-CoV-2, clear and simple guidance is needed to ensure appropriate use.

Given the uncertainties around the virology and transmission of SARS-CoV-2 aerosols, ventilation-based measures should be encouraged only as a supplement to established preventive public health measures such as staying home when sick, physical distancing, avoiding crowds, surface cleaning, hand hygiene, and use of facemasks. Existing guidance on infectious aerosols[8] by the American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE) recommends that facilities of all types meet, as a minimum, the latest HVAC standards[9,10]. Where this is not achievable, short-term practical actions can be taken to improve ventilation in a given space.

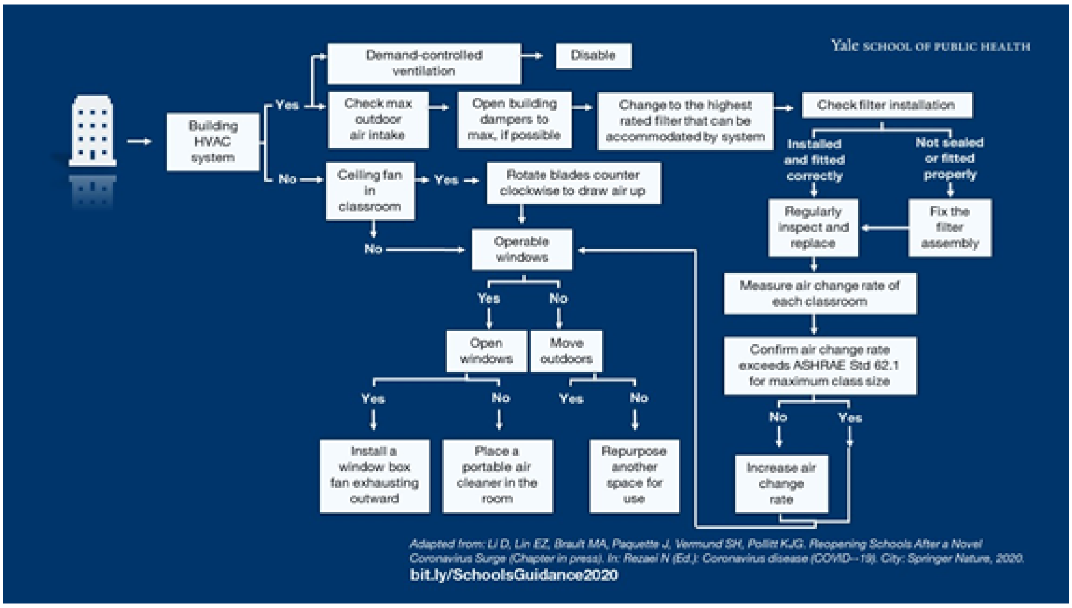
The COVID-19 pandemic also offers an opportunity, while the spotlight is on disease transmission, to take long-term steps to transform systems and behaviours that can help improve indoor air quality overall.

Based on available data and guidance, the following practical considerations could be used to improve ventilation and air quality over the short and longer term. In addition, addressing key research questions could further refine suggested approaches over time.

PRACTICAL CONSIDERATIONS REGARDING IMPROVING VENTILATION AND INDOOR AIR QUALITY:

i) Short-term options to reduce indoor transmission of SARS-CoV-2 and other diseases:

1) For spaces in non-healthcare public settings and multi-dwelling residential buildings, improve ventilation as much as possible following a general hierarchy of actions, such as this sample flowchart designed for schools:



Taken from Li et al. Reopening schools after a novel coronavirus surge. (Chapter In Press). In: Rezaei N (Ed): Coronavirus disease (COVID-19). City: Springer Nature, 2020.

Hierarchy of actions:

- Improve ventilation or filtration directly through the building HVAC system (e.g. ensuring the air change rate meets the latest ASHRAE standards, upgrading to MERV13 or HEPA filters and ensuring proper installation and maintenance).

- Open windows to promote input of outdoor air if possible and if weather permits. Another option is to move indoor group activities outside where and when possible (e.g. outdoor classes, sheltered tents/gazebos, heating outdoor spaces).

- Reduce the concentration of particulates in indoor air using methods such as:
    - Certified portable air filtration devices.
    - Low-cost methods like modified box fans with MERV13 or HEPA filters.

2) Ventilation management should be mandatory in public and crowded spaces, including ventilation characterization, optimization, and design.
3) Use low-cost air quality sensors (e.g. CO_2 sensors) with proven effectiveness, integrated with existing building automation and energy management systems, to conduct real-time evaluations on ventilation and filtration measures in specific buildings.
4) In some instances, it may be beneficial to communicate the ASHRAE standards for ventilation rate (L/s/person or $L/s/m^2$) to managers of public spaces and buildings (e.g. to calculate maximum occupancy). This information is unlikely to be helpful for individuals or domestic settings.
5) In the context of reopening buildings after lockdown, consult existing guidance[11] on preventive measures against other airborne pathogens, such as mold and *Legionella*.

ii) Long-term options to improve indoor air quality in general:

1) Consider approaches to better monitor and promote compliance to current indoor ventilation standards.
2) In new buildings and existing buildings that can be modified:
    - Consider the need to balance energy-saving measures for indoor heating with the benefits of ventilation for improving indoor air quality and reducing pathogen transmission.
    - Integrate disinfection control approaches (e.g. in-duct, upper air germicidal UV systems) into building design.
    - Integrate multi-point air exchange monitoring (feedback) systems to provide real-time information on air quality.
3) Air management should be included in infection control strategies for communicable diseases with a suspected airborne or droplets component (e.g. norovirus, influenza, measles, etc.).
4) Through consultation with relevant industries, develop a comprehensive but simple environmental risk assessment tool that includes physical factors (e.g. building ventilation, high-touch surfaces) and behavioural and other human factors (e.g. number of people, frequency of cleaning) that could be selectively applied to guide administrators, owners, and operators of buildings, particularly in non-healthcare settings. A similar strategy was previously employed to associate indoor radon levels and lung cancer[12, 13].
5) Develop a national strategy to effectively communicate the existing information about the importance of indoor air quality, which considers the needs of different communities in terms of guidance and communication needs.

KEY COVID-19 RESEARCH QUESTIONS REGARDING BIOAEROSOL-MEDIATED SARS-COV-2 TRANSMISSION:

1) Monitoring
   - How can air sampling for SARS-CoV-2 and monitoring for overall air quality be improved?
   - What are the environments under which indoor transmission occurs?
2) Clinical virology
   - What is the dominant exhaled particle size of SARS-CoV-2 that causes infection, what is the infective dose, and how do these change depending on activity and environment?
   - How is the production of bioaerosols impacted by parameters such as respiratory fluid (viscosity, composition), airway geometries (children vs. adults), and stage and severity of illness?
   - What is the risk of SARS-CoV-2 aerosolization resulting from medical procedures (e.g. tracheal suctioning) or resuspension due to ventilation devices?
3) Ventilation and filtration
   - What ventilation rate is effective for reduction of indoor transmission risk?
   - What are the dispersion characteristics of aerosols as a function of time and distance due to human movement and HVAC in buildings?
   - ·What is the impact of portable ventilation/filtration devices on overall air quality,

4) Animal models and genomics
   - What is the impact of temperature, humidity, and air circulation on respiratory infection?
   - Do transmission phenotype and survival capacity vary in different SARS-CoV-2 variants (e.g. D614G)?
5) Modelling
   - How can models be developed to evaluate risk of indoor near- and far-field exposures, using parameters such as fluid dynamics, building parameters, occupancy, and existing mitigation measures?
6) Ventilation and filtration
   - What are user-friendly benchmarks that can be used to communicate basic requirements of acceptable indoor air quality to the general public?

CONCLUSION

Developing science-informed guidance based on available evidence regarding indoor air quality and SARS-CoV-2 bioaerosol transmission demands a collaborative approach that is multi-disciplinary and nimble. As further research proceeds and new evidence becomes available that fills knowledge gaps, approaches will adapt.

LIST OF EXPERTS

Disease modelling

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ANNEX A

Some considerations for the appropriate use of portable air filtration devices include:

1) Unit selection
    - Independent reviews such as the Wirecutter or Consumer Reports provide useful information for unit selection.
    - Devices need to remove enough particulates from the air to make a difference in a space. A general good practice is 2-3 air changes per hour (ACH) for low and moderate risk environments, and 6 ACH for higher risk environments.
    - Due to concerns around harmful by-products, devices with ionizers, plasma, photocatalytic oxidation, or UV features should be avoided unless there is clear evidence of efficacy and safety.

2) Placement – The placement of the device is an important consideration[14] :
    - If the goal is to protect or capture emissions from a specific individual, then the device
    - should be placed as close to that person as possible.
    - In a generic scenario, the centre of the room is likely the best location.
    - Avoid placing the device in an obstructed area such as the corner of a room.
    - In a classroom setting, a location close to the teacher should be considered, both to protect them and to enable control of the device.
    - Deploying multiple smaller devices could be useful for getting more distributed coverage.
    - Devices that have downward outlet airflows should be elevated to avoid resuspending particulates that have settled on the floor.

3) Noise – Portable air filtration devices are loud, especially in an otherwise quiet environment. One strategy to circumvent this problem is to do room flush outs before and after occupancy (e.g. run at maximum speed before and after occupancy, and at a lower speed during occupancy). This is not as effective as running at maximum speed during occupancy.

4) Existing ventilation – If the space is already well-ventilated via building HVAC or open windows, the added benefits of a portable filtration device would be negligible.

5) Filter replacement – Filters need to be periodically replaced, and this can be associated with significant costs. Filters also need to be changed outdoors by someone wearing appropriate PPE and disposed of properly.

ANNEX B

Detailed COVID-19 research questions and suggestions regarding indoor air quality, bioaerosols, ventilation, and transmission

1) Monitoring
    - How can air sampling, via filter forensics or other techniques, for SARS-CoV-2 be improved for detection, size characterization, and assessment of viability?
        - One potential approach is to focus sampling on the particle size most relevant to aerosol transmission where there will be fewer interfering substances collected.
    - What are the most feasible and effective surrogate measures for ventilation or pathogenic aerosols (e.g. CO_2 levels, oxidative potential) and what would an effective implementation strategy look like?

- What is the association between the quantity and quality of ventilation and infection outbreaks? What are the environments in which indoor transmission is occurring? The reopening of schools is an opportunity for prospective natural experiments across a wide range of populations, geographies, and building types.
    - One potential approach is to develop an outbreak report form that collects information on venue type, occupant density, indoor/outdoor setting, nature of ventilation, person turnover, and length of time spent in the setting.
    - Where data exists, retrospective studies could be conducted to determine if there is an association between outbreaks (number and size) and environmental characteristics (e.g. air quality) in specific settings (e.g. long-term care facilities, schools).

2) Clinical virology
    - What is the dominant exhaled particle size of SARS-CoV-2 that causes infection and what is the infective dose? How do these change depending on the type of activity an infected individual is performing and their environmental conditions (e.g. airflow, humidity)?
    - How is the production of bioaerosols impacted by parameters such as respiratory fluid (viscosity, composition), airway geometries (children vs. adults), and stage and severity of illness?
    - What is the risk of SARS-CoV-2 aerosolization resulting from various medical procedures (e.g. tracheal suctioning)?
    - What is the contribution of virus resuspended into the air from surfaces and contaminated dust?
    - Can SARS-CoV-2 be inactivated by germicidal UVs or LEDs, and how could this be implemented in indoor spaces?

3) Ventilation and filtration
    - What ventilation rate is effective for reduction of indoor transmission risk?
    - What are energy efficient approaches to achieving high ventilation rates in buildings?
    - What are the dispersion characteristics of aerosols as a function of time and distance due to human movement and HVAC in buildings?
    - What is the impact of portable ventilation/filtration devices on overall air quality, including bioaerosols in confined spaces? How can they be optimally deployed?

4) Animal models and genomics
    - What is the impact of temperature, humidity, and air circulation on aerosol transmission?
    - What are the transmission phenotypes of different SARS-CoV-2 variants (e.g. D614G) and do they differ in capacity to survive in the air and on surfaces? We can leverage Canadian SARS-CoV-2 genomes available through CANCoGeN to determine whether there is a role for a variant-specific approach to outbreak investigation.

5) Modelling
    - How can models be developed to evaluate risk of indoor near- and far-field exposures, using parameters such as fluid dynamics, building parameters, occupancy, and existing mitigation measures?

- How can models be developed to evaluate risk of indoor near- and far-field exposures, using parameters such as fluid dynamics, building parameters, occupancy, and existing mitigation measures?

6) Communication
    - What are user-friendly benchmarks that can be used to communicate basic requirements of acceptable indoor air quality to the general public?