INNOVATING CROSS-DOMAIN SOLUTIONS TO DETECT EMERGING BIOLOGICAL THREATS

Biosurveillance Of Emerging Viral Threats Through Indoor Air Sampling: A Comprehensive Review

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Background: The early detection of emerging viral pathogens is crucial for mitigating the spread of infectious diseases and preventing future pandemics. While the U.S. government has implemented various air sampling-based surveillance systems, such as BioWatch, the U.S. Postal Service's Biohazard Detection System, and SIGMA+, these efforts have faced challenges and were not optimized for the detection of viruses, which are more difficult to capture and identify than bacteria and fungi but pose a significant threat.

Purpose and Objective: This comprehensive review explores the potential of indoor air sampling for viral bioaerosol detection as a tool for biosurveillance of emerging threats. We examine the current state of air sampling techniques, the viral content of indoor air and dust, and promising strategies for effective viral surveillance in urban settings.

Methods: We conducted an extensive literature review, analyzing over 300 studies on bioaerosol sampling, aerobiology, and the indoor microbiome. We compiled data on the concentrations and dynamics of different viruses in indoor air and dust, as well as the performance of various air samplers. Metagenomic sequencing data from multiple studies was also summarized to assess the nucleic acid composition of air and dust and the range of detectable viral species present.

Findings: A wide range of human viruses have been detected in indoor air using nucleic acid methods like PCR and metagenomic sequencing. Respiratory viruses such as influenza and SARS-CoV-2 have been consistently found in high-risk settings like hospitals and public transport, but their detection is nevertheless challenging due to low concentrations, degradation during sampling, and the poor efficiency of many air samplers for ultrafine viral aerosols. Metagenomic sequencing demonstrates the potential for pathogen-agnostic surveillance, identifying a diverse array of viral species, including respiratory viruses as well as skin-associated viruses like papillomavirus and polyomavirus. These findings can guide the development of robust biosurveillance systems. HVAC systems and high-traffic locations like airports and hospitals are promising sampling sites, enabling the aggregation of airborne material from many individuals over extended periods, including those with asymptomatic or presymptomatic infections. Passive dust sampling approaches, such as sampling vacuum dust collected in buildings, also show potential but remain underexplored.

Impact: This work provides a foundation for the development of next-generation viral bioaerosol sampling techniques and biosurveillance networks to protect against disease outbreaks. Our findings can guide the design of improved air samplers optimized for viral aerosols and inform the implementation of surveillance in high-risk facilities. By incorporating air sampling into existing biosurveillance frameworks, we can enhance the early detection of emerging biothreats, allowing for more rapid and effective interventions to safeguard public health and military readiness.

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