Airborne Pathogens and Biosafety Measures

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Abstract- Indoor microbial communities significantly affect human health, especially as people spend about 90% of their time indoors. This review focuses on airborne bacteria—less studied than fungi—highlighting that while their concentrations vary with human occupancy, their community composition remains stable Main sources of indoor airborne bacteria are people, outdoor air, and building materials, while factors like temperature, humidity, ventilation, and number of occupants affect their presence and spread. The COVID-19 pandemic emphasized the urgency of controlling pathogen transmission in confined spaces like public transport. A theoretical model and lab simulations using train cabins informed the development of effective decontamination and biosafety strategies, aiding safer indoor environments and pandemic preparedness.

AIRBORNE ORGANISMS

Airborne pathogens commonly cause inflammation of the upper respiratory tract, affecting the nose, sinuses, throat, and lungs, leading to symptoms such as sinus congestion, sore throat, and respiratory distress. These pathogens are transmitted through aerosolized particles generated by coughing or sneezing. Diseases commonly spread through airborne transmission include anthrax, aspergillosis, blastomycosis, chickenpox, adenovirus, influenza, tuberculosis, measles, mumps, and COVID-19, among others. COVID-19, in particular, has highlighted the importance of active airborne transmission prevention strategies. Airborne diseases can also affect animals, such as poultry, which are susceptible to Newcastle disease. However, mere exposure to an infected person or animal does not guarantee infection; transmission also depends on factors like host immunity, the intensity of exposure, and duration of contact.

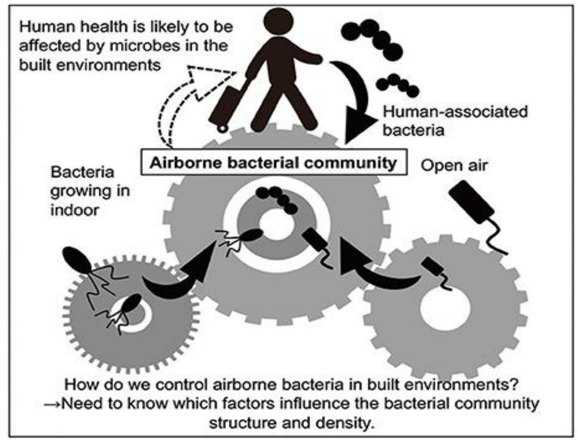

Figure 1

The figure illustrates the sources and dynamics of airborne bacterial communities within built environments. It shows that human health can be affected by microbes present in indoor air. Humans introduce bacteria into these environments, known as human-associated bacteria, which become part of the airborne bacterial community. Additionally, bacteria can originate from indoor sources where they grow, as well as from the open air outside the building. These different sources interact, contributing to the overall bacterial community found in indoor air. The figure highlights the importance of understanding which factors influence the structure and density of airborne bacterial communities in order to effectively control them and protect human health in built environments.

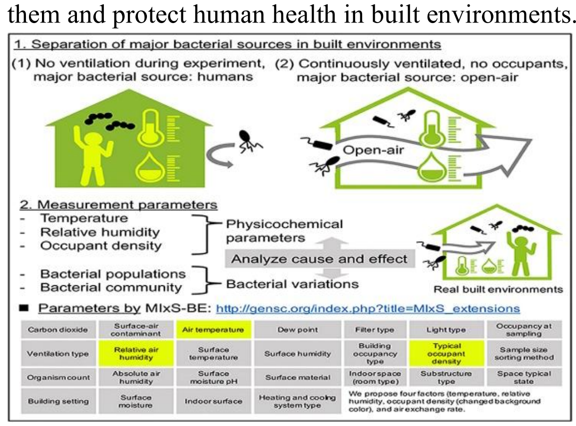

Figure 2

illustrates how major bacterial sources in built environments can be separated and analyse, along with the key parameters for measuring indoor bacterial communities. The top section shows two scenarios: (1) when there is no ventilation and humans are present, people are the main source of indoor bacteria; (2) when there is continuous ventilation and no occupants, bacteria primarily come from the open air. The lower section highlights important measurement parameters, including temperature, relative humidity, and occupant density (physicochemical parameters), as well as bacterial populations and community structure (bac terial variations). These factors are used to analyse cause-and-effect relationships in real built environments. The figure also references the Mix S-BE standard, emphasizing four critical factors—temperature, relative humidity, occupant density, and air exchange rate—for understanding and managing bacterial dynamics indoors.

THE SOURCES AND CHARACTERIZATION OF AIRBORNE MICROBES

The spread of microorganisms from liquid systems or soil to the atmosphere is largely driven by air currents and droplet dispersal, explaining the presence of specific bacteria such as *Bacillus bataviensis*, *Sphingomonas*, and *Arcobacter* in diverse environments (1). In extreme locations like Antarctica, studies have found that only *Brevundimonas* sp. was identified in the soil, while *Sphingomonas* was detected in Antarctic dust (2). Research on the eolian dusts of Southern Australia revealed that microorganisms found in saline lake sediments and biological soil crusts are the primary sources of these dust-borne communities (3). During intense Saharan dust events, a highly diverse and abundant bacterial community has been observed, highlighting the role of air mass movement in spreading microbes over long distances (4)125. Composting processes, which involve the microbial degradation of waste, release a variety of bacteria and fungi during different stages such as waste delivery, shredding, and pile turning (5). In wastewater treatment plants, studies show that the composition of microorganisms in water is a major contributor to the bacterial community found in bioaerosols (6). Plants and soil are also recognized as significant sources of airborne bacteria in aerosols (7). Marine systems, known for their microbial diversity, serve as reservoirs for millions of bacteria, fungi, and protozoans (8). Aerosols and droplets formed at the surface of aquatic systems facilitate the transfer of microbes across the liquid–air interface (9). Notably, many microorganisms originating from marine environments have also been detected in non-liquid settings (10). Finally, studies in urban Mediterranean areas, such as Thessaloniki, Greece, have shown that while some airborne bacteria like *Synechococcus* sp. may have a marine origin, most species are traced back to soil and wastewater sources (11).

Table 1. Source of representative species in aerosols.

Representative Species	Sources	Destination
Sphingomonas	Antarctic dust	Airborne microbes
Helicobacter	Wastewater treatment plants	Aerosolization
Brevundimonas sp.	Antarctica soil	Antarctic aerosol
Stenotrophomonas, Acidovorax	Saharan dust	Aerosol
Thermoactinomyces spp., *Aspergillus* spp.	Composting process	Aerosol
Sphingomonadales	Common inhabitant of leaves	Megalopolis aerosol
Burkholderiales, Pseudomonadales	Soil inhabiting bacteria	

THE EffECT OF ATMOSPHERIC PARTICULATE MATTERS (PM) ON AIRBORNE MICROBES

Particulate matter (PM) is primarily classified into two main categories: PM2.5, which includes particles with a diameter less than 2.5 µm, and PM10, which covers particles between 2.5 and 10 µm in diameter (1). PM is further divided into six dynamic diameter stages: Stage 1 (≥7.0 µm), Stage 2 (7.0–4.7 µm), Stage 3 (4.7–3.3 µm), Stage 4 (3.3–2.1 µm), Stage 5 (2.1–1.1 µm), and Stage 6 (1.1–0.65 µm) (1). The greatest proportion of airborne bacteria is typically found in Stage 3 (3.3–4.7 µm), and the size distribution of these microbes varies with weather conditions: fine PM dominates on hazy days, coarse PM on foggy days, and there are dual peaks at 1.1–2.1 µm and 4.7–7.0 µm on sunny days (2). In severe haze, the highest bacterial concentrations are observed in the PM0.32–0.56, PM0.18–0.32, and PM0.56–1 size ranges, with cell counts exceeding 7,000 cells/m^3 (3). Fungal distribution also varies by region and weather, with coastal areas often reporting the highest fungal concentrations in the 2.1–3.3 µm range (4). The concentration of microbes in different PM sizes can affect the analysis of microbial communities, especially due to the limitations of sampling devices (5). Chemical components within PM, such as water-soluble ions (SO_4^{2-}, NO_3^-, NH_4^+, K^+, Cl^-) and metals, serve as attachment media and microenvironments for microbial growth and survival, and these components have strong correlations with bacterial community structure (6). Air pollutants, particularly during heavy haze, can reduce microbial abundance and diversity by inhibiting bacterial growth, while chemical pollutants in PM can alter both bacterial concentrations and community composition (7). The relationship between PM and microbes is non-linear: microbial concentrations rise with moderate PM accumulation but decline under severe pollution due to the buildup of toxins like sulfate, nitrate, and PAHs (8). There is also competition between growth-promoting nutrients and toxic chemicals (such as heavy metals and PAHs) in PM, with levels of heavy metals (Pb, Zn, As) and PAHs being three to eight times higher during severe haze (9). During haze events, bioaerosol concentrations spike at the onset but decrease as chemical pollutants accumulate, and the levels of culturable bacteria and fungi are lower on severe haze days compared to non-haze days (10).

Table 2. Factors that influence the characteristics of airborne community.

Factors		Ways
Particulate matters in hazy/foggy weather	Formaldehyde, O_3, H_2O_2, PAHs	Noxious effects on microbial growth
	Water-soluble ions, organic carbon	Provide habitat and nutrients for microbes
	Strong acids	Noxious effects
Strong solar radiation (UVs)		Noxious effects
Temperature (relative humidity)		Provide comfortable survival environment
Dust		Carry microbes to far distances
Thunderstorm		Uplift microorganisms in altitude above the tropopause

Issues of Concern

Factors That Influence Airborne Transmission

Airborne transmission depends on several physical variables, such as the characteristics of the infectious particle and the environment. Factors that influence the spread of airborne infections include the following:

- Temperature: Certain viruses are more active at lower temperatures. For example, influenza tends to spread more easily in cold climate conditions. In contrast, the infectivity of bacterial pathogens decreases in cold temperatures as they are less resistant and thus remain dormant.
- Amount of sunshine: Ultraviolet rays of the sun harm bacteria and viruses. The strength and duration of ultraviolet light exposure can determine the survival of infectious pathogens in the air. Countries with a higher average daily sunshine are thus less prone to airborne transmission.
- Humidity: The percentage of water vapor in the air also determines airborne droplet nuclei's effectiveness in spreading from person to person. It has been studied that high humidity levels are protective against ultraviolet light destruction as water vapor forms a protective barrier around the droplet nuclei.
- Wind: Air currents increase the distance infectious airborne particles travel. Wind also, however, decreases the concentration of droplet nuclei, thus decreasing airborne infectivity.

Other Factors

- Tropical storms: Several studies have shown that tropical storms decrease the quantity of fungal spores in the air. The number of fungal spores does, however, increase after a few days.
- *Socioeconomic and living conditions*: Like infectious diseases that are spread via contact, living conditions, and socioeconomic factors also play a key role in airborne transmission. Housing and the number of people residing in 1 room/area is an important determinant of airborne transmission. Room ventilation and aeration are also key factors. Air conditioning is also a culprit for the increased airborne spread in closed environments.
- Rural vs urban environment: In urban areas, close living conditions result in increased transmission of bacterial and viral pathogens. In contrast, rural areas are more prone to airborne transmission of fungal spores.
- Inadequate sewage and drainage systems: Biowaste accumulation also increases the risk of forming and spreading of airborne particles.

An article published in 2009 highlights how every pathogen has its own set of ideal environmental conditions for airborne transmission. Generalization of the unfavorable conditions for aerosol transmission may be misleading. Each pathogen should be separately studied in this regard.

Enhancing Healthcare Team Outcomes

1. Interprofessional Team and Administrative Controls: Effective airborne infection management requires a coordinated interprofessional team approach, supported by

hospital guidelines, with clear roles, training, and administrative controls to minimize exposure opportunities and ensure infection control practices13.

2. Environmental Controls: Ensuring adequate ventilation through natural or mechanical means, use of negative pressure rooms, and environmental measures like ultraviolet germicidal irradiation are critical to reduce airborne infectious particle concentrations in healthcare settings14.
3. Personal Protective Measures: Healthcare workers must use appropriate personal protective equipment (PPE), including fit-tested N95 respirators, and adhere to respiratory hygiene and cough etiquette to protect themselves and prevent transmission14.
4. Immune Status and Vaccination: Awareness of healthcare workers' immune status is essential; unvaccinated or immunocompromised staff should avoid caring for patients with vaccine-preventable airborne infections, and vaccination of susceptible personnel is recommended promptly after exposure

AIRBORNE PRECAUTIONS

1. Airborne precautions are implemented for patients who are known or suspected to be infected with microorganisms that are transmitted by airborne droplet nuclei, such as those causing tuberculosis, measles, varicella (chickenpox), and SARS.
2. Healthcare workers must wear appropriate personal protective equipment (PPE), specifically a fit-tested N95 respirator or a higher-level respirator, before entering the patient's room; alternatively, powered air-purifying respirators (PAPR) may also be used.
3. Patients should be placed in an Airborne Infection Isolation Room (AIIR) that has negative pressure and adequate air exchanges to prevent the spread of infectious particles. If an AIIR is not available, the patient should be placed in a single room with the door closed, and a surgical mask should be provided to the patient.
4. To minimize transmission, patient movement outside the room should be limited to only medically necessary purposes; if the patient must be transported, they should wear a surgical mask and adhere to respiratory hygiene and cough etiquette.

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