Abstract

Understanding the relationship between viral load and transmission risk is essential for controlling the spread of respiratory infections such as SARS-CoV-2 and influenza. While it is often assumed that higher viral shedding results in more secondary infections, empirical data suggests this relationship is non-linear and context-dependent. This project explores the extent to which viral load alone can explain transmission patterns in indoor environments using a physics-based simulation model. The model incorporates key parameters such as room size, ventilation rate, exposure duration, and viral concentration, simulating the dispersion of aerosolized viral particles and estimating infection probability via a Poisson process.

Simulation outputs were generated under various environmental conditions and analyzed using statistical and bioinformatics techniques. Results show that although viral load is a significant factor, increases in shedding do not proportionally increase transmission risk. Instead, room ventilation and size strongly modulate the likelihood of infection. A generalized linear model confirmed that both room characteristics and viral load independently and significantly affect transmission. These findings highlight the importance of environmental controls and suggest that mitigation strategies must go beyond individual viral shedding levels. The model provides a generalizable framework for assessing infection risk from respiratory viruses and supports data-driven policy decisions in public health and indoor design.

Background

Respiratory viruses such as SARS-CoV-2 and influenza remain major public health threats due to their ability to spread rapidly, especially in indoor environments. These viruses are primarily transmitted through respiratory droplets and aerosols generated by infected individuals during activities such as talking, coughing, or breathing. One might intuitively expect that individuals with higher viral loads—measured as the concentration of viral particles in bodily fluids—would be significantly more infectious. However, real-world data has shown that this relationship is often weak or inconsistent.

Several studies have documented cases where individuals with low viral loads caused many secondary infections (super-spreader events), while others with high viral loads caused few or none. This suggests that other factors, such as indoor airflow, room volume, time spent in proximity to others, and individual behaviors, may mediate the relationship between viral shedding and actual transmission outcomes. Furthermore, the decay of viral particles in air and the dilution effect in well-ventilated environments can reduce transmission risk substantially, even when viral load is high.

To better understand this complex interplay, this project applies a physics-based simulation model that mimics aerosol transmission in indoor settings. This approach allows us to control for environmental variables and quantify how viral load interacts with room conditions to affect infection risk.

**Objectives**

The primary aim of this project is to investigate how viral load influences the transmission potential of respiratory viruses in indoor environments, using a simulation-based approach. Specifically, the project seeks to:

Simulate the dispersal and infection potential of aerosolized viral particles across a range of indoor environments characterized by different room sizes, ventilation rates, and exposure durations.

Quantify the extent to which viral shedding alone explains transmission outcomes, and determine whether high viral load consistently results in increased secondary infections.

Identify thresholds and non-linear behaviors in the relationship between viral load and estimated infection rates, especially under different environmental conditions.

Apply bioinformatics workflows to preprocess and visualize large-scale simulation outputs using tools such as dimensionality reduction (e.g., PCA or t-SNE) to reveal patterns in transmission dynamics.

Compare the behavior of different viruses, such as SARS-CoV-2 and influenza, by modifying model parameters like infectious period and droplet decay rate, to develop transferable insights relevant to future respiratory pathogens.

By achieving these objectives, the project aims to generate practical insights into the role of viral shedding within real-world transmission contexts and inform evidence-based strategies for reducing infection risk indoors.