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## Airborne infection with Covid-19? A historical look at a current controversy

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## ABSTRACT

Since the start of the COVID-19 pandemic, experts and the broader public have vigorously debated the means by which SARS CoV-2 is spread. And understandably so, for identifying the routes of transmission is crucial for selecting appropriate nonpharmaceutical interventions to control the pandemic. The most controversial question in the debate is the role played by airborne transmission. What is at stake is not just the clinical evidence, but the implications for public health policy, society, and psychology. Interestingly, however, the issue of airborne transmission is not a new controversy. It has reappeared throughout the history of western medicine. This essay traces the notion of airborne infection from its development in ancient medical theories to its manifestation in the modern era and its impact today.

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By mid-February 2020, a month before the WHO declared COVID-19 a pandemic, the international research community had already analyzed 40 complete genome sequences of SARS-CoV-2 isolates, providing deep insights into the pathogen's molecular structure and replication mechanisms [1]. Nevertheless, the transmission path of the virus continues to be disputed. Infectious disease practitioners traditionally distinguish between respiratory droplet transmission via large droplet spray occurring at close range (<2 m), and airborne transmission, which occurs by dissemination of small aerosol particles (microdroplets), that can be inhaled at close range and potentially transport infectious agents over larger distances [2]. Since March 2020, the WHO has maintained that COVID-19 is primarily spread through direct contact with infected persons or surfaces and through the impact of large droplets on eyes, nose, and mouth. It has regarded the possibility of aerosol transmission with great skepticism, citing a lack of evidence [3–5]. Since the beginning, the stance of the WHO has caused great concern among specialists and the general public [6,7]. The debate came to a preliminary head on July 6, 2020, when 239 scientists from 32 countries issued an open letter calling on the WHO to acknowledge that “airborne transmission of COVID-19 is a real risk [8].” The appeal provoked an unusually sharp reaction from a group of Canadian scientists, who accused the signatories of fueling fears and sowing distrust in the public healthcare system [9]. In

response, the letter's authors noted that the history of infectious disease experts being fearful of talking about “invisible and therefore terrifying infection in the air” is long [10].

The controversy surrounding airborne infection is as old as the concept itself. One might think that the idea of airborne infection first appeared in the miasma theory advanced by ancient Greek physicians. But a closer inspection indicates that things are not so simple. When did the idea of airborne infection originate, and how? An admittedly narrow, thematically focused examination of the history of this issue may help facilitate a better understanding of the tensions at the heart of the contemporary Covid-19 droplet versus airborne transmission controversy, and of what is at stake in this controversy.

### 1. Miasmas

Today, an airborne infection is an infection that can be transmitted from person to person through the inhalation of expiratory aerosols in the air. It can occur over the short range and long range [11]. This form of transmission is fundamentally different from what Hippocrates and physicians through the late 19th century called miasmatic poisoning. “Whenever many men are attacked by one disease at the same time,” the author of the Hippocratic text *On the Nature of Man* writes, “the cause should be assigned to that which is most common, and which we all use most. This it is which we breathe in.” ([12], p. 25) What was meant was not the air exhaled by the sick. Instead, the doctors of earlier epochs believed

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that the atmosphere could, depending on the weather, make people sick. The views of Thomas Sydenham (1624–1689) on the constitution of the air were formative for the epidemiology of the early modern era:

There are various general conditions of years, that owe their origin neither to heat, cold, dryness, nor moisture; but rather depend upon a certain secret and inexplicable alteration in the bowels of the earth, whence the air becomes impregnated with such kinds of effluvia, as subject the human body to particular distempers ([13], p. 8).

The atmosphere was considered to be a necessary but insufficient cause for most disease outbreaks. Certain local factors also played a role. Beginning the 18th century, filth theory provided a supplementary account of disease. Large amounts of decomposing organic matter could amplify the atmosphere's disease-causing potential to epidemic proportions. Swamps, stagnant bodies of water, cemeteries, slaughterhouses, fishing markets, and pit latrines emitted poisonous, foul-smelling vapors, or miasmas, that could travel long distances on "unhealthy winds" like a swarm of locusts ([14], p. 95). Whether or not a certain person was affected by the epidemic depended on individual disposition and lifestyle.

## 2. Contagion

The Hippocratic pathology of the humors could scarcely account for person-to-person transmission, though the existence of mass contagion was indisputable and described by the Greek historian and general Thucydides ([15], p. 343, 349). It was not until the early modern times that idea of person-to-person transmission was placed on a solid basis by Italian physician Girolamo Fracastoro (1476–1553) ([16], p. 8). More and more physicians came to believe that inanimate poisonous substances on the surface of the body could pass from person to person through direct contact and reproduce endlessly in the human body. They surmised that the toxins proliferated through a process resembling fermentation, "assimilating" the surrounding tissue ([17], p. 75). Physicians in the 18th and 19th centuries developed a two-part matrix for classifying infection routes: on the one side were purely miasmatic diseases, capable of affecting large crowds yet disappearing again as soon as the air improves. (Malaria and yellow fever fell under this category.) On the other were purely contagious diseases, which required direct contact for transmission. (These included smallpox, measles, rabies, and syphilis.)

## 3. Human effluvia

But physicians were dumbfounded by a third group of diseases, which seemed to spread both through the atmosphere and through physical contact and inhalation. These diseases included influenza, cholera, typhoid fever, and plagues. Fierce disputes about how these epidemics spread erupted in the 18th and 19th centuries.

The contagionists regarded the diseases to be transmissible through direct contact and insisted on the introduction of rigorous protective measures such as quarantines and cordons sanitaire, while the anti-contagionists believed they arose from miasmas caused by local pockets of malignant air and urged the state to improve the environment. Another group of medical professionals,

so-called "contingent contagionists," tried to mediate between disputing parties by arguing that some contagions could only flourish in a corrupted atmosphere ([18], p. 51).

The dispute between the two schools originated in the United Kingdom, and later spread to France, Germany and US. Ultimately, it morphed into a political struggle between liberals (anti-contagionists) and conservatives (contagionists), between individual freedom and oppressive bureaucracy [19]. In one anti-contagionist pamphlet, the English physician Charles Maclean (1766–1824) suggested that contagionist policies would give rise to a grim dystopia:

When sanitary laws shall be correctly administered according to the strict principles of the doctrine of pestilential contagion, a difficulty of a very similar nature may be expected to arise. All persons suspected of having had intercourse with persons labouring under a disease of a suspected character, being supposed to be buried, either dead or alive, the difficulty would be, how, in order to avoid re-infection, the last survivor should contrive to bury himself! [20].

Commercial interests also appeared to play a role, as anti-contagionists published treatises on the economic damage supposedly inflicted by contagionist health policy ([19], p. 18). The fact that quarantines and cordons frequently failed to prevent the spread of diseases seemed to confirm the miasma theory endorsed by the anti-contagionists. To explain this puzzling phenomenon, the contagionists proposed another model of transmission: under certain conditions, contagia may enter into the atmosphere and travel beyond the sanitary measures. The model would later represent the historical crystallization point of the basic concept of airborne transmission.

The idea that disease could spread from human to human via the air had first appeared several centuries earlier in the work of already mentioned Girolamo Fracastoro. In *De Contagione et contagiosis morbis et eorum curatione* (1546), Fracastoro argues that infection can spread *per contactum* (touch), *per fomitem* (objects), and *ad distans* (at a distance) ([21], p. 10). This idea started the classification of contagions into "fixed" and "volatile." The latter type can dissolve into the air and poison the atmosphere around the infected ([22], p. 140). In the grey zone between fixed contagion and miasmas, physicians introduced the notions of vapors or effluvia, which polluted the air around patients and announced themselves with a terrible stench. This view was modeled on the observation that rotten apples could befoul freshly picked ones without coming into contact with them ([23], p. 2).

But opinions differed when it came to the distance that human effluvia (volatile contagions) could travel ([24], p. 54). For the idea of long-range airborne transmission threatened to make the miasma theory of the anticontagionists redundant. Volatile contagions also represented a significant danger for civil peace. While quarantines would suffice to prevent infection for fixed contagions, the range of volatile contagions was unknown and thus terrifying. The consequences from the existence of volatile contagions would exceed the worst nightmares of the anticontagionists:

The calamity in this case must be very great ... cordons may be established to prevent flight, when flight would seem to be the only means of safety to thousands; and families, under a false

impression, may be induced to shut themselves up in localities where every breeze is bane ([25], p. 769).

As a result, even many contagionists endeavored to downplay the range of volatile contagions. In 1842, the physician Ernst August Ludwig Hübener (1796–1876) disputed the very existence of volatile contagions:

These example may suffice to show that the oft-cited *actio in distans* of contagions do not in fact exist ... I would wish that this pronounced view would be more exactly examined by observers. If confirmed, people will no longer be so fearful of infectious diseases. Relatives will not be wrested from dear family members based on a pronouncement by doctors ([22], p. 197–198).

At the beginning of the 19th century, the medical world attempted to develop a more or less coherent paradigm from miasma and contagion theories. But much uncertainty remained, even when it came to the basic distinction between the etiologies. In the case of the volatile vapors of the infected, the line between them seemed to blur. So miasmas were reserved for gaseous products released by the environment ([26], p. 154, 27, p. 49), while contagions were defined as products released by an infected organism that caused the same disease in other organisms ([26], p. 154, 27, p. 49). This distinction caused even more problems than it solved, however. One had to assume that two pathogens – miasmas and volatile contagions – zipped through the air around the infected. This prompted the staunch contagionist and pioneer of bacteriology Jakob Henle (1809–1885) to abandon the miasmatic-contagious dichotomy in its entirety:

If the sick can show that he came into close contact with another suffering from the same disease, then he was infected [through contagion]. If the contagious atmosphere of a sick person drifts across a person a street a few houses away, then the latter contracted the disease through miasma. There can, therefore, be only a gradual difference ... Below I will thus unify miasmas and contagions of the miasmatic-contagious diseases under the name “infectious matter.” ([27], p. 50–51).

In *The Structure of Scientific Revolution*, Thomas S. Kuhn describes the epistemological confusion that makes normal scientific practice increasingly unstable; “professional insecurity” ultimately necessitates the total rearrangement of an existing categorical framework ([28], p. 68). The perception that something was wrong with the dichotomy between miasmas and contagions was merely a precursor to paradigm change. Henle concluded that in essence there were no miasmatic-contagious diseases, only contagious diseases that spread via animate infectious matter ([16], p. 164).

#### 4. Droplets and aerosols

The understanding that epidemics are not spread by miasmas or inanimate contagions, but rather by the biological activity of microbes or viruses, did not take hold until the last part of the 19th century. Several decades more have had to pass before in 1965 viruses causing common colds in humans – a family of human coronaviruses that now includes SARS-CoV-2 – has been

discovered [29]. The paradigm shift towards the germ theory of Louis Pasteur (1822–1895) and Robert Koch (1843–1910) did nothing to diminish the controversy surrounding airborne infection, however. In 1889, the Berlin physician Georg Cornet (1858–1915) described the fears raised by the possibility of airborne tuberculosis:

If not only sputum but also the expired air or air that passes over tubercular lesions contains bacilli, then we have no choice but to place our hands on our laps in resignation and wait until fate reaches us through an infected breath. The fate of those suffering would be terrible, and would have to be avoided like those with the plague or banished from society like lepers of previous centuries ([30], p. 279).

But Cornet vehemently rejected the idea that tuberculosis could be spread by the air. “Fortunately, things are different .... We must keep in mind that we are not dealing with volatile contagions, not with gaseous miasmas, but with corpuscular elements that are subject to the laws of gravity, adhesion, and cohesion.” “The phthisic,” he stated confidently, “is almost entirely harmless.” This was meant as a rebuff to all those “who would like nothing more but to put all phthisics on an island in the Pacific Ocean ([30], p. 311). For a time, Cornet’s finding had a calming effect on the public as the state concentrated its tuberculosis efforts on removing infected dust.

In 1897, the director of the Hygiene Institute in Göttingen, Carl Flügel (1847–1923), questioned Cornet’s optimistic view and caused a sensation by advancing the theory of droplet transmission. Before Flügel, the commonplace notion today that patients release fine, invisible droplets when coughing, sneezing, or speaking that can infect others through the air had not been demonstrated experimentally. Scientists like Cornet only considered the large visible droplets that infected people emit and that fall to the ground and desiccate ([30], p. 311). In 1897, however, Flügel announced the good news that the risk of infection from dried sputum is low [31]. The bad news, however, was “that the coughing phthisic can pollute the air with fine droplets containing tubercular bacteria that remain in the air for a while.” ([31], p. 666).

A colleague of Flügel’s, the Russian chemist Porfirij N. Laschtschenko (1869–1937), investigated droplet transmission in a series of experiments. He first had test subjects rinse their mouths with a fresh culture of *Bacterium prodigiosum* and speak or cough at different volumes. He then placed agar-filled petri dishes at various distances and heights in the test room and measured the intensity of the air infection by recording where colonies grew and their size. Laschtschenko found that the bacteria in the droplets released while speaking and coughing could travel through the air up to 9 m horizontally and reach as high as the ceiling ([32], p. 131).

Hermann Königer (1876–1940) modified Laschtschenko’s experiment to determine the range of the drops and the length of time they remained suspended in the air. He conducted the experiment in an 88-square-meter lecture hall and exposed the agar plates to air at different times. He found that the droplets remained in the air for up to two hours, though most had gathered on surfaces within the first 30 min. But their spatial dispersion seemed to be unlimited. All the petri dishes were contaminated, even the ones at the far corners of the lecture hall, near the ceiling, on the sides, and behind the test subject ([33], p. 149). In addition, Königer studied the phenomenon of “wet pronunciation” and

determined that different letters, dialects, and languages produced different amounts of germ-containing droplets.

At the beginning of the 20th century, experiments on airborne transmission were reproduced and developed further in other countries and the discussion obtained an international character [34]. But the findings of Flügge and his colleagues elicited alarmed reactions among some people in the medical community, especially when it came to tuberculosis. The Berlin physician Bernhard Fränkel (1836–1911) worried “that the discovery of the danger of airborne infection from the phthisics would make the fight against invisible enemies in the air considerably more difficult.” ([35], p. 24) In light of Flügge’s hypothesis that the avoidance of direct contact with the infected provided insufficient protection, physicians rightly feared that calls for strict preventative measures against the “bacilli carriers” could grow long.

Possibly due to a certain helplessness on the part of health officials, the range of airborne infection projected in the medical literature shrank again after the turn of the century ([36], p. 706, 788). Although Flügge had recognised and described the long-range aerosol transmission route, in the worldwide perception his contribution has been reduced to the discovery of the short-range large droplets transmission. The American public health leader Charles Value Chapin (1856–1941) believed that it will be a great relief “to be freed from the specter of infected air, a specter which has pursued the race from time of Hippocrates” ([37], p. 314). He maintained that the clinical effects of exposure can be minimized by keeping one’s distance, because the inhaled threshold dose that triggers an infection is not reached at a distances greater than two or three feet from the emission source ([38], p. 300, 313). A practical consequence of this was the recommendation that protective masks be worn only for in-person contact at close distances. These views were in turn motivated decisively by public health policy:

Infection by air, if it does take place, as is commonly believed, is so difficult to avoid or guard against, and so universal in its action, that it discourages effort to avoid other sources of danger .... It is impossible, as I know from experience, to teach people to avoid contact infection while they are firmly convinced that the air is the chief vehicle of infection ([37], p. 314).

However, this view underwent a major correction in the 1930s. The American tuberculosis researcher William Firth Wells (1887–1963) contradicted Chapin in a widely read study from 1934, pointing out that the decisive factor influencing the behavior of expiratory droplets in the air – evaporation time – has yet to be taken into account. Droplets larger than 100 microns in diameter reach the ground before drying out and can only infect another person if they are expelled in close proximity or if they land on an object that the person touches and then transmits to the eyes or nose. Smaller droplets however shrink to under 100  $\mu\text{m}$  due to evaporation before they touch the ground and can float for an unlimited time as droplet nuclei, the aerosols of dried infected droplets. They are then lifted by minuscule air currents ([38], p. 615) that keep them in the air significantly longer than normal dust particles ([39], p. 1700). “Whenever a person sneezes,” Wells wrote, “many thousand nasopharyngeal organisms remain suspended in the air, and in commonly occupied, enclosed spaces, the exchange of nasopharyngeal flora is inevitable.” ([39], p. 1701).

Similar to Flügge’s idea, Wells’s theory of airborne transmission failed to reach a satisfying epidemiological impact ([40], p. 5). Nevertheless, Wells’s distinction between direct droplet and aerosol transfer remains the basis of WHO guidelines to this day [41]. The tendency of downplaying airborne transmission seems unbroken, however. Only a few diseases are acknowledged to produce

aerosol particles. These include pulmonary tuberculosis, measles, and chickenpox, but not influenza, SARS, and SARS-CoV-2.

Respiratory particles smaller than 5  $\mu\text{m}$  are considered capable of airborne transmission. The distinction between droplets and aerosols based on the cutoff size of 5  $\mu\text{m}$  has been usually attributed to Wells. As Randall et al. in their recent paper have shown however, a widespread confusion has crept in. A size threshold of 5  $\mu\text{m}$  have apparently arisen by confusing the size of particles that reaches the deepest part of the lungs and thus transmit Tuberculosis (<5  $\mu\text{m}$ ), investigated in the 1960th, with the size of the particles that fall to the ground before drying out ( $\sim 100 \mu\text{m}$ ), suggested by Wells ([41], p. 7).

The most debated issue seems to be the dichotomous approach itself, however. While most experts still believe the droplet spray versus aerosol inhalation dichotomy to be very useful [11], some like Lydia Bourouiba argue against the dichotomy [42]. Bourouiba, in her JAMA essay “Potential Implications for Reducing Transmission of COVID-19,” correctly points out that the current understanding of the transmission pathways of respiratory diseases is based on Wells’s dichotomous classification [42]. Bourouiba describes a new model that has grown out of recent work: “exhalations, sneezes, and coughs not only consist of mucosalivary droplets following short-range semiballistic emissions trajectories but, importantly, are primarily made of a multiphase turbulent gas (a puff) cloud that entrains ambient air and traps and carries within it clusters of droplets with a continuum of droplet sizes.” The “locally moist and warm atmosphere” of the gas clouds can increase the lifetime of pathogen-bearing droplets by a factor of 1000. The droplets can hover in the air for hours and travel up to 8 m [43]. Like Henle, she argues against a distinction between aerosols and droplets. Remarkably, it was Flügge’s colleague Koeniger who conjectured that air bubbles in the droplets kept them aloft for long periods, similar to balloons and soap bubbles ([33], p. 151).

Today, the ambivalence towards aerosol transmission resulted in muddled public health policies and resurfaced in inconsistent statements of health officials regarding the effectiveness of non-pharmaceutical interventions to control the pandemic. On April 6, 2020, the WHO stated that “the wide use of masks by healthy people in the community setting is not supported by current evidence and carries uncertainties and critical risks.” [43] The thinking was that surgical masks<sup>1</sup> can protect others but not the wearer. But this seemed at odds with the WHO’s initial assessment that the COVID-19 was not airborne transmissible. Because only if COVID-19 spreads via aerosols does it make sense to say that surgical masks can reduce the emission of the virus but due to leakage cannot keep out the virus during inhalation. Were COVID-19 transmissible only via large droplets, masks would be effective in both directions, as large droplets cannot circumnavigate the mask [45].

The inconsistency regarding face masks in preventing the spread of the coronavirus is just a tip of the iceberg by the confusion about the viral mode of transmission. If the viral transmission by aerosols is not the main route by which SARS-CoV-2 spreads, the key control measures are contact-and-droplet precautions like physical distancing (1–2 m), respiratory hygiene, hand sanitization and use masks within ballistic droplet distance. Reducing airborne transmission of virus, however, requires other measures focused on distinction between indoors and outdoors. It includes air filtration, ventilation, reducing time spent indoors and use of masks whenever indoors [46]. Although this meanwhile being performed in many countries [47] and the WHO understanding of the dichotomy of airborne versus droplet transmission has been fundamentally questioned [12], the necessary clarity on this issue in the

<sup>1</sup> For the history of the surgical Mask see Ref. [44].



international public health community has not yet been achieved. Only recently WHO has accepted the possibility of viral transmission by aerosols [48,49]. According to WHO, in reply to BMJ questions in April 2021, however, it is still not considered to be a significant route by which SARS-CoV-2 spreads [50].

## 5. Conclusion

This article sought to highlight some important threads in the history of the concept of airborne infection, without offering an exhaustive history, in order to provide more context to current debates. As I have shown, the concept – and the uncertainties and fears that accompanied it – reach far back into the past. The idea of volatile contagions served as a productive irritation in the medical world, similar to the “anomalies” described by Thomas S. Kuhn ([28], p. 52). They pushed their way into the hard-to-define zone between miasmas and fixed contagions and destabilized existing epidemiological theory. Circulating between the dominant viewpoints, they resisted being interpreted out of existence and cast doubt on the ruling paradigm. At the same time, however, state health officials and medical experts were reluctant to take up the idea because of its paralyzing and frightening effect on the general public. Whereas a balanced lifestyle could help against miasmas, and distance offered protection from fixed contagions, physicians from previous centuries had nothing to offer against the danger of volatile contagions. The advocates of airborne infection were also faced by a long-term structural problem: The burden of evidence lies with the claimant. This standard applies today very particularly to the domain of evidence-based medicine. In this way, while we should be careful not to overemphasize the correspondence between current debates and the described historical controversies, the parallels are illustrative, as they showcase similar interplay of fears, interests, implications, and explanatory models.

## Declaration of competing interest

The author has no conflicts of interest to disclose.

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