Technical Review

Reduction of Contagion Risks by SARS-Cov-2 (COVID-19) in Air-Conditioned Work Environments

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Background: The coronavirus emergency obliged Italy's government to stop production and trade activities to limit the =risk of contagion. Italy will restart activities in a few days and some security measures will have to be taken to limit the risks of spreading the virus as much as possible.

Objective: This work summarizes the rules that are to be adopted for the reduction of the risks of SARS-CoV-2 infection with particular regard to the air conditioning systems in working environments, the sources of risk, and possible risk reduction measures.

Results: Ducted air systems are of great importance, widespread, and often overlooked in risk assessment. Scientific evidence has shown that air conditioning systems can be both an infection risk reducer and, if misused, a multiplier of infection possibility.

Limitations: A narrative review with paucity of literature.

Key words: Coronavirus, COVID19, HVAC, primary airflow, SARS-CoV-2

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In modern work environments, thermal heating, ventilation and air conditioning (HVAC) systems ensure comfort and microclimate parameters with air heating and cooling and fresh air intake for air exchange.

We will study air management in HVAC systems to reduce SARS-CoV-2 infection risk.

Primary HVAC equipment includes heating equipment, ventilation equipment, and cooling or air-conditioning equipment:

- Total recirculation devices, with no outside air and recirculation of cooled and dehumidified ambient air, can be centralized or autonomous radiant and ventilating devices, such as fan coils, cassette units, split units, or ducted air units with total recirculation
- Partial air replacement devices, with a partial exchange of air from outside
- All-air systems, in which air is taken from outside and no internal air recirculation is provided

The greater the intake of external air, the greater the energy consumption needed to achieve the environmental requirements for the comfort of occupants.

Whenever possible, it is more energy efficient to reuse the air taken from inside the building with the activation of recirculation. Although very advantageous in terms of energy, this choice is very harmful for the well-being of occupants, who need pollutant-free fresh air. One more reason to deprecate this practice is the possibility of spreading pathogens.

A better way to introduce fresh air from the outside, with minor energy cost, is to use energy recovery systems, in which the air taken from inside the building is used to pretreat the primary external air. In this way, you can achieve a management cost reduction of more than 50%. This type of ventilation is called controlled mechanical ventilation (CMV).

In the next days, offices and shopping centers in Italy with commercial activities will reopen and there are many doubts about how to modify and maintain air conditioning systems, especially full air systems (i.e. air conditioning systems using full outside air intake without any inside air recirculation), to eliminate the infection from COVID-19.

Reduction of Infection risk

From a scientific point of view, we observe that COVID-19 is the name of the disease while the correct name of the virus is SARS-CoV-2 (1). Obviously, it is known that the risk of contagion cannot be completely eliminated; we can only try to reduce it to a minimum.

The Italian Istituto Superiore della Sanità (ISS) recently published a series of recommendations to be followed to reduce the risk of SARS-CoV-2 infection (1).

In summary, the ISS recommendations concerning air conditioning systems in the workplace are:

1. Ensure good air exchange in environments without CMV by frequently opening windows to dilute the presence of pollutants.
2. Where existing, keep CMV systems active 24 hours per day, closing air recirculation if possible.
3. Where possible, replace the filters with others of higher filtering capacity (e.g., F7-F9 high efficiency particulate air [HEPA] filters) [Italian National Unification Organization (UNI) European Norm (EN) International Standard Organization (ISO) 16890].
4. In buildings with fan coil heating and cooling systems, heat pumps, or split systems, keep systems off. If the systems cannot be shut down, clean the filters weekly. In any case, open the windows frequently to ensure air exchange.

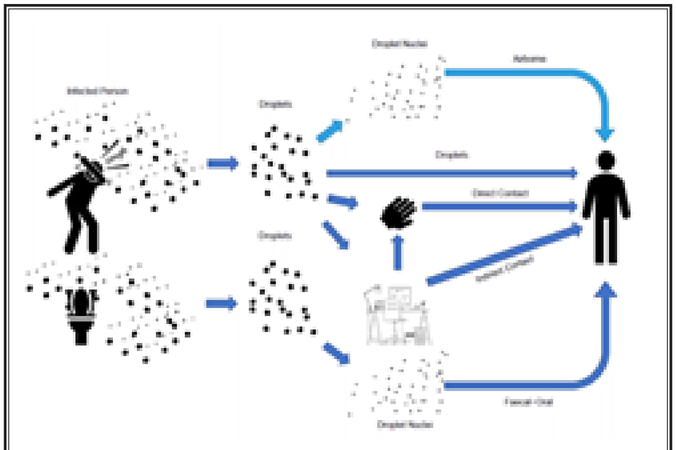

Fig. 1. *How SARS-CoV-2 infects people (fonte REHVA 2020).*

5. Clean the vents and ventilation grilles with 75% alcohol or soap and water.
6. In windowless rooms, always keep fans and extractors on while people are present.

ISS recommendations are certainly excellent and well founded, but they neglect some characteristic features of air conditioning systems that will be addressed below.

Virus Transmission

First of all, we analyze the transmission of the SARS-CoV-2 virus to better identify how to improve HVAC system performances.

It is now well established that infection spreads mainly through droplets expelled by people affected by COVID-19 while breathing, coughing, sneezing, or simply speaking (2).

The saliva droplets containing virus travel in the air along a short journey of an estimated range of 1 m to 1.8 m, are inhaled by people close by, or fall towards the floor or settle on nearby objects from which they can still spread the infection by contact (Fig. 1).

There are some hypotheses that particulate matter of 10 microns in diameter or smaller (PM10) and PM2.5 particulates may be a possible carrier for the virus, increasing its flow rate, but these studies are still ongoing.

Therefore, virus transmission takes place directly via inhaling the droplets containing the virus (so-called aerosol infection) or by bringing unwashed hands contaminated with the virus (deposited on objects) to the mucous membranes (eyes, mouth, nose) (2). Mainly, to have an effective infection, the infected and the healthy persons must share the same physical space, at short distance and for an extended period of time.

In the case of airborne aerosol infections, if infectious nuclei remain suspended in the air indefinitely without falling to the ground, transmission can also take place merely by sharing breathed air (3). For example, this occurs between offices in the same building or between rooms in the same office that share the same ducted air conditioning system. This mode of transmission for the SARS-CoV-2 virus was initially excluded by experts, but some studies have recently been presented that challenge these conclusions (4-6). {

Some recent studies confirm the disappearance of SARS-CoV-2 on different surfaces after less than 4 hours on copper and 24 hours on paper and cardboard. On other surfaces, the 50% tissue culture infective dose (TCID50), the amount of virus needed to destroy or cause any other type of cytopathic effect in 50% of infected cells or cultures, decreases from 103.7 to 100.6 a.u. after 72 hours on plastic and after 48 hours on stainless steel. In air-dispersed aerosol, the SARS-CoV-2 virus has an exponential decay with an emi-value of approximately 1.2 hours (4).

Infection capability depends on available virus quantity, which must exceed a certain threshold for the infection to be effective. This is called the minimum infectious dose (DI0).

To estimate the number of infections, we can use the well-known Wells-Riley formula, developed by a famous health engineer (Wells) who, together with a medical student (Riley), in the 1930s studied the transmission mechanisms of pathogens in textile industries in England.

According to this model, the number of infected people varies with the following mathematical law (7):

$$N_C = S\left(1 - e^{\frac{Iqpt}{Q}}\right)$$

(1)

In the meantime, many other studies on fluid dynamics have proposed much more valid and detailed models, but in general the results are similar.

In Wells-Riley's (W-R) law, the number of infected people (NC) depends on:

S: number of sensitive people present in the environment in question

I: number of infected people capable of transmitting the virus

p: lung ventilation rate of sensitive subjects

q: response of subjects sensitive to the inhalation of infectious nuclei. This variable depends on the fact that not all subjects respond in the same way to the inhalation of infectious nuclei causing the disease. Moreover, it represents the number of "infected" doses introduced into the ambient air, which will be effective in generating the disease.

Q: renewal room airflow rate

W-R's law is based on Poisson's law of small numbers (also called rare events), which assumes that one and only one infection occurs in a sufficiently short period. This is plausible and true for most airborne infections.

How to Reduce Virus Transmission Risk

We need to act on several fronts to reduce the infection risk.

- Reduce the number of people in the environment (S) to reduce the number of infectious subjects
- Reduce the number of people capable of transmitting the virus (I)
- Reduce the exposure time (t)
- Increase the fresh airflow rate (Q)

The first and most important element to act on is the number of infectious people (S) and the exposure time (t) that must be reduced to the bare minimum, managing individual appointments with customers/patients, avoiding waiting in closed rooms, and limiting the number of people present at the same time.

Another aspect of virus transmission reduction concerns the identification of people capable of transmitting the virus (I) by screening incoming people, who must be immediately removed if there is a possible ongoing infection. For this purpose, body temperature-measuring instruments and hand-sanitizing procedures with alcoholic gel are useful. The use of gloves and masks must be made mandatory where possible, remembering that they are not to be considered personal protective equipment (PPE) because they do not protect the wearer but may avoid infection transmission to people close by.

How to Maintain and Modify Air Conditioning Systems to Reduce Risk

In air conditioning systems, increasing renewal air flow (Q) is necessary to dilute pathogens in the environment by reducing the concentration of viruses below DI0.

This is achieved by activating outdoor air systems, avoiding the reuse of recirculated air taken from the environment to prevent the virus from being recirculated.

In systems with internal air recirculation, without external air exchange, any filtering of the recirculated air may not give the desired results. In fact, the submicrometric size of the virus must be considered, which for effective filtering requires the use of very high-efficiency filters (HEPA or absolute). These filters, even if they were dimensionally compatible with existing air ducts, would introduce a big pressure drop in return channels by limiting the useful air flow. Many systems, especially when there are no air handling units but only simple ceiling ducted units, do not allow the use of these filter devices due to their fans' low prevalence. Another important fact to consider is their high operating costs due to the need for periodic replacement of the HEPA filters.

What Can We Do?

We can act on: dilution, filtration, pressurization, and disinfection.

Diluting internal air with fresh primary air taken from the outside, which we consider free of pathogens, allows us to reduce the concentration of infectious nuclei but increases management costs due to the need for a thermal treatment of the external fresh air by heating in winter and cooling in summer.

Filtering the internally recirculated air with filters suitable for blocking particles smaller than 0.1 μm avoids virus circulation of the same size as SARS-CoV-2, reducing the infection risk between different rooms served by a single air duct system. Coronaviruses have roundish morphology and a diameter of about 100-150 nm. It is also necessary to filter the primary external fresh air that we consider free of pathogens in order to avoid capturing polluting particles, PM10 and PM2.5, which are believed to be vectors for the virus.

Pressurizing rooms where there are operators and visitors, with respect to the outside these rooms or other dirty environments, allows us to avoid the return of contaminated air into the workplaces. When we pressurize rooms, it is necessary to ensure an air outlet to the outside, avoiding contamination of common areas such as corridors and lobbies.

Disinfection of environments allows us to reduce the viral and microbial load deposited on objects. Disinfection must be carried out periodically using standardized procedures that provide for the cleaning of exposed surfaces, handles, buttons, telephones, keyboards, touch screens, tables, doors, and walls. It is useful to provide a checklist and a schedule. Disinfection must be a shared job between employees and cleaning companies.

A different system is made up of individual total recirculation devices, such as fan coils, split units, and cassette units. In this case, ISS suggests keeping the systems off to prevent infectious nuclei from being raised from the floor that can increase virus permanence in the air. When air conditioning systems cannot be turned off because of work requirements, intermittent operation must be avoided. Constant speed mode must be selected, in order to prevent infectious nuclei from depositing on the filters and batteries of the indoor air conditioning units and then returned to circulation in the air at the next start of the fans in quantities greater than normal.

Therefore, the best air conditioning systems have primary air flow that "washes" room air, taking away any infectious nuclei in the shortest time.

An In-Depth Analysis of the Transmission Methods

W-R's law is very simple but at the same time has big limits. Rudnick and Milton (8) have shown that W-R's law is valid only in steady state and for total mixing conditions, and it also requires the measurement of external air flow. If the source of infection is punctual (single person) and exposure time is limited (arrival at the instant t0 and duration for a limited Δt) then W-R's law does not provide valid results. In these cases, a fluid dynamic analysis must be performed to calculate the position of every particle in the air instant by instant.

It is widely reported in scientific literature, especially in sanitary engineering studies, that the position of the air intake and intake terminals is fundamental in determining the possibility of contagion between people in the same environment.

Khankari (9), in his case study, examined an environment in which there was an HVAC all-air system (without recirculation); that is the ideal system, as expressed before, in accordance with W-R's law. In this study, he used fluid dynamic modeling software and showed that the position of the terminals, suitably arranged with respect to the occupants, determined a different circulation of the infectious nuclei with a significant increase or decrease in the risk of contagion.

Fig. 2 shows the simulations made by numerical calculation. It is shown how the appropriate choice of the position of the terminals (Fig. 2d) drastically reduces the possibility of bringing the breathing of the lying person (patient) in proximity of the standing person (doctor).

A second, well-known example is the study of SARS-CoV-2 infection in a Chinese restaurant (10). In this case, 10 people from different households but sitting at adjacent tables in the same restaurant room got a positive test result for COVID19 in January 2020.

None of the other 68 guests seated at the other 15 tables and none of the restaurant waiters tested positive for COVID19. In the restaurant there were both total recirculation air conditioning devices and an air exchange system with external primary air intake. It was therefore a partial recirculation system. The au-

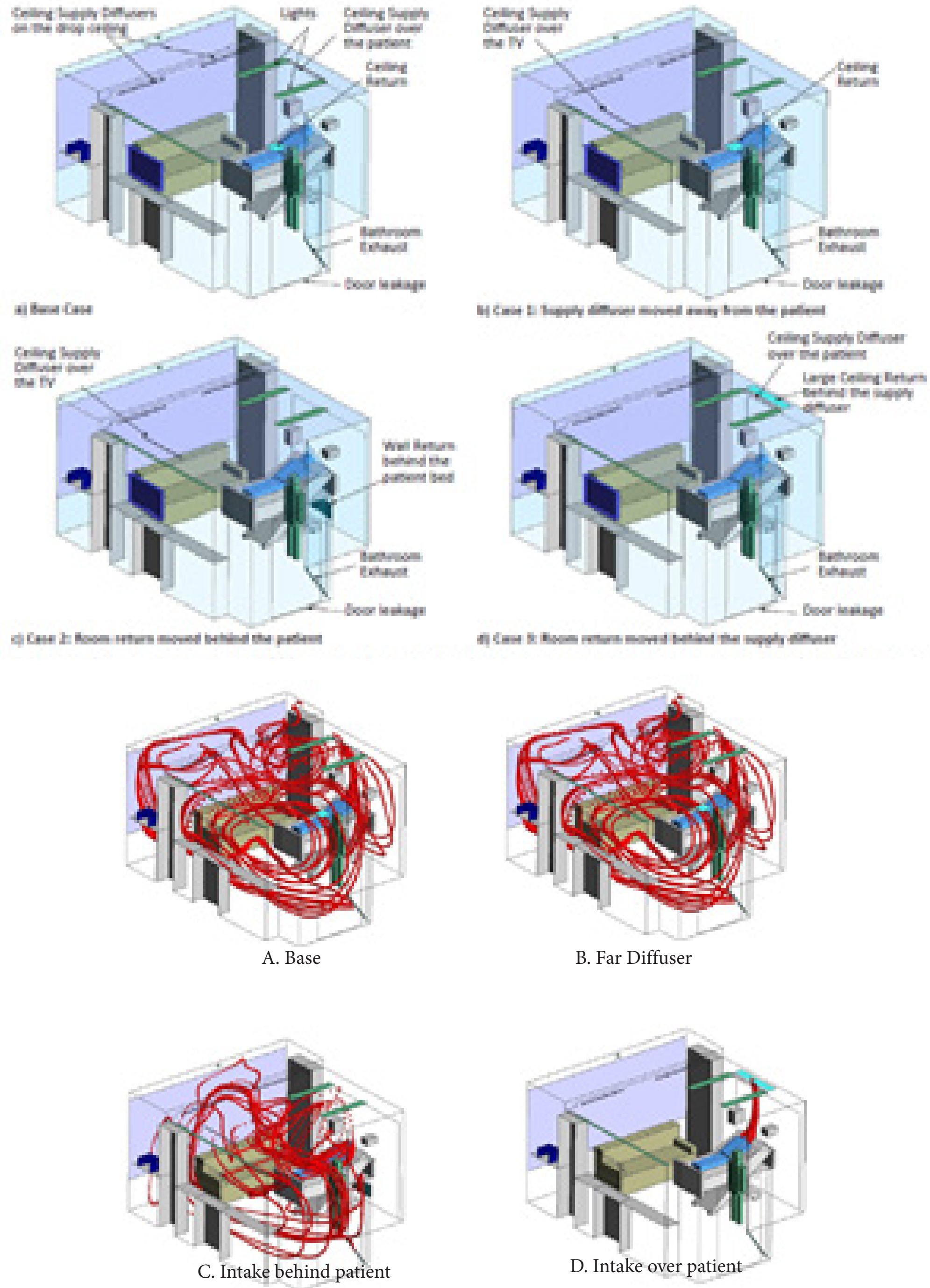

Fig. 2. *Patient room modeling with different HVAC configurations*.

thors' conclusions are that the spread of the virus originated from patient zero (in blue in the simulation) (Fig. 3) and, through the air flow generated by the total recirculation unit, it spread reaching the remaining guests located in the air flow direction.

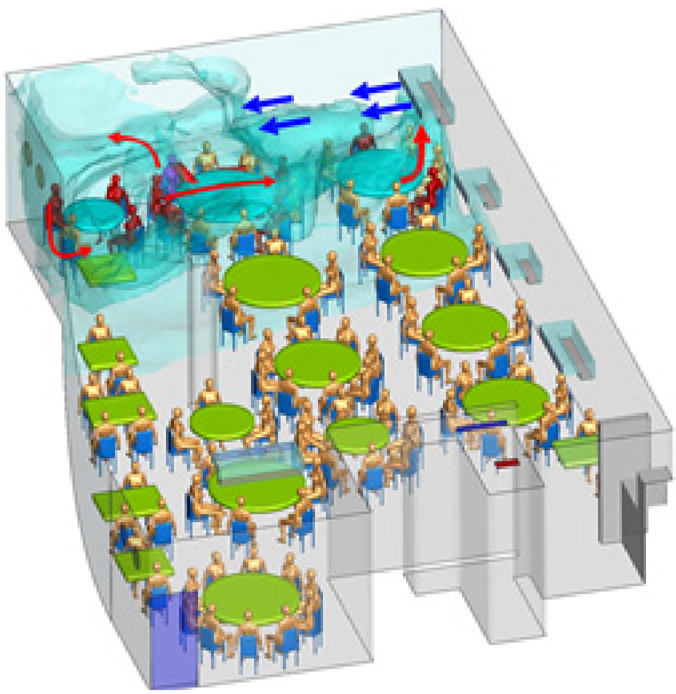

Fig. 3. *Spread simulation of infectious nuclei from patient A (blue). Infected patients are marked in red.*

Infection was made possible both by insufficient dilution of the infectious nuclei, possible only in the presence of an all-air system, and by the long period time that the guests spent in the restaurant.

Effectiveness of Ventilation

The effectiveness of indoor ventilation (physically removing the pathogen) is specified in the US Centers for Disease Control and Prevention guidelines and represents the most effective measure in the infection control pyramid. PPE, the most visible tools that people use, are the least effective (Fig. 4).

Conclusions

Infection from SARS-CoV-2 can occur by contact with contaminated surfaces, absorption of infectious droplets, and, in rare cases, airborne diffusion.

The actions to be taken to reduce the risk of infection in air-conditioned working environments are:

- Eliminate the recirculation of internal air
- Use only systems with all external air
- Ventilate the rooms both in the presence of people and during the night
- Switch off the systems autonomous with recirculation
- Ensure good air exchange even by opening the windows

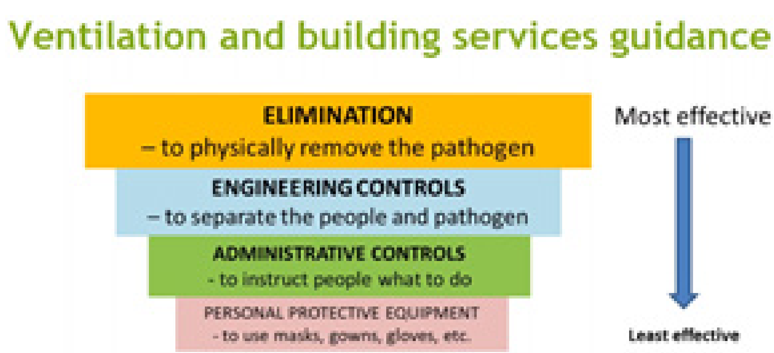

Fig. 4. *Infection control (US Centers for Disease Control & Prevention)*

Indoor air quality is not only a matter of flow rate of primary air input or air cleaning, but it is also necessary to study and optimize the airflow inside the rooms; to extend the risk analysis not only to procedures and activities, but also to the disposition of the furnishings and the relative positions of the occupants.

All the other suggested maintenance activities, such as cleaning the filters, cleaning the ducts, installing HEPA filters, and installing standalone filtering systems, must be considered to be minimally effective strategies in preventing SARS-Cov-2 infection.

The presence of outdoor air systems is very rare, limited to large offices, common areas of shopping centers and cinemas. In these places it will be necessary to verify that the recovery ducts have been closed. Most of the HVAC systems installed in Italy are split, multisplit, or total recirculation air conditioners and they do not guarantee the minimum requirements for the prevention of infection. For these systems it will be necessary to modify the air ducts to provide fresh outside air intake to guarantee the dilution of the virus.

Disclaimer

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Conflict of interest

Each author certifies that he or she, or a member of his or her immediate family, has no commercial association (i.e., consultancies, stock ownership, equity interest, patent/licensing arrangements, etc.) that might pose a conflict of interest in connection with the submitted manuscript.

References

1. Covid-19 - Che cos'è il nuovo coronavirus. Ministero della Salute. www.salute.gov.it/portale/nuovocoronavirus/dettaglioFaqNuovoCoronavirus.jsp?id=228&lingua=italiano#1. Date Updated 06/17/2020.
2. World Health Organization. Getting your workplace ready for COVID-19. www.who.int/docs/default-source/coronaviruse/getting-workplace-ready-for-covid-19.pdf?ua=1. Date Published 03/03/2020. {AU: if you have it, add Date Accessed mm/dd/yyyy}.
3. Encyclopedia of Microbiology, Four-Volume Set - a cura di Martin Alexander, Barry R. Bloom, David A. Hopwood, Roger Hull, Barbara H. Iglewski, Allen I. Laskin, Stephen G. Oliver, Moselio Schaechter, William C. Summers 4. Doremalen N, Bushmaker T, Morris DH, et al. Aerosol and surface stability of SARS-CoV-2 as compared with SARS-CoV-1. *N Engl J Med* 2020; 382:1564-1567.
5. Nishiura H, Linton NM, Akhmetzhanov AR. Serial interval of novel coronavirus (COVID-19) infections. *Int J Infect Dis* 2020; 93:284-286.
6. Allen J, Marr L 2020. Re-thinking potential for airborne transmission of SARS-CoV-2. The Journal of Infectious Diseases, Manuscript Draft.
7. Noakes CJ, Sleigh PA. Applying the Wells-Riley equation to the risk of airborne infection in hospital environments: The importance of stochastic and proximity effects. Paper presented at: Indoor Air 2008; August 17-22 2008; Copenhagen, Denmark.
8. Rudnick SN, Milton DK. Risk of indoor airborne infection transmission estimated from carbon dioxide concentration. *Indoor Air* 2003; 13:237-245.
9. Khankari K. Airflow dynamics of a patient room. *REHVA J* 2017; 5:52-58.
10. Li Y, Qian H, Hang J, et al. Evidence for probable aerosol transmission of SARS-CoV-2 in a poorly ventilated restaurant. *medRxiv* 2020; doi.org/10.1101/2020.04.16.20067728.