Airborne spread of SARS-CoV-2 – a commentary by the Division of Internal Medicine, University Medical Centre Ljubljana

Aerogeno širjenje virusa SARS-CoV-2 – komentar Interne klinike Univerzitetnega kliničnega centra Ljubljana

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Abstract

Slovenia is one of the countries that have been most affected by the autumn/winter 2020/21 wave of the COVID-19 pandemic regarding the incidence and excess mortality among the general population as well as regarding the incidence among health care workers and nursing personnel. The World Health Organization has underestimated the importance of the airborne spread of SARS-CoV-2 and the recommended safety measures have not been entirely sufficient. When people breathe, talk, sing, cough, or sneeze, they emit respiratory droplets of various sizes, most of which are always smaller than 1 μm. Respiratory droplets smaller than 5 μm stay airborne in indoor spaces for a long time and travel over distances much longer than 2 m. Thus, an infected person in an indoor environment creates an infectious aerosol that may infect other people without close interpersonal contact. This short review presents the mathematical model and internet application by authors from the Massachusetts Institute of Technology for calculating the safe time before probable airborne infection occurs in indoor spaces. The importance of ventilation, air filtration, air humidity, and air disinfection by ultraviolet light is briefly discussed. The principles of preventing the airborne spread of SARS-CoV-2 are summarized.

Izvleček

Slovenija sodi med države, ki jih je jesensko-zimski val 2020/21 pandemije covida-19 najhuje prizadel tako glede obolevnosti v presežne umrljivosti med splošnim prebivalstvom kot glede obolevnosti med zdravstvenimi in negovalnimi delavci. Svetovna zdravstvena organizacija (SZO) je do nedavnega močno podcenjevala možnost aerogenega prenosa virusa

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1 Introduction

During the fall and winter season 2020/21 of the COVID-19 pandemic, Slovenia was among the hardest-hit European countries with a huge increase in excess mortality (Figure 1) (1). The health care system of Slovenia was stressed to its upper limit and an unusually high proportion of health care workers contracted COVID-19. At the Division of Internal Medicine of the University Medical Centre Ljubljana, 315 out of 1,347 employees (23.4%) were infected by SARS-CoV-2 by 23 December 2020, among them 122 out of 292 (41.8%) nurses, 99 out of 471 (21.0%) registered nurses, 47 out of 282 (16.7%) physicians, 31 out of 134 (23.1%) administrative workers, and 16 out of 168 (9.5%) other employees. Since health care workers were well-aware of the recommended preventive measures, including hand hygiene, wearing surgical masks, and maintaining a safe interpersonal distance, it is questionable whether the high rate of Covid-19 infection could be attributed only to non-compliance or perhaps also to the incompleteness of the recommendations. Until the end of December 2020, the health care personnel of the University Medical Centre Ljubljana dealing with “non-COVID” patients, among whom many were actually infected, were advised to wear a surgical mask and eye protection - goggles or a visor. However, surgical masks shield only against droplet transmission of COVID-19, but not against airborne transmission.

Figure 1: Excess mortality during the autumn/winter 2020/2021 period of the COVID-19 pandemic in Slovenia and Germany, according to Our World in Data, 2021 (1).
The percentage difference between the reported number of weekly or monthly deaths in 2020–2021 and the average number of deaths in the same period over the years 2015–2019. The reported number might not count all deaths that occurred due to incomplete coverage and delays in reporting.
2 Modes of SARS-CoV-2 transmission

SARS-CoV-2 can be transmitted between individuals in three ways (2):

- by touching surfaces that have been contaminated by the virus (fomites) and touching their eyes, nose, or mouth without cleaning their hands;
- by droplet transmission – through „large“ (> 5 μm) infective droplets, exhaled, sneezed or coughed out by an infected person, which reach the respiratory tract or eyes of the next person in close contact, at a distance of up to 1.5 – 2m;
- by airborne (aerosol) transmission - inhalation of »small« (< 5 μm) infective droplets that remain suspended in the air for a long time and travel much further than 2 m.

Fomite transmission of SARS-CoV-2 seems to be of little importance (2,3). Droplet transmission has long been regarded as the most important, since the World Health Organization (WHO) long acknowledged airborne (aerosol) transmission only under special circumstances of aerosol-generating procedures, such as noninvasive high-flow oxygenation, and only recognized transmission by aerosols in poorly ventilated or crowded rooms at the end of April 2021 (4). Weighing the evidence for and against the possibility of airborne transmission has given SARS-CoV-2 a high probability score of 8 on a 9 point scale, together with tuberculosis and influenza (5). Recently, it has been proposed that the dichotomy between the droplet and aerosol transmission is artificial and that a unique airborne transmission mode should be recognized (6). Soon after the beginning of the COVID-19 pandemic, infections were recorded in people who had not been in close contact with infected individuals (7-9). For example, at the 2.5-hour-long Skagit Valley Chorale choir practice, 53 out of 61 attendees became infected, most of them without being in close contact with the infected individual (7). Airborne transmission of SARS-CoV-2 between ferrets has been convincingly demonstrated in an experimental setting (10).

The importance of airborne spread in poorly ventilated indoor spaces is supported by epidemiological data that show a much higher incidence of Covid-19 in developed European countries, including Slovenia, and North American countries during the autumn/winter season than in African or Asian countries with a milder climate, where people spend more time outdoors (Figure 2) (11).

Figure 2: Graphs of daily new confirmed COVID-19 cases per million people show a much larger incidence in Europe, including Slovenia, and the United States in contrast to Africa and Asia. Summarized after Our World in Data, 2021 (11).
3 When does airborne transmission occur?

Aerosol scientists have long known that there is no clear boundary between droplet transmission and aero-
sol transmission (12). Since 2009 it has been known that
people exhale droplets with a continuous distribution
of sizes at all kinds of respiratory activities and that the
peak of the distribution is always at sizes smaller than
1 μm (13). The absolute number of excreted droplets is
much larger at singing or coughing than at quiet breath-
ing (13). With airflow velocities typical of indoor spac-
es, droplets up to 5 μm in diameter travel several tens
of meters before falling to the ground (14). These facts
were emphasized by Lidia Morawska, an aerosol scien-
tist, and by Donald K. Milton, a physician, professor of
public health, and expert on virus transmission, in an
invited commentary for Clinical Infectious Diseases in
July 2020, where they warned of SARS-CoV-2 transmis-
sion in poorly ventilated indoor spaces (15). The com-
ment was endorsed by 239 scientists from all over the
world (15). Their message was summarized for the
lay public by the New York Times (16) and for the scien-
tific community by Nature (17). In October 2020, the
airborne transmission of SARS-CoV-2 was addressed by
a letter to Science (18), where the authors claimed that
droplets not only up to 5 μm in diameter but up to 100
μm contribute to infective aerosols, and that airborne
transmission is the major route of spreading COVID-19
(18). The danger comes from poorly ventilated indoor
spaces where an infected individual resides for a lon-
ger time (18). The medical community was informed of
this matter by a commentary in Lancet Respiratory Dis-
eases (19). A review of studies testing air samples from
hospitals for the presence of SARS-CoV2 RNA found
the highest concentrations in toilets, bathrooms, inner
rooms for personnel, and in hallways /waiting rooms
without windows (20).

The importance of airborne transmission of SARS-
CoV-2 is in good agreement with the results of the re-
search group led by Jure Leskovec from Stanford Uni-
versity, who have published in Nature on patterns of
mobility and probable sites of contracting COVID-19
by analyzing the data from 98 million American mobile
phone users (21). The conclusion was that a minority of
sites were responsible for the majority of disease trans-
missions (21). Low-income Americans were most likely
to contract COVID-19 in churches, whereas high-in-
come Americans were most likely to become infected in
restaurants, cafés, and fitness centres (21).

Authors from the Massachusetts Institute of Tech-
ology (MIT) have developed a mathematical model
predicting the probable time to airborne infection in
confined spaces with an infected individual, taking into
account the number and activity of other people in the
room, the volume of the confined space, ventilation, air
filtration, air humidity and some other variables (22).
An infective dose of a few tens of SARS-CoV-2 virus
particles was assumed, which is consistent with a re-
cent review and with the fact that the infective dose is
smaller in transmission through the lower respiratory
tract than through the upper respiratory tract (23). Ad-
mittedly, the infective dose of SARS-CoV-2 in humans
is not precisely known, since all assumptions are based
on animal data and modelling (24). However, according
to the MIT model, the results can be dire: in a poorly
ventilated nursing-home room, where an infected indi-
vidual has resided long enough to create stationary con-
ditions of the infective aerosol, another person entering
the room without protective equipment becomes infect-
ed on average after only 3 minutes (22).

4 Room ventilation

Based on their mathematical model, the authors
from MIT have developed an application that calculates
the time to probable infection of another person under
non-steady-state conditions, after an infected individual
to the room (25). When an infected individual en-
ters a (hospital) room with a floor surface of 30 m2
and ceiling height of 3.66 m, with an air humidity of 20%,
ventilated by natural outdoor air exchange rate of 0.3
air changes per hour (ACH) – corresponding to closed,
non-sealing windows, the other susceptible person in
the room will likely (with 10% risk tolerance) become
infected via airborne transmission, i.e., over distanc-
es larger than 1.8 m, within 13 hours by the wild-type
(Wuhan) strain or within 9 hours by the alpha strain
and within 7 hours by the delta strain, assuming that
both subjects are resting and not wearing face masks
(25). If room ventilation is improved from 0.3 to 8 ACH,
the time to likely airborne infection of the other suscep-
tible person increases to 14 days by the wild-type strain, to
8 days by the alpha strain, and to 2 days by the delta
strain, respectively (25).

5 Air humidity

Relative air humidity is an important factor in air-
borne virus transmission (26). In dry air, water evapo-
rates from exhaled infective droplets, hence the droplets
decrease in size and float in the air for longer periods
than larger droplets that fall to the ground sooner (26).
The air's capacity for water vapour strongly depends on its temperature: for instance, air with a temperature of 30°C can hold more than three times as much water vapour as air at 10°C (26). When cold winter air warms up to room temperature in indoor spaces, it remains dry (26). The optimal air humidity in indoor spaces is 40–60%, since dry air not only promotes the airborne spread of infective exhaled droplets but also dries the respiratory mucosa and reduces its resistance to pathogenic viruses and bacteria (26). According to the model by authors from the MIT, increasing relative air humidity from 20% to 60% prolongs the time to likely airborne infection of the next susceptible person in a poorly ventilated hospital room from 13 to 18 hours (25), which means that air humidification cannot sufficiently substitute for good ventilation.

6 Air filtration

High-efficiency particulate air (HEPA) filters are increasingly recognized as useful tools for maintaining good air quality in indoor environments. According to European standards, HEPA filters must remove at least 99.95% of particles with a diameter of 0.3 μm or larger from the air that passes through (27). HEPA filters are a vital adjunct to ventilation systems, especially those that do not directly exchange indoor air with outdoor air, but rather air between indoor spaces, which is dangerous without proper filtration (28). The size of the SARS-CoV-2 virus has been estimated to be 50 -140 nm (29) and HEPA filters are still efficient in retaining particles of this size by the diffusion and interception regime (30,31). It is noteworthy that the New York public school system has purchased 30,000 HEPA filters as of November 2020, to augment their heating, ventilation and air-conditioning systems in classrooms (31).

7 Ultraviolet light for pathogen inactivation

Ultraviolet (UV) light effectively inactivates pathogens in the air and on non-porous surfaces (32). UV lights may nowadays only be used in rooms that are not simultaneously occupied by people (32,33). However, between 1937 and 1943, outbreaks of measles, mumps, and chickenpox were highly contained in American classrooms that employed UV lights installed at 2.1 m height and pointed upwards (34). Promising results for contemporary use in inhabited rooms have been reported by far-UVC light with wavelengths of 207-222 nm, which should not be harmful to human tissues, since such wavelengths penetrate only a few μm into tissues but still efficiently inactivate viruses (33).

8 Concluding remarks

The whole world has high expectations especially from mRNA vaccines against SARS-CoV-2 that have been developed in record time and have been proven remarkably effective and safe (35,36). Unfortunately, at first due to the limited supply of vaccines, and later due to vaccine hesitancy, vaccination has been proceeding slowly in many countries, including Slovenia, and herd immunity has not yet been reached. Additionally, there are other respiratory pathogens besides SARS-CoV-2 that are transmitted by aerosols, among them influenza (37,38). It is therefore prudent to address the prevention of the airborne spread of respiratory diseases in addition to promoting large-scale vaccination against COVID-19. It is still advisable to adhere to proper hand hygiene, mask use in indoor spaces and also outdoors under crowded conditions, and maintain a reasonable interpersonal distance. However, for children, it is better to wash their hands than to use disinfectants since systemic resorption of disinfectants resulting in poisoning has been reported in children (39).

From the public health perspective, it is wise to promote outdoor activities (16-18), which however is not a reasonable alternative for hospitals and nursing homes that urgently need adequate ventilation and air filtration systems. Morawska and co-workers have appealed in their Science paper that airborne virus transmission should be recognized as a serious public health threat that should be systematically addressed, just as contaminated water and food have been addressed and successfully dealt with in the past (40).

From the public health perspective, it is more rational to focus on preventing super-spreader events in poorly ventilated indoor environments than to restrict the mobility of people outdoors (21). CO₂ meters are advisable for public indoor spaces since the concentration of CO₂ approximates the concentration of exhaled contagious aerosols (41,42). The recommended safe level CO₂ in the air is less than 750 parts per million, but one should keep in mind that CO₂ no longer reflects the contagious aerosol content of air when people sing or shout (41,42).

For nursing and healthcare personnel who are at high risk of being in contact with infected individuals, personal protective equipment should be provided (18). Regarding airway protection, personal protective
equipment according to the Slovenian standards begins at the level of FFP2/N95 masks (43-45).

Physical protection against respiratory virus transmission is not cheap, but the costs of a pandemic are by far greater.

**Conflict of interest**
None declared.

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A similar text in Slovenian language has been published in the July 2021 issue of ISIS, the professional journal of the Medical Chamber of Slovenia (47).
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