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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 in 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 SARS-CoV-2, zato tudi varnostna priporočila niso bila v celoti ustrezna. Ob dihanju, govoru, petju, kašljanju in kihanju

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Ključne besede: covid-19; aerogeni prenos; zračenje; filtriranje zraka; zračna vlaga; ultravijolična svetloba

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človek izloča iz dihal v svojo okolico kapljice različnih velikosti, vselej pa je največ kapljic, manjših od 1 µm. Kapljice, ki so manjše od 5 µm, se v zaprtih prostorih dolgo zadržijo v zraku in se širijo na razdalje, ki so mnogo daljše od 2 m. Okužena oseba v zaprtih prostorih ustvarja kužni aerosol, s katerim se lahko okužijo druge osebe, tudi če z okuženim niso v tesnem stiku. Kratek pregledni članek predstavi matematični model in internetno aplikacijo avtorjev z Massachusetts Institute of Technology za izračunavanje verjetnosti aerogene okužbe v zaprtih prostorih. Na kratko je predstavljen pomen zračenja ter filtriranja, vlaženja in dezinfekcije zraka z ultravijolično svetlobo za preprečevanje aerogenega prenosa. Besedilo povzema načelna priporočila za omejevanje aerogenega prenosa virusa SARS-CoV-2.

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.

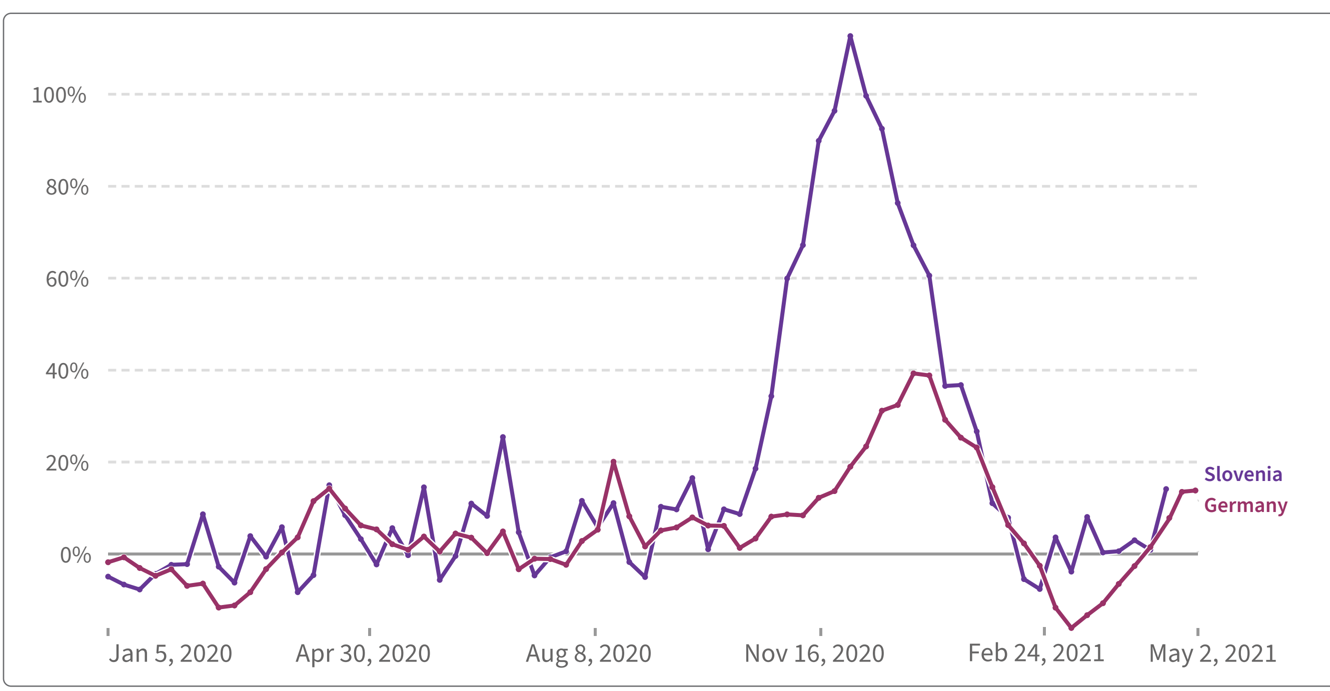

Figure 1: Excess mortality during the autumn/winter 2020/2021 period of the COVID-19 pandemic in Slovenia and Germany, according to Our World in Data, 2021 (1).
The percentage difference between the reported number of weekly or monthly deaths in 2020–2021 and the average number of deaths in the same 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 aerosol 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 breathing (13). With airflow velocities typical of indoor spaces, 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 scientist, 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 transmission in poorly ventilated indoor spaces (15). The commentary 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 scientific 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 longer time (18). The medical community was informed of this matter by a commentary in Lancet Respiratory Diseases (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 research group led by Jure Leskovec from Stanford University, 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 transmissions (21). Low-income Americans were most likely to contract COVID-19 in churches, whereas high-income Americans were most likely to become infected in restaurants, cafés, and fitness centres (21).

Authors from the Massachusetts Institute of Technology (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 recent 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). Admittedly, 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 individual has resided long enough to create stationary conditions of the infective aerosol, another person entering the room without protective equipment becomes infected 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 enters the room (25). When an infected individual enters 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 distances 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 susceptible 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 airborne virus transmission (26). In dry air, water evaporates 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). CO_2 meters are advisable for public indoor spaces since the concentration of CO_2 approximates the concentration of exhaled contagious aerosols (41,42). The recommended safe level CO_2 in the air is less than 750 parts per million, but one should keep in mind that CO_2 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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This mini-review is a follow-up of the lecture presented at the meeting of the Medical Board of the University Medical Centre Ljubljana on December 21, 2020, that is available on-line (46).

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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