Indoor air purifiers as part of the effort to reduce the spread of COVID-19: The advantage of circumferential outflow diffusers

Yevgen Nazarenko[1], Parisa A. Ariya[1, 2]

[1] Department of Atmospheric and Oceanic Sciences, McGill University

805 Sherbrooke St. West Montreal, QC H3A 0B9

[2] Department of Chemistry, McGill University

801 Sherbrooke St. West Montreal, QC H3A 2K6

Abstract

It has been shown that airborne transport occurs for aerosol particles containing virions or the ribonucleic acid (RNA) of the Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2). A recent perspective suggested that a directional outflow from an indoor air purifier could entrain unpurified surrounding air and carry potentially infectious aerosol particles around indoor spaces. The phenomenon could potentially increase the safe distance between people aimed at reducing COVID-19 spread. Because only the case of a directional outflow was examined, here we set out to investigate an indoor air purifier that does not have a unidirectional outflow and has a circumferential outflow diffuser instead (Model C600, Airpura Industries, Inc.). We measured the airflow velocity at two different angles to the surface of the outflow diffuser and two motor/fan speeds (maximum and minimum). We found a significant difference in airflow velocity between the maximum and minimum motor/fan speeds at 45°: 0.01 – 0.02 m/s for 0° vs. 0.01 – 0.65 m/s for a 45° angle at 1 m distance from the diffuser. We further visualized the deflection of a vertical mist spray cone from a sneeze-simulating propellant-powered indoor air freshener nebulizer parallel to the side of the air purifier running at the lowest and highest speed of the motor-fan. The spray cone was imaged in scattered light. It was determined that, under the experimental conditions, the operation of the tested indoor air purifier with a circumferential outflow diffuser does not have a visually significant effect on the shape and direction of the spray cone when the air purifier is operated at the lowest speed. No visible deflection of mist by the outflow at the lowest speed of the motor-fan was observed. At the highest motor-fan speed, the increased airflow through the tested indoor air purifier deflected the spray cone of mist particles around the circumferential outflow diffuser by approximately 5 cm horizontally. We conclude that the deflection of the visible spray mist particles by the tested indoor air purifier with the circumferential outflow, under the experimental conditions, is low relative to the recommended safer distances between people in indoor spaces aimed to reduce the spread of COVID-19 (2 m). Equipping indoor air purifiers with circumferential outflow diffusers has a considerably lower potential to spread infectious aerosols in indoor spaces, compared to devices with unidirectional outflow.

Keywords: Mist, air current, air purifier, airflow, indoor air.

Introduction

Recent research has shown that airborne transport of particles containing virions or the ribonucleic acid (RNA) of the Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) is possible. When SARS-CoV-2 virions were aerosolized, some of them were observed to remain airborne and viable for at least three hours (van Doremalen et al., 2020). The RNA of SARS-CoV-2 was found in airborne particles of 1 μm in diameter and larger in the indoor spaces where patients with Coronavirus Disease 19 (COVID-19) were housed (Chia et al., 2020). SARS-CoV-2 RNA was found in the indoor air at least 3 m from people with COVID-19 (Y. Liu et al., 2020). SARS-CoV-2 RNA was also detected in some particles of air pollution (Setti et al., 2020).

The SARS-CoV-2 virus is around 60 – 140 nm in diameter (Zhu et al., 2020). However, it has been found within larger aerosol particles, including droplets emitted by people infected with COVID-19. Droplets can partially evaporate, resulting in a reduction of their aerodynamic diameter (Vejerano & Marr, 2018; Wells, 1934). Aerosol particles with a smaller aerodynamic diameter can stay airborne longer. A recent study found 12 – 21 µm speech-generated wet droplets drying and shrinking to ~ 4 µm diameter (Stadnytskyi, Bax, Bax, & Anfinrud, 2020). These smaller desiccated droplets were observed to fall in the air by only 30 cm in about 8 minutes (Stadnytskyi et al., 2020). This is the rate of settling that supports numerous observations that viable or non-viable SARS-CoV-2 virions can travel considerable distances through the air. Using ventilation, indoor air purification, and personal protective equipment, such as masks and respirators, is a recommended intervention aimed at reducing the spread of COVID-19 (World Health Organization, 2020).

A recent perspective raised a question on whether air currents generated by the outflow from indoor air purifiers could push unpurified surrounding air within indoor spaces, thereby increasing the distance aerosol particles emitted by people infected with COVID-19 could spread (Ham, 2020). This Perspective included a visualization of an experiment with an indoor air purifier that had a unidirectional outflow with a speed of 10 m/s. The authors mentioned the study limitation that only one model of indoor air purifiers was tested.

Here we set out to test a model of the indoor air purifier that does not have a unidirectional outflow, but rather the cleaned air is expelled through a circumferential diffuser. A circumferential diffuser releases the purified air through multiple openings located all around a section of the device (360°). We hypothesized that a replication of the experiment by Ham (2020) would show a considerably less significant deflection of the spray mist cone in the case of an indoor air purifier with a circumferential outflow through a 360° diffuser.

Methodology

We used an indoor air purifier manufactured by Airpura Industries, Inc., model C600, placed on the floor. This indoor air purifier has a circumferential diffuser with a height of 7 cm all around the perimeter of the air purifier. The indoor air purifier was operated at the lowest and highest speed of the motor-fan. We measured the air velocity at 0° and 45° angles to the vector perpendicular to the surface of the outflow diffuser at ten distances between 0 and 100 cm.

We generated a vertical upward spray cone using a typical pressurized propellant-powered indoor air freshener nebulizer located approximately 5 cm from the floor and 1 – 8 cm from the side of the air purifier. Fluorescent light was used to illuminate the setup from above to visualize the mist particles in the spray cone visible due to light scattering by the mist particles. A Panasonic Lumix TS7 digital camera was used to take photographs of the spray cone.

Results and Discussion

The airflow velocity decreased sharply with the increasing distance from the outflow diffuser of the tested indoor air purifier (Table 1).

Table 1. The velocity of airflows around the indoor air purifier.

Distance, cm	**Airflow, m/s**							
	Horizontal Anemometer Position				45˚Vertical Anemometer Position			
	Max 1	Max 2	Min 1	Min 2	Max 1	Max 2	Min 1	Min 2
0	3.85	3.81	0.42	0.54	3.85	3.81	0.3	0.45
3	1.05	1.68	0.34	0.46	2	2.31	0.2	0.35
5	1.02	1.2	0.14	0.28	2	2.03	0.4	0.29
7	0.36	0.47	0.12	0.13	2	1.9	0.45	0.5
10	0.24	0.31	0.1	0.1	0.81	1.92	0.7	0.58
15	0.19	0.2	0.05	0.05	0.81	1.9	0.6	0.41
20	0.12	0.16	0.01	0.01	0.8	1.36	0.4	0.25
30	0.05	0.07	0.01	0.01	0.8	1.3	0.2	0.19
50	0.03	0.02	0.01	0.01	0.8	0.8	0.01	0.02

100	0.02	0.01	0.01	0.01	0.6	0.65	0.01	0.02

The highest outflow velocity was measured at the surface of the diffuser with the motor/fan of the indoor air purifier running at the highest speed (3.83 ± 0.03 m/s). This velocity was lower than one of the lowest previously reported velocities of the visible particles in cough and sneeze ejecta (4.5 – 5 m/s) (Tang et al., 2013) and much lower than 10 – 35 m/s reported elsewhere (L. Liu, Wei, Li, & Ooi, 2017; Scharfman, Techet, Bush, & Bourouiba, 2016).

With distancing from the diffuser, the airflow velocity dropped sharply. At the minimum motor/fan speed, the airflow velocity dropped to 1 – 2 cm/s at the distance of 20 cm horizontally (0° angle) and 50 cm at a 45° angle from the outflow diffuser of the indoor air purifier. At the maximum motor/fan speed, the airflow velocity dropped to 2 – 3 cm/s at the distance of 50 cm horizontally (0° angle) and to 0.6 – 0.65 m/s at the distance of 1 m at a 45° angle from the outflow diffuser. Therefore, a significant difference in the airflow pattern farther than about 50 cm from the circumferential outflow diffuser of the indoor air purifier was observed only at the maximum motor/fan speeds and at 45° angle: 0.6 – 0.8 m/s for a 45° angle at 0.5 – 1 m distance from the diffuser vs. 0.01 – 0.03 m/s for 0° at both minimum and maximum motor/fan speed (Figure 1).

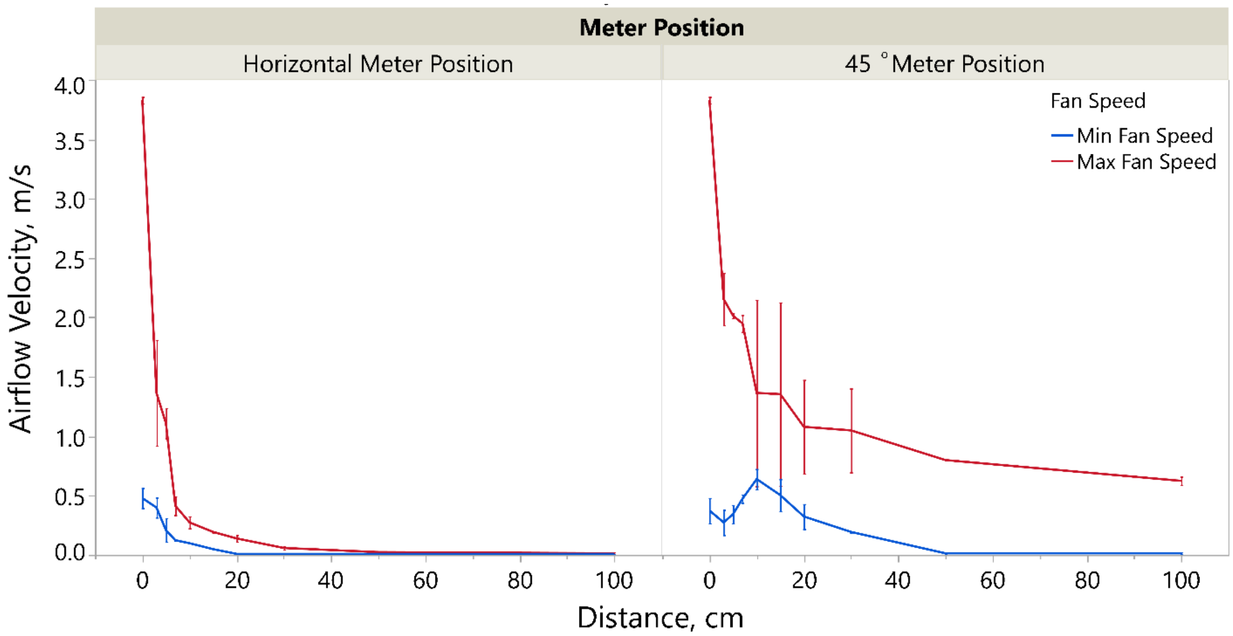

Figure 1. Average airflow velocity drop with increasing distance from the outflow diffuser of the indoor air purifier. Each error bar is constructed using 1 standard deviation from the mean.

In the case of the minimum motor/fan speed, the drop of the airflow velocity with increasing distance from the outflow diffuser was rapid at both the 0° and the 45° angle. In the case of the maximum motor/fan speed, the difference between 0° and the 45° angles was more pronounced. At a 0° angle with the motor/fan at the maximum speed, the drop of the airflow velocity was rapid and reached airflow velocities similar to those at the minimum motor/fan speed already around 50 cm from the diffuser. At 45°, the drop of the airflow velocity was rapid with distancing from 0 to 20 cm from the outflow diffuser. After 20 cm, the rate of decrease of the airflow velocity at 45° slowed down, dropping from 1.08 ± 0.40 to 0.63 ± 0.04 m/s.

We observed no significant deflection of the spray mist particles visible in scattered light by the circumferential diffuse outflow from the C600 indoor air purifier when the air purifier was operated at the lowest speed of the motor-fan (Figure 2 A, B).

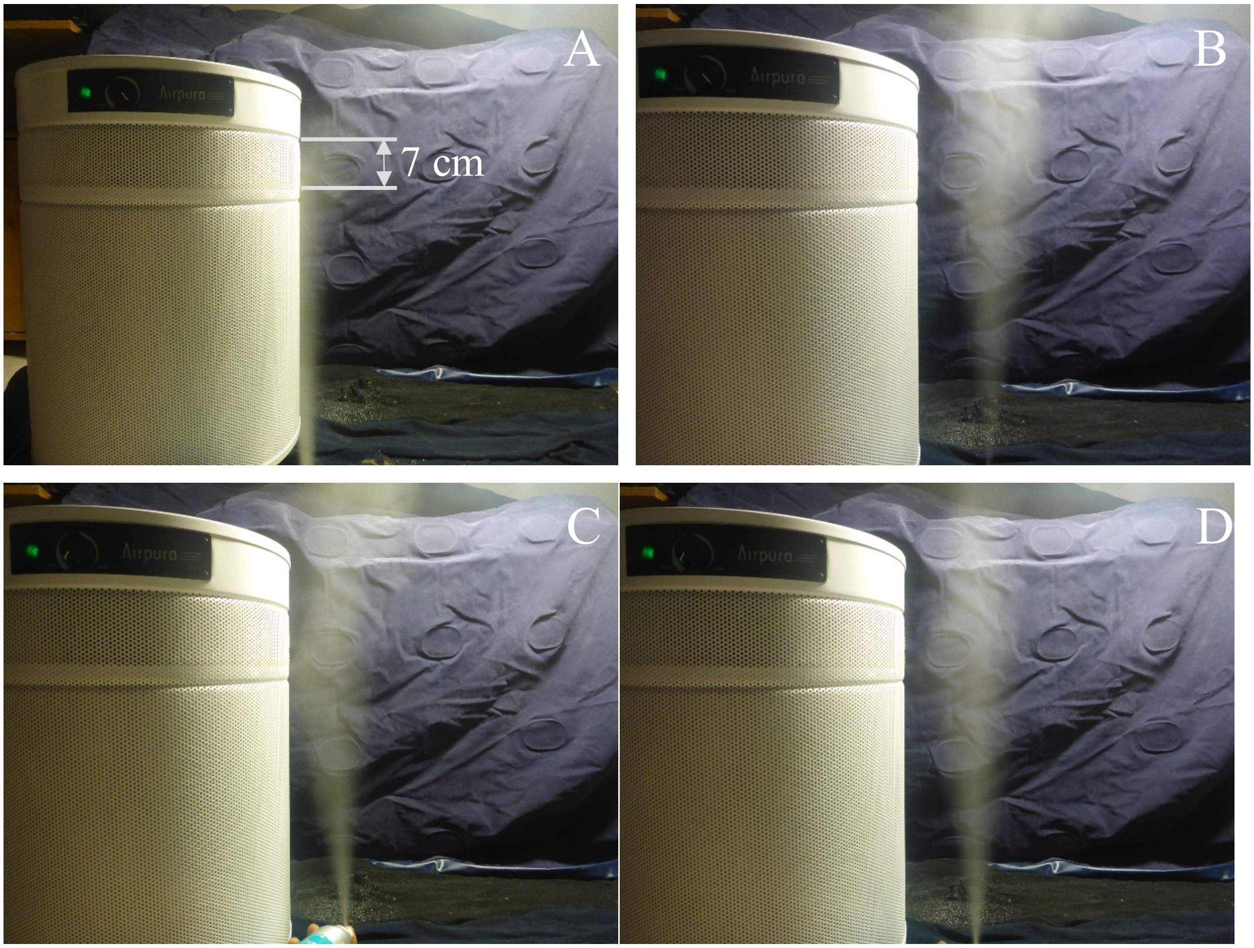

Figure 2 Photographs of the air freshener mist cone parallel to the side of the indoor air purifier. A, B) Air purifier operating at the lowest motor-fan speed. C, D) Air purifier operating at the highest motor-fan speed.

When the air purifier was operated at the highest speed, a minimal deflection of the spray mist cone was observed (Figure 2). This deflection was by approximately 2 cm along the 7 cm vertical stretch of the outflow diffuser, meaning that the propagation velocity of the visible spray particles was 13.4 ± 0.1 m/s, somewhat higher than measurements of the cough and sneeze visible particle velocities reported previously (4.5 – 5 m/s) (Tang et al., 2013). The deflection was by an additional ~ 3 cm extending to the top of the air purifier (a further 6.5 cm vertical distance) when the spray cone just touched the outflow diffuser (Figure 2 C). The deflection was similar when the spray cone was 3 cm farther away from the air purifier (Figure 2 D).

The aerosol generation method, the initial position of the spray cone and the dynamics of the aerosol size distribution are expected to influence the time potentially infectious particles would spend in different locations within the air currents next to the outflow diffuser of an indoor air purifier. Aerosol dynamics is highly complex and highly varies (Hinds, 1999), so testing for all possible scenarios is impossible. However, aerosol particles will be pushed farther if they spend more time in front of the outflow diffuser, which is the case when they move at a slower velocity parallel to the surface of the diffuser. The airflow dynamics around the circumferential outflow diffuser shows that the potentially infectious particles, in the worst-case scenario of the highest motor/fan speed, could be moved only at velocities many times slower than those sneeze or cough particles typically reach. At the lowest motor/fan speed, air current velocities drop to negligible levels at 0.5 m distance from the indoor air purifier with a circumferential outflow diffuser.

The first limitation of the study is that the experiment was conducted with a mist generated by an indoor air freshener. The aerosol size distribution of this mist will differ from that of the aerosol generated by coughing, sneezing or speaking. The second limitation of the study is that only one velocity of the aerosol particles in the spray cone, and one direction of the spray cone propagation were tested. The aerosol generated by the propellant-powered indoor air freshener contains rapidly evaporating particles. The rate of evaporation of these particles is expected to be faster than that of aqueous particles generated by coughing, sneezing or speaking, so their aerodynamic diameter is likely to decrease faster after emission compared to respiratory droplets. Particles with smaller aerodynamic diameter can be carried farther through the air. The third limitation is that one type of aerosol spray cone was tested. It is characterized by a certain movement of the aerosol particles in the vicinity of the indoor air purifier in contrast to the real-world situation when air currents and turbulence in indoor spaces are varied.

Conclusions

Under the experimental conditions, at the lowest motor-fan speed, we observed a rapid drop of airflow velocity with distancing from the indoor air purifier of only 20 cm and no visible deflection of sneeze-mimicking mist by the outflow from the tested indoor air purifier with a circumferential outflow diffuser. The increased airflow through the tested indoor air purifier at the highest motor-fan speed led to a slightly slower airflow velocity drop horizontally and a less significant drop at a 45° angle. The highest motor-fan speed caused a deflection of the sneeze-mimicking mist particles around the outflow diffuser by approximately 5 cm horizontally. The direction of movement and the velocity of potentially infectious respiratory droplets relative to the air currents around an indoor air purifier, as they are emitted by people, are important. We expect the outflow to push farther aerosol particles that spend more time in front of the outflow diffuser. Additionally, the lower the aerodynamic diameter of the aerosol particles, the farther they may be pushed. However, we tested the worst-case simulation scenario of infectious aerosol emission using a propellant-powered sprayer. Propellant-powered sprayers are the type known to generate overwhelmingly ultrafine and fine particles (Chen et al., 2010; Hagendorfer et al., 2010; Lorenz et al., 2011; Nazarenko, Lioy, & Mainelis, 2014), substantially smaller than most respiratory droplets (L. Liu et al., 2017; Scharfman et al., 2016). We conclude that maximum air velocities generated immediately at the outer casing of the tested indoor air purifier with a circumferential outflow diffuser are lower than the velocities of the sneeze or cough droplets. The outflow velocities from the investigated circumferential outflow diffuser drop considerably below the sneeze or cough droplet velocities within a few centimeters to a fraction of a meter distance from the indoor air purifier equipped with such an outflow diffuser – closer than the recommended safer distances between people in indoor spaces aimed to reduce the spread of COVID-19 (2 m), marking their advantage over directional outflow ports.

Acknowledgments

We are grateful to Airpura Industries, Inc. for performing the outflow velocity measurements.

Conflict of interest

Dr. Yevgen Nazarenko is supported by the Mitacs Elevate Fellowship, partially funded by Airpura Industries, Inc., a manufacturer of indoor air purifiers.

References

Chen, B. T., Afshari, A., Stone, S., Jackson, M., Schwegler-Berry, D., Frazer, D. G., . . . Thomas, T. A. (2010). Nanoparticles-containing spray can aerosol: characterization, exposure assessment, and generator design. *Inhalation Toxicology, 22*(13), 1072-1082. Retrieved from http://informahealthcare.com/doi/pdfplus/10.3109/08958378.2010.518323

Chia, P. Y., Coleman, K. K., Tan, Y. K., Ong, S. W. X., Gum, M., Lau, S. K., . . . Marimuthu, K. (2020). Detection of Air and Surface Contamination by Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) in Hospital Rooms of Infected Patients. *medRxiv*, 2020.2003.2029.20046557. doi:10.1101/2020.03.29.20046557

Hagendorfer, H., Lorenz, C., Kaegi, R., Sinnet, B., Gehrig, R., Goetz, N. V., . . . Ulrich, A. (2010). Size-fractionated characterization and quantification of nanoparticle release rates from a consumer spray product containing engineered nanoparticles. *Journal of Nanoparticle Research, 12*(7), 2481-2494. doi:10.1007/s11051-009-9816-6

Ham, S. (2020). Prevention of exposure to and spread of COVID-19 using air purifiers: challenges and concerns. *Epidemiol Health, 42*(0), e2020027-2020020. doi:10.4178/epih.e2020027

Hinds, W. C. (1999). *Aerosol technology: properties, behavior, and measurement of airborne particles* (2, illustrated ed.). New York, NY: John Wiley & Sons, Inc.

Liu, L., Wei, J., Li, Y., & Ooi, A. (2017). Evaporation and dispersion of respiratory droplets from coughing. *Indoor Air, 27*(1), 179-190. doi:10.1111/ina.12297

Liu, Y., Ning, Z., Chen, Y., Guo, M., Liu, Y., Gali, N. K., . . . Lan, K. (2020). Aerodynamic analysis of SARS-CoV-2 in two Wuhan hospitals. *Nature*. doi:10.1038/s41586-020-2271-3

Lorenz, C., Hagendorfer, H., von Goetz, N., Kaegi, R., Gehrig, R., Ulrich, A., . . . Hungerbühler, K. (2011). Nanosized aerosols from consumer sprays: experimental analysis and exposure modeling for four commercial products. *Journal of Nanoparticle Research, 13*(8), 3377-3391. doi:10.1007/s11051-011-0256-8

Nazarenko, Y., Lioy, P. J., & Mainelis, G. (2014). Nanomaterial Inhalation Exposure from Nanotechnology-Based Consumer Products. In H. Salem & S. A. Katz (Eds.), *Inhalation Toxicology* (3rd ed., pp. 623). Boca Raton, London, New York: CRC Press.

Scharfman, B. E., Techet, A. H., Bush, J. W. M., & Bourouiba, L. (2016). Visualization of sneeze ejecta: steps of fluid fragmentation leading to respiratory droplets. *Experiments in Fluids, 57*(2), 24. doi:10.1007/s00348-015-2078-4

Setti, L., Passarini, F., De Gennaro, G., Baribieri, P., Perrone, M. G., Borelli, M., . . . Miani, A. (2020). SARS-Cov-2 RNA Found on Particulate Matter of Bergamo in Northern Italy: First Preliminary Evidence. *medRxiv*, 2020.2004.2015.20065995. doi:10.1101/2020.04.15.20065995

Stadnytskyi, V., Bax, C. E., Bax, A., & Anfinrud, P. (2020). The airborne lifetime of small speech droplets and their potential importance in SARS-CoV-2 transmission. *Proceedings of the National Academy of Sciences*, 202006874. doi:10.1073/pnas.2006874117

Tang, J. W., Nicolle, A. D., Klettner, C. A., Pantelic, J., Wang, L., Suhaimi, A. B., . . . Tham, K. W. (2013). Airflow Dynamics of Human Jets: Sneezing and Breathing - Potential Sources of Infectious Aerosols. *PLoS ONE, 8*(4), e59970. doi:10.1371/journal.pone.0059970

van Doremalen, N., Bushmaker, T., Morris, D. H., Holbrook, M. G., Gamble, A., Williamson, B. N., . . . Munster, V. J. (2020). Aerosol and Surface Stability of SARS-CoV-2 as Compared with SARS-CoV-1. *New England Journal of Medicine, 382*(16), 1564-1567. doi:10.1056/NEJMc2004973

Vejerano, E. P., & Marr, L. C. (2018). Physico-chemical characteristics of evaporating respiratory fluid droplets. *Journal of the Royal Society, Interface, 15*(139), 20170939. doi:10.1098/rsif.2017.0939

Wells, W. F. (1934). On Air-Borne Infection*: Study II. Droplets and Droplet Nuclei. *American Journal of Epidemiology, 20*(3), 611-618. doi:10.1093/oxfordjournals.aje.a118097

World Health Organization. (2020). *Severe Acute Respiratory Infections Treatment Centre: Practical manual to set up and manage a SARI treatment centre and a SARI screening facility in health care facilities*.

Zhu, N., Zhang, D., Wang, W., Li, X., Yang, B., Song, J., . . . Tan, W. (2020). A Novel Coronavirus from Patients with Pneumonia in China, 2019. *New England Journal of Medicine, 382*(8), 727-733. doi:10.1056/NEJMoa2001017