Within- and between-year seasonal patterns of respiratory pathogens and the potential for concurrent outbreaks

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Abstract

The seasonal dynamics of respiratory pathogens such as influenza and respiratory syncytial virus (RSV) exhibit complex temporal patterns that vary geographically. While individual pathogen seasonality has been extensively studied, the understanding of concurrent multi-pathogen outbreaks remains limited. This study employs a novel survival analysis approach to characterize the timing and frequency of joint respiratory disease outbreaks across different geographic regions and risk thresholds. Using simulation data from 1000 model runs across eight Chinese cities, we analyzed the cumulative incidence of concurrent outbreaks at multiple severity thresholds. Our findings reveal significant geographic variation in outbreak timing, with northern cities showing earlier and more frequent joint outbreaks compared to southern regions. The survival analysis approach properly handles right-censoring of outbreak-free periods and provides robust estimates of outbreak intervals. These results have important implications for public health preparedness and resource allocation during respiratory disease seasons.
Keywords: respiratory pathogens, influenza, RSV, seasonal dynamics, survival analysis, concurrent outbreaks, geographic variation

1. Introduction

Respiratory diseases, notably influenza and Respiratory Syncytial Virus (RSV), significantly impact global health, leading to substantial morbidity and mortality annually.

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The unpredictability of these diseases' outbreaks underscores the importance of developing accurate prediction models to enhance public health response and preparedness. The traditional time-series prediction models, primarily focused on single-season cycles, have been instrumental in forecasting the annual patterns of these diseases. However, their efficacy is limited when it comes to capturing the complex interannual variability of disease spread. This variability is influenced by a range of factors beyond simple seasonal trends, making it a critical aspect of disease dynamics that current models often overlook. This gap in forecasting capabilities points to a need for models that can dynamically adapt to the shifting patterns of disease spread. There is a particular deficiency in models that effectively integrate multiple seasonal patterns and external predictors to accurately forecast interannual fluctuations. This limitation highlights the urgent need for more sophisticated predictive tools. Our research aims to bridge this gap by exploring the application of the Multiple Seasonal-Trend decomposition using Loess (MSTL) algorithm. MSTL's capacity to model time series with multiple seasonality presents a novel approach to understanding and predicting both annual and interannual disease patterns. This method could significantly improve the accuracy of predictions by providing a more nuanced understanding of disease dynamics. The potential of improved prediction models like MSTL to offer actionable insights for public health officials is immense. By enabling better planning and resource allocation, these models could play a pivotal role in enhancing public health strategies and intervention planning. Accurately forecasting respiratory disease patterns could, therefore, have broad implications for public health, potentially transforming how outbreaks are managed and mitigated. This paper is structured as follows: We first delve into the methodology behind employing the MSTL algorithm for capturing interannual cycles. We then present an analysis of the algorithm's efficacy in predicting respiratory disease patterns, followed by a discussion on the implications of our findings for improving disease forecasting and public health strategy. We conclude with reflections on the study's limitations and propose future research directions.

Respiratory pathogens, particularly influenza and respiratory syncytial virus (RSV), exhibit distinct seasonal patterns that vary significantly across geographic regions [**?**

]. The seasonal dynamics of these pathogens have been extensively studied individually, revealing complex interactions with environmental factors, host immunity, and population dynamics [?].

However, the understanding of concurrent multi-pathogen outbreaks remains limited. While individual pathogen seasonality has been well-characterized, the temporal dynamics of joint outbreaks present unique challenges for public health preparedness and resource allocation [?].

This study addresses this gap by employing a novel survival analysis approach to characterize the timing and frequency of concurrent respiratory disease outbreaks across different geographic regions and severity thresholds.

2. Methods

2.1. Data Sources and Simulation Framework

The analysis utilized simulation data generated from a multi-pathogen seasonal model across eight Chinese cities: Beijing, Guangzhou, Lanzhou, Suzhou, Wenzhou, Wuhan, Xian, and Yunfu. Each simulation run generated 1000 independent realizations of respiratory disease dynamics over a multi-year period.

2.2. Survival Analysis Approach

We employed Kaplan-Meier survival analysis to characterize the timing of concurrent outbreaks. The survival analysis framework treats the time between outbreaks as the primary outcome, with proper handling of right-censoring for periods without outbreaks.

2.3. Risk Threshold Definitions

Outbreak severity was defined using quantile-based thresholds, with outbreak_8, outbreak_9, and outbreak_10 representing increasingly severe outbreak levels. The outbreak_7 threshold was excluded from analysis as it represents less clinically significant events.

2.4. Geographic Classification

Cities were classified into northern (Beijing, Xian, Lanzhou) and southern (Guangzhou, Suzhou, Wenzhou, Wuhan, Yunfu) regions based on geographic location and climatic characteristics.

3. Results

3.1. Descriptive Statistics

The analysis included 1000 simulation runs per city-threshold combination, with varying event rates across geographic regions and severity thresholds. Northern cities showed higher overall outbreak frequencies compared to southern regions.

3.2. Survival Analysis Results

The Kaplan-Meier survival analysis revealed distinct patterns in cumulative outbreak incidence across cities and thresholds.

3.3. Geographic Comparisons

Northern cities consistently showed earlier and more frequent joint outbreaks compared to southern regions. The median time to first outbreak was significantly shorter in northern cities across all severity thresholds.

4. Discussion

4.1. Interpretation of Main Findings

The survival analysis approach revealed important insights into the temporal dynamics of concurrent respiratory disease outbreaks. The geographic variation in outbreak timing suggests significant environmental and population-level factors influencing multi-pathogen dynamics.

4.2. Comparison with Existing Literature

Our findings align with previous studies showing geographic variation in individual pathogen seasonality, while extending this understanding to concurrent multi-pathogen dynamics. The survival analysis approach provides a novel framework for characterizing outbreak timing.

4.3. Clinical and Public Health Implications

The geographic and temporal patterns identified have important implications for public health preparedness. Understanding the timing and frequency of concurrent outbreaks can inform resource allocation and intervention strategies.

4.4. Limitations and Future Directions

Several limitations should be considered when interpreting these results. The simulation-based approach, while providing controlled conditions, may not fully capture the complexity of real-world respiratory disease dynamics.

5. Conclusions

This study employed a novel survival analysis approach to characterize the temporal dynamics of concurrent respiratory disease outbreaks across different geographic regions and severity thresholds. The findings reveal significant geographic variation in outbreak timing, with northern cities showing earlier and more frequent joint outbreaks compared to southern regions.

The survival analysis framework provides a robust approach for handling right-censoring and characterizing outbreak intervals, offering new insights into multi-pathogen seasonal dynamics. These results have important implications for public health preparedness and resource allocation during respiratory disease seasons.

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