Medical Hypotheses 141 (2020) 109781

Contents lists available at ScienceDirect

Medical Hypotheses

journal homepage: www.elsevier.com/locate/mehy

Airborne route and bad use of ventilation systems as non-negligible factors in SARS-CoV-2 transmission

G. Correia[a,b,*], L. Rodrigues[b], M. Gameiro da Silva[c], T. Gonçalves[a,b]

[a] CNC - Center for Neurosciences and Cell Biology, University of Coimbra, Portugal
[b] FMUC - Faculty of Medicine, University of Coimbra, Coimbra, Portugal
[c] ADAI, LAETA Department of Mechanical Engineering, University of Coimbra, Portugal

ARTICLE INFO

Keywords:
SARS-Cov-2
COVID-19
Aerosol
Ventilation
HVAC

SUMMARY

The world is facing a pandemic of unseen proportions caused by a corona virus named SARS-CoV-2 with unprecedent worldwide measures being taken to tackle its contagion. Person-to-person transmission is accepted but WHO only considers aerosol transmission when procedures or support treatments that produce aerosol are performed. Transmission mechanisms are not fully understood and there is evidence for an airborne route to be considered, as the virus remains viable in aerosols for at least 3 h and that mask usage was the best intervention to prevent infection.

Heating, Ventilation and Air Conditioning Systems (HVAC) are used as a primary infection disease control measure. However, if not correctly used, they may contribute to the transmission/spreading of airborne diseases as proposed in the past for SARS.

The authors believe that airborne transmission is possible and that HVAC systems when not adequately used may contribute to the transmission of the virus, as suggested by descriptions from Japan, Germany, and the Diamond Princess Cruise Ship. Previous SARS outbreaks reported at Amoy Gardens, Emergency Rooms and Hotels, also suggested an airborne transmission.

Further studies are warranted to confirm our hypotheses but the assumption of such way of transmission would cause a major shift in measures recommended to prevent infection such as the disseminated use of masks and structural changes to hospital and other facilities with HVAC systems.

Background

The world is now facing a pandemic caused by a novel coronavirus, named Severe Acute Respiratory Syndrome virus corona virus 2 (SARS-CoV-2). The disease was called COVID-19 by the World Health Organization (WHO) [1]. Although it is the third epidemic caused by coronavirus in the 21st century, the current number of infected individuals has already surpassed the previous two [2]. So far only compulsory social isolation and mass mask usage have shown to potentially control the spread of the disease [3].

The contagiousness and rapid spread has been a main characteristic of this outbreak but the transmission routes for person-to-person virus infection are not fully understood [4,5]. It is highly contagious as it spread to almost the whole China in just 14 days [2], and it is continuing to spread all over the world. As the mechanisms of transmission are not completely known it is difficult to evaluate the effectiveness of different measures for controlling the pandemic [6]. So far, WHO considers that the route of human-to-human transmission of SARS-CoV-2 is either via respiratory droplets or contact and recommends the use of N95 masks only in the context of aerosol generating procedures based on findings suggested by available information [7,8].

Aerosol transmission refers to the possibility that fine aerosol particles, called droplet nuclei, remain airborne for prolonged periods. True aerosol transmission involves particles of < 5 μm [8].

Airborne transmission for corona virus has not yet been clearly established but there is growing evidence for aerosol-driven infection [9,4,10,11,12,13] (Figs. 1 and 2).

The hypothesis – Airborne transmission is possible for SARS-CoV-2 and the bad use of ventilation systems may contribute to its propagation

The authors believe in airborne transmission of the SARS-CoV-2 in addition to droplet transmission, as an important cause of infection and spreading. We address the issue of aerosol transmission of the disease in closed environments but also consider the possibility of community

* Corresponding author.

https://doi.org/10.1016/j.mehy.2020.109781
Received 14 April 2020; Accepted 21 April 2020

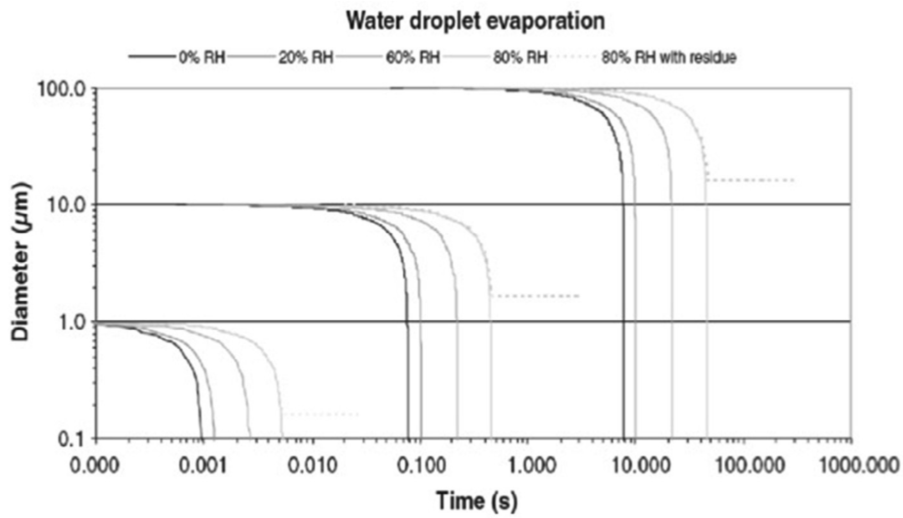

Fig. 1. Liquid phase evaporation for water droplets relative to their dimension and RH [23].

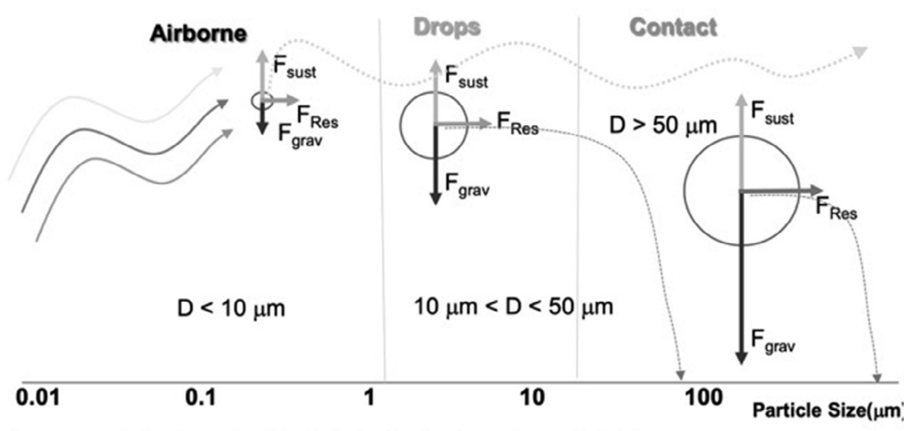

Fig. 2. Typical particle trajectory for air particles relative to their dimension [23].

transmission. Specifically, the authors reviewed the possible impact of Heating, Ventilation and Air Conditioning Systems (HVAC) in buildings, such as hospitals or other healthcare facilities, as contributors for the spread of the virus.

SARS-CoV-2 belongs to the betaCoVs category. It has a diameter of approximately 60–140 nm and spherical or ellipsoid and often pleomorphic form [14]. Still, standard ventilation systems use filters with pore diameter often > 1micron. Only specific locations, such as isolation rooms or intensive care units are equipped with more efficient filters, such as HEPA. The same applies to exhausted air from health care facilities.

The Federation of European Heating, Ventilation and Air Conditioning associations (REHVA), recently published an updated guidance on *How to operate and use building services in order to prevent the spread of the coronavirus disease (COVID-19) virus (SARS-CoV-2) in workplaces*. This document suggests changes to operation of the HVAC systems in order to "prevent the spread of COVID-19 depending on HVAC or plumbing systems related factors". The recommendations addressed are mainly to stop air recirculation and to increase the inflow of outdoor air [15]. When such conditions are not met, we propose three hypothetic ways in which HVAC systems can contribute to virus transmission:

A) Through air circulation in confined compartments with infected patients;

Production of infectious droplets and subsequent spread to surrounding environment is determined by generation and annihilation processes [16] and may be affected by many variables such as air temperature, relative humidity and ventilation rate(VR) [17,18]. Thus, airborne particles that diffuse can be carried by air movements due to ventilation systems [16,55]. Still, there is no definite consensus about the ideal VR [18].

Sanitary facilities must also be addressed as a major factor of virus propagation [15], since it has been proven that the virus is excreted on urine and feces [19] and sanitary facilities ventilation systems are potentially quite sensitive for the possible propagation of SARS-CoV-2.

B) Through recirculating air in building ventilation systems;

This type of propagation depends on the characteristics of settings and air circuits for HVAC systems. This is a possible mechanism by the which the virus can spread to different floors or to different compartments on the same floor [20].

C) Every HVAC system comprises a pool of recirculating air to allow for systematic renovation of that air by exchanges with air outside the building. Usually these units are placed on top of the buildings and can be a potential threat to the environment surrounding healthcare facilities. Although posing a smaller probability for transmission, we believe this hypothesis should be addressed in case adequate exhaust filtering systems are not mounted.

Missing links in transmission - SARS-COV-2

Transmission of infectious diseases can occur through direct contact with infected individuals, indirect contact via fomites, droplet transmission, and aerosolized fine particles (airborne transmission). WHO and CDC define droplets as being > 5 μm and airborne pathogen transmission to occur from desiccated droplets < 5 μm in size [7]. The latter are both air transmission routes but differ in the way that large droplet (> 10 μm) formed from coughing and sneezing typically fall to surfaces no further than 1–2 m from the infected person. On the contrary, airborne transmission is due to small particles (< 5 μm) that may stay airborne for hours and therefore can travel long distances. These particles form from droplets which evaporate and desiccate [15].

For the current pandemic, WHO considers 3 main routes for transmission: infective respiratory droplets, fomites and specific circumstances and settings in which procedures or support treatments that generate aerosols are performed [14,1]. Nevertheless, other routes for transmission cannot be excluded [21,20,5,22].

Corona Virus have a lipid envelope and therefore survive longer in conditions with lower (< 50%) relative humidity (RH) and their persistence eliminated at RH > 80%.

During the first stages of the current outbreak, two case descriptions point out to recent transmission of the disease because of identical genome of the virus, albeit there was no direct link between cases or between cases and Huanan Seafood Market [24].

Also in the current outbreak, 18 patients with confirmed infection, in Zhuhai, Guangdong, China, were assessed for viral loads in their noses and throats. Loads detected in symptomatic patients with SARS-COV-2 were high, comparing to those with SARS-CoV-1. Authors stated that the viral nucleic acid shedding pattern of these patients resembled that of patients with influenza, and found an asymptomatic patient with a similar viral load [25]. This finding further supports the hypothesized transmission from an asymptomatic patient as also suggested by a case report in Germany [26] and was later confirmed that asymptomatic individual could be shedding the virus 2–3 days before the onset of symptoms [27].

Such cases reinforce the hypothesis of airborne transmission in the sense that transmission is less likely to occur through droplets as people transmitting the disease are not coughing or sneezing.

The hypothesis may be further supported by the evidence that most cases of infection remain undocumented [28,3] and therefore the transmission routes accepted can be insufficient to explain the large number of infected individuals. This idea is reinforced by the fact that, in China, before the application of travel restrictions and other heightened control measures, a large proportion - as high as 86% - of SARS-COV-2 infections were undocumented and these were 55% as contagious as documented infections [6].

The occurrence of the so-called super spreading events provides further indirect evidence for the airborne route to be considered, as well as for the ventilation effect on the dispersion of infective particles. Super spreaders are contagious individuals who, in given circumstances, transmit the virus to many more others [20,29]. These instances contribute to the heterogeneity of R0 and are dependent on many factors, including pathogen-specific, host and environmental. Healthcare facilities pose great risks for this type of events with COVID-19 rapid person-to-person transmission [30]. The authors believe that factors such as high population density and possible dispersion of viral particles by ventilation systems with low ventilation rates could have contributed to superspreading events in such settings.

A recent event illustrating airborne route as a major contributor for superspreading events occurred in a choir rehearsal where 45 out of 60 people were infected, despite adequate caution measures for fomite and droplet transmission being taken and none presented symptoms [31].

Past examples

Back in 2003, a cluster of SARS in Hong Kong led researchers to believe that indirect transmission of the disease occurred. This happened presumably, from the index case to another individual staying in the same hotel floor, and some secondary cases occurred after indirect exposure in hospital facilities in a confined space [32]. Other SARS outbreaks like the Amoy Garden outbreak in 2003 led to the hypothesis of, at least, an opportunistic airborne transmission [9,13]. Bathrooms sewage systems were the probable contamination route for residents at Amoy Gardens. Researchers believed that the drainage of contaminated fluids from one bathroom floor could have led the virus into the sewage system. It was also suggested that the droplets could enter other bathrooms by the negative pressure generated when the door is closed. The authors didn't found support for other routes of transmission such as the airborne [33]. Also, during the 2003 SARS outbreak, an emergency room (ER) outbreak was studied. Researchers failed to trace a common source for several cases of SARS, especially amongst hospital care workers (HCWs). Samples were collected at multiple ER sites, including positive samples for the outlet of the central air supply. Air samples were collected at central air supply and all turned up negative. However, the operation of the ER was suspended three days earlier to the air samples collection [22].

Another example of an air distribution study on a hospital ward where an outbreak of SARS took place, provided evidence of an environmental transmission route for SARS in that setting. It was the largest nosocomial outbreak reported at the time where an airborne transmission was considered.[12]

Other arguments towards an airborne transmission route

In COVID19, as in other diseases, there has been considerable debate on airborne transmissibility in the absence of droplets and physical contact [4]. According to their size and environment conditions, particles will assume different trajectories and dissemination patterns. For airborne infectious particles longer distances for transmission and longer floating times are possible [23,4,17].

As in Middle East Respiratory Syndrome (MERS-CoV) virus [34], it has been demonstrated in SARS-COV-2 that the virus remains viable in aerosols for at least 3 h and it remains stable on plastic and stainless steel for up to 72 h. This makes it plausible for easy aerosol [4] and fomite transmission [2,35]. Also, the virus has been detected in stool samples.[36,35] In the 2015 MERS outbreak there was an environmental detection of infectious MERS-CoV in the air and on inaccessible surfaces suggesting that MERS-CoV might be transmitted via contact and airborne routes, and not only from droplet exposure [37,4].

Other fact supporting this hypothesis is the high basic reproduction number. The basic reproduction number (R0) represents the average number of new infections that an infectious individual generates in a totally naïve population. Estimation for R0 of SARS-CoV-2 is variable but larger than the R0 for the MERS and SARS-CoV outbreaks.

In the cruise ship Diamond Princess, the overall mean reproduction number reached values as high as ∼ 11 [28]. This indicates larger transmissibility of the SARS-CoV-2 in a confined setting [38,28].

A study designed to evaluate the use of N95 masks in medical staff (doctors and nurses) in hospital facilities concluded that none of the 278 medical staff using N95 masks became infected with SARS-CoV-2 whereas 10 out of 213 doctors or nurses became infected, regardless of their lower risk of exposure [39]. In 2011, a Cochrane review highlighted that masks were the best intervention in infection prevention across population, settings and threats. The authors found no evidence for the superiority of FFP over surgical masks [40].

Aerosol transmission allows for the virus to be transported over longer distances by airflow [21]. Also, small aerosols are more likely to be inhaled deep into the lung and cause infection in the alveolar tissues of the lower respiratory tract [41,42], leading to more severe forms of the disease [4]. Likewise, as in SARS, high viral load was associated with more severe forms of the disease [43] in COVID-19[44].

HVAC systems as a mean of propagation

Ventilation is a primary infectious disease control strategy in hospitals and other facilities [45]. It promotes the dilution of room air around a source and the removal of infectious agents. However, factors related to HVAC systems in buildings have a role in airborne pathogen transmission [18,4,42,17,46,55]. Additionally, the authors consider that the spreading of the disease among patients may be facilitated in facilities via common ducts, where there are no HEPA filters [47].

Ventilation systems have been reported as a way of transmission/spreading of infectious diseases such as measles, tuberculosis, chickenpox, influenza, smallpox and SARS [18,4]. In the case of measles, an airborne infection caused by an RNA virus, HVAC systems are warranted in order to protect from nosocomial infections but, in such cases, HEPA filters must be used, not only in settings [4], but also in outlet exhaustion tubes. In tuberculosis, airborne transmission, specifically in healthcare facilities, is influenced by many factors but ventilation with fresh air is a major determinant to reduce transmission risk to staff and other patients. Low rate of air changes per hour and poor maintenance of ventilation systems are also associated with TB outbreaks [48,49].

In healthcare facilities the density of infected individuals increases the rate that pathogen-loaded droplets are shed [16], which can be problematic in overcrowded hospital rooms and lead to more severe disease [43,44].

In the current outbreak, the Diamond Princess cruise ship is a study case for the propagation of the disease. The main route for transmission was considered to be from person-to-person but other routes should not be neglected such as aerosol transmission via central air supply or drainage systems [50].

Transmission by aerosols was also addressed regarding airplanes, but has been put aside, because the disease only spread from infected passengers to others in close contacts, with lower transmissible rates [51,24]. This supports our airborne transmission hypothesis since airplane cabin ventilation systems have HEPA filters which will allow the extraction of air viral particles [52].

Legionelosis is the prototype for aerosol transmission for community acquired infection transmitted by buildings cooling towers [53]. Legionella is an aerosol transmitted pathogen that has a unique water-to-air transmission route and cooling towers are perhaps the most widely known source of legionellosis [46,54]. It is possible for the HVAC systems, including ductwork, to have a role in its transmission, although they remain unexplored [46].

Likewise, there is a theoretical possibility that the aerosolized particles containing the virus that enter the ventilation ducts in hospitals attending COVID-19 patients may be exhausted through ventilation system to the environment and contribute to further sporadic cases, as in the case of Legionella, with cooling tower associated transmission. This has already been hypothesized and verified through air flow analysis of transmission to other blocks of apartments in the Amoy Gardens outbreak in 2003 and was affected by wind direction [13].

Discussion

As a major threat to humans worldwide, strong unprecedent measures are being taken to control the SARS-CoV-2 pandemic. Some of these have been implemented without a complete understanding of their effects on controlling viral spread, mostly because of the lack of knowledge on the transmission routes of the SARS-CoV-2. There are missing links in transmission and possible unknow indirect infection routes in many epidemiological studies. Pure aerosol transmission is denied by WHO but several pieces of evidence support this hypothesis. The witnessed rapid spread of the virus points out to an even more effective transmission route and hence, airborne transmission must be considered plausible. HCWs are, also, at greater risk of acquiring the infection and the most effective way of protection has been through the use of N95 masks [39,40]. Person-to-person transmission is accepted and possibly asymptomatic patients can be a major source of contagiousness.

The authors address HVAC as major source for indoor and environmental contamination that can explain the swift viral spread. The confirmation of such way of transmission can constitute a major shift in the battle against the pandemic.

Upon considering the airborne transmission for the COVID-19 pandemics, urgent measures need to be taken to guarantee effective control of the pandemic. This can include the widespread recommendation for mask use, the use of more protective equipment for HCWs, as well as structural changes to hospital facilities regarding ventilation systems.

Funding

The authors declare no funding sources or grants were attributed to this work.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Coronavirus disease (COVID-2019) situation reports. 2020. (Accessed 26th of February 2020, at https://www.who.int/emergencies/diseases/novel-coronavirus-2019/situation-reports/.).
[2] Wang D, Zhou M, Nie X, Qiu W, Yang M, Wang X, et al. Epidemiological characteristics and transmission model of Corona Virus Disease 2019 in China. J Infect [Internet]. 2020 Mar; Available from: https://linkinghub.elsevier.com/retrieve/pii/S0163445320301201.
[3] Leung CC, Lam TH, Cheng KK. Mass masking in the COVID-19 epidemic: people need guidance. Lancet (London, England) [Internet]. 2020;395(10228):945. Available from: http://www.ncbi.nlm.nih.gov/pubmed/32142626.
[4] Shiu EYC, Leung NHL, Cowling BJ. Controversy around airborne versus droplet transmission of respiratory viruses. Curr Opin Infect Dis [Internet]. 2019 Aug;32(4):372–9. Available from: http://insights.ovid.com/crossref?an=00001432-201908000-00012.
[5] Han Q, Lin Q, Ni Z, You L. Uncertainties about the transmission routes of 2019 novel coronavirus. Influenza Other Respi Viruses. 2020:1–2.
[6] Li R, Pei S, Chen B, Song Y, Zhang T, Yang W, et al. Substantial undocumented infection facilitates the rapid dissemination of novel coronavirus (COVID-19). medRxiv. 2020;3221(March):2020.02.14.20023127.
[7] World Health Organization (WHO). Advice on the use of masks in the community, during home care and in healthcare settings in the context of the novel coronavirus (2019-nCoV) outbreak. Who [Internet]. 2020;2020(January):1–2. Available from: https://www.who.int/docs/default-source/documents/advice-on-the-use-of-masks-2019-ncov.pdf.
[8] Modes of transmission of virus causing COVID-19 : implications for IPC precaution recommendations. 2020;(March):10–2.
[9] Roy CJ, Milton DK. Airborne transmission of communicable infection - the elusive pathway. N Engl J Med. 2004;350(17):1710–2.
[10] Judson SD, Munster VJ. Nosocomial transmission of emerging viruses via aerosol-generating medical procedures. Viruses. 2019.
[11] Luongo JC, Fennelly KP, Keen JA, Zhai ZJ, Jones BW, Miller SL. Role of mechanical ventilation in the airborne transmission of infectious agents in buildings. Indoor Air 2016;26(5):666–78.
[12] Li Y, Huang X, Yu ITS, Wong TW, Qian H. Role of air distribution in SARS transmission during the largest nosocomial outbreak in Hong Kong. Indoor Air 2005;15(2):83–95.
[13] Yu ITS, Li Y, Wong TW, Tam W, Chan AT, Lee JHW, et al. Evidence of Airborne Transmission of the Severe Acute Respiratory Syndrome Virus. N Engl J Med. 2004;350(17):1731–9.
[14] Cascella M, Rajnik M, Cuomo A, Dulebohn SC, Di Napoli R. Features, Evaluation and Treatment Coronavirus (COVID-19) [Internet]. StatPearls. 2020. Available from: http://www.ncbi.nlm.nih.gov/pubmed/32150360.
[15] Kurnitski J, Boerstra A, Franchimon F, Mazzarella L, Hogeling J, Hovorka F, et al. REHVA COVID-19 guidance document , March 17 , 2020 (updates will follow as necessary) How to operate and use building services in order to prevent the spread of the. 2020;2020(i):1–6.
[16] Robinson M, Stilianakis NI, Drossinos Y. Spatial dynamics of airborne infectious diseases. J Theor Biol. 2012;297:116–26.
[17] Shajahan A, Culp CH, Williamson B. Effects of indoor environmental parameters related to building heating, ventilation, and air conditioning systems on patients' medical outcomes: A review of scientific research on hospital buildings. Indoor Air 2019;29(2):161–76.
[18] Li Y, Leung GM, Tang JW, Yang X, Chao CYH, Lin JZ, et al. Role of ventilation in airborne transmission of infectious agents in the built environment ? a multidisciplinary systematic review. Indoor Air [Internet]. 2007 Feb;17(1):2–18.

Available from: http://doi.wiley.com/10.1111/j.1600-0668.2006.00445.x.
[19] Wang W, Xu Y, Gao R, Lu R, Han K, Wu G, et al. Detection of SARS-CoV-2 in Different Types of Clinical Specimens. Jama [Internet]. 2020;23–4. Available from: http://www.ncbi.nlm.nih.gov/pubmed/32159775.
[20] Mkhatshwa T, Mummert A. Modeling super-spreading events for infectious diseases: Case study SARS. IAENG Int J Appl Math. 2011;41(2):82–8.
[21] Tellier R, Li Y, Cowling BJ, Tang JW. Recognition of aerosol transmission of infectious agents: A commentary. BMC Infect Dis. 2019;19(1):1–9.
[22] Chen YC, Huang LM, Chan CC, Su CP, Chang SC, Chang YY, et al. SARS in Hospital Emergency Room. Emerg Infect Dis. 2004;10(5):782–8.
[23] Gameiro da Silva M. An analysis of the transmission modes of COVID-19 in light of the concepts of Indoor Air Quality, preprint published in Research Gate, April 2020, DOI: 10.13140/RG.2.2.28663.78240 < https://www.researchgate.net/publication/340435784_An_analysis_of_the_transmission_modes_of_COVID-19_in_light_of_the_concepts_of_Indoor_Air_Quality > .
[24] Okada P, Buathong R, Phuygun S, Thanadachakul T, Parnmen S, Wongboot W, et al. Early transmission patterns of coronavirus disease 2019 (COVID-19) in travellers from Wuhan to Thailand, January 2020. Euro Surveill [Internet]. 2020;25(8). Available from: http://www.ncbi.nlm.nih.gov/pubmed/32127124.
[25] Rna Z, Control D, Guiana F, Rna Z, Zika R, Kit VR, et al. SARS-CoV-2 Viral Load in Upper Respiratory Specimens of Infected Patients. N Engl J Med. 2017;7–9.
[26] Rothe C, Schunk M, Sothmann P, Bretzel G, Froeschl G, Wallrauch C, et al. Transmission of 2019-nCoV Infection from an Asymptomatic Contact in Germany. N Engl J Med. 2020;2019–20.
[27] He X, Lau EH, Wu P, Deng X, Wang J, Hao X, et al. Temporal dynamics in viral shedding and transmissibility of COVID-19. medRxiv [Internet]. 2020;2020.03.15.20036707. Available from: https://www.medrxiv.org/content/10.1101/2020.03.15.20036707v2.
[28] Mizumoto K, Chowell G. Transmission potential of the novel coronavirus (COVID-19) onboard the diamond Princess Cruises Ship, 2020. Infect Dis Model [Internet]. 2020;5:264–70. Available from: https://doi.org/10.1016/j.idm.2020.02.003.
[29] James A, Pitchford JW, Plank MJ. An event-based model of superspreading in epidemics. Proc R Soc B Biol Sci. 2007;274(1610):741–7.
[30] Frieden TR, Lee CT. Identifying and Interrupting Superspreading Events—Implications for Control of Severe Acute Respiratory Syndrome Coronavirus 2. Emerg Infect Dis [Internet]. 2020 Jun;26(6). Available from: http://wwwnc.cdc.gov/eid/article/26/6/20-0495_article.htm.
[31] Read R. A choir decided to go ahead with rehearsal. Now dozens of members have COVID-19 and two are dead. (Accessed 13th of April 2020) Available from: https://www.latimes.com/world-nation/story/2020-03-29/coronavirus-choir-outbreak.
[32] Kenneth W. Tsang, M.D., Pak L. Ho, M.D., Gaik C. Ooi, M.D., Wilson K. Yee, M.D., Teresa Wang, M.D., Moira Chan-Yeung, M.D., Wah K. Lam, M.D., Wing H. Seto, M.D., Loretta Y. Yam, M.D., Thomas M. Cheung, M.D., Poon C. Wong, M.D., Bing Lam, M.D., Mary S. Ip, DS. A Cluster of Cases of Severe Acute Respiratory Syndrome in Hong Kong. N Engl J Med. 2003;348:1977–85.
[33] Lee SH. The SARS epidemic in Hong Kong. J Epidemiol Community Heal [Internet]. 2003 Sep 1;57(9):652–4. Available from: http://jech.bmj.com/cgi/doi/10.1136/jech.57.9.652.
[34] Pyankov O V., Bodnev SA, Pyankova OG, Agranovski IE. Survival of aerosolized coronavirus in the ambient air. J Aerosol Sci [Internet]. 2018;115(September 2017):158–63. Available from: Doi: 10.1016/j.jaerosci.2017.09.009.
[35] Zhang J, Wang S, Xue Y. Fecal specimen diagnosis 2019 novel coronavirus–infected pneumonia. J Med Virol. 2020;7(March):8–10.
[36] Xie C, Jiang L, Huang G, Pu H, Gong B, Lin H, et al. Comparison of different samples for 2019 novel coronavirus detection by nucleic acid amplification tests Available from Int J Infect Dis [Internet]. 2020;93:264–7.
[37] Kim S-H, Chang SY, Sung M, Park JH, Bin Kim H, Lee H, et al. Extensive Viable Middle East Respiratory Syndrome (MERS) Coronavirus Contamination in Air and Surrounding Environment in MERS Isolation Wards Available from Clin Infect Dis [Internet]. 2016 Aug 1;63(3):363–9.
[38] Liu Y, Gayle AA, Wilder-Smith A, Rocklöv J. The reproductive number of COVID-19 is higher compared to SARS coronavirus. J Travel Med. 2020:1–4. (Figure 1).
[39] Wang X, Pan Z, Cheng Z. Association between 2019-nCoV transmission and N95 respirator use. J Hosp Infect [Internet]. 2020 Mar; Available from: Doi: 10.1016/j.jhin.2020.02.021.
[40] Jefferson T, Del Mar CB, Dooley L, Ferroni E, Al-Ansary LA, Bawazeer GA, et al. Physical interventions to interrupt or reduce the spread of respiratory viruses. Cochrane database. Syst Rev. 2011;7.
[41] Thomas RJ. Particle size and pathogenicity in the respiratory tract. Virulence. 2013;4(8):847–58.
[42] Memarzadeh F, Olmsted RN, Bartley JM. Applications of ultraviolet germicidal irradiation disinfection in health care facilities: Effective adjunct, but not stand-alone technology. Am J Infect Control [Internet]. 2010;38(5 SUPPL.):S13–24. Available from: Doi: 10.1016/j.ajic.2010.04.208.
[43] Hung IFN, Cheng VCC, Wu AKL, Tang BSF, Chan KH, Chu CM, et al. Viral loads in clinical specimens and SARS manifestations. Emerg Infect Dis. 2004;10(9):1550–7.
[44] Liu Y, Yan L, Wan L, Xiang T, Le A, Liu J, et al. Viral dynamics in mild and severe cases of COVID-19Dysregulation of immune response in patients with COVID-19 in Wuhan, China Chuan. Lancet Infect Dis [Internet]. 2020;2019(20):2019–20. Available from: Doi: 10.1016/S1473-3099(20)30232-2.
[45] Francisco PW, Emmerich SJ. ASHRAE Position Document on Airborne Infectious Diseases. Ashrae Stand. 2014.
[46] Prussin AJ, Schwake DO, Marr LC. Ten questions concerning the aerosolization and transmission of Legionella in the built environment Available from Build Environ [Internet]. 2017 Oct;123:684–95.
[47] Shakoor S, Mir F, Zaidi AKM, Zafar A. Hospital preparedness in community measles outbreaks-challenges and recommendations for low-resource settings. Emerg Health Threats J. 2015;8(1):1–13.
[48] Escombe AR, Ticona E, Chávez-Pérez V, Espinoza M, Moore DAJ. Improving natural ventilation in hospital waiting and consulting rooms to reduce nosocomial tuberculosis transmission risk in a low resource setting. BMC Infect Dis. 2019;19(1):1–7.
[49] Nardell EA. Transmission and institutional infection control of tuberculosis. Cold Spring Harb Perspect Med. 2016;6(2):1–12.
[50] Zhang S, Diao MY, Yu W, Pei L, Lin Z, Chen D. Estimation of the reproductive number of novel coronavirus (COVID-19) and the probable outbreak size on the Diamond Princess cruise ship: A data-driven analysis. Int J Infect Dis [Internet]. 2020;93:201–4. Available from: Doi: 10.1016/j.ijid.2020.02.033.
[51] Wilder-Smith A, Paton NI, Goh KT. Short communication: Low risk of transmission of severe acute respiratory syndrome on airplanes: The Singapore experience. Trop Med Int Heal. 2003;8(11):1035–7.
[52] Mazumdar S, Chen Q. A one-dimensional analytical model for airborne contaminant transport in airliner cabins. Indoor Air 2009;19(1):3–13.
[53] Walser SM, Gerstner DG, Brenner B, Höller C, Liebl B, Herr CEW. Assessing the environmental health relevance of cooling towers - A systematic review of legionellosis outbreaks. Int J Hyg Environ Health [Internet]. 2014;217(2–3):145–54. Available from: Doi: 10.1016/j.ijheh.2013.08.002.
[54] Orkis LT, Harrison LH, Mertz KJ, Brooks MM, Bibby KJ, Stout JE. Environmental sources of community-acquired legionnaires' disease: A review. Int J Hyg Environ Health [Internet]. 2018;221(5):764–74. Available from: Doi: 10.1016/j.ijheh.2018.04.013.
[55] Qian H, Zheng X. Ventilation control for airborne transmission of human exhaled bio-aerosols in buildings. J Thorac Dis 2018;10(Suppl 19):2295–304. https://doi.org/10.21037/jtd.2018.01.24.