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## A Multilevel Framework for Assessing Geographic Disparities in Post-Acute COVID-19 Conditions and Associated Symptom Burden Across U.S. States and Urban Metropolitan Regions

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**Abstract:** Post-acute COVID-19 conditions, commonly referred to as Long COVID, have emerged as a persistent and heterogeneous public health challenge with significant geographic variability across populations. Despite increasing recognition of its clinical and socioeconomic burden, limited analytical frameworks exist for systematically evaluating spatial disparities in symptom prevalence and severity across U.S. states and metropolitan regions. This study develops a multilevel analytical framework integrating epidemiological surveillance, socioeconomic stratification, and health system capacity indicators to assess geographic inequalities in Long COVID outcomes. Drawing on national surveillance datasets and prior empirical evidence, the framework conceptualizes Long COVID as a layered outcome influenced by individual-level infection severity, community-level vulnerability, and structural determinants of health.

The findings synthesized from existing literature highlight substantial disparities in Long COVID prevalence, with higher burdens observed in socioeconomically disadvantaged and geographically diverse regions. Evidence suggests that post-acute sequelae are strongly associated with pre-existing health inequities, occupational exposure risks, and uneven access to healthcare resources. The study further emphasizes the need for standardized surveillance mechanisms and integrated data systems to capture long-term outcomes. As highlighted in national research planning discussions, the current response to Long COVID remains insufficiently coordinated and requires stronger analytical infrastructure to guide policy decisions (Abbasi, 2022).

The proposed framework provides a scalable model for understanding spatial heterogeneity in post-COVID conditions and supports targeted intervention strategies. Ultimately, this work contributes to advancing population health analytics by integrating multilevel determinants into a unified geographic disparity assessment model.

**Key words:** Long COVID, geographic disparities, multilevel modeling, post-acute sequelae, health inequities, spatial epidemiology, United States, metropolitan regions, public health surveillance.

### INTRODUCTION

#### Background

The global COVID-19 pandemic has transitioned from an acute infectious crisis to a long-term public health burden characterized by persistent post-acute sequelae among survivors. These conditions, collectively termed Long COVID, include a wide spectrum of symptoms

such as fatigue, cognitive dysfunction, respiratory complications, and cardiovascular irregularities. Health systems globally continue to struggle with defining, measuring, and managing these prolonged outcomes. Despite increasing clinical recognition, Long COVID remains poorly integrated into routine surveillance frameworks.

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National research efforts have underscored the urgency of developing structured analytical approaches to address Long COVID as a sustained health condition rather than an isolated post-infection event. However, critiques of existing research strategies highlight gaps in coordination and data integration across jurisdictions (Abbasi, 2022). These limitations are particularly evident in the United States, where healthcare delivery and surveillance systems vary significantly across states and metropolitan areas.

### Problem Statement

A key challenge in Long COVID research is the absence of a unified multilevel framework capable of capturing geographic disparities in symptom burden and disease persistence. Existing studies often focus on clinical or demographic determinants without adequately incorporating spatial heterogeneity or structural inequality. This results in fragmented evidence that limits policy applicability and resource allocation efficiency.

Furthermore, national-level analyses often mask subnational disparities that are critical for understanding the true burden of disease. Variability across urban and rural regions, socioeconomic strata, and healthcare infrastructure contributes to uneven health outcomes. Without a structured multilevel analytical approach, these disparities remain underexplored.

### Research Objectives

This study aims to develop a conceptual multilevel framework to assess geographic disparities in Long COVID outcomes across U.S. states and metropolitan regions. The specific objectives include:

1. To synthesize existing evidence on Long COVID prevalence and determinants.
2. To construct a multilevel analytical model incorporating individual, community, and structural factors.
3. To identify spatial patterns of disparity in post-acute COVID-19 conditions.

4. To evaluate the implications of geographic heterogeneity for health policy and surveillance systems.

### Scope and Significance

The significance of this study lies in its integration of epidemiological, socioeconomic, and spatial perspectives into a unified analytical framework. By addressing multilevel determinants, the proposed model enhances understanding of how structural inequities shape Long COVID outcomes. This is particularly relevant given ongoing concerns regarding the adequacy of national research responses to Long COVID management and surveillance (Abbasi, 2022).

The framework also supports health policymakers in identifying high-risk geographic clusters and optimizing resource allocation strategies. In doing so, it contributes to the broader field of spatial epidemiology and health systems research.

## LITERATURE REVIEW

### Conceptualization of Long COVID

Long COVID has been widely recognized as a multifaceted condition characterized by persistent symptoms extending beyond the acute phase of SARS-CoV-2 infection. Clinical definitions emphasize variability in symptom duration, severity, and organ system involvement. According to clinical reviews, Long COVID encompasses both mild and disabling conditions that significantly affect quality of life and functional capacity (Johns Hopkins Medicine, 2022).

National-level discussions emphasize the need for structured research frameworks to better understand these long-term effects. However, concerns remain regarding the adequacy of current research planning efforts in addressing the complexity of Long COVID (Abbasi, 2022). This highlights a critical gap between clinical recognition and analytical operationalization.

### Geographic and Socioeconomic Disparities

Evidence suggests that COVID-19 outcomes, including Long COVID, are not evenly distributed across populations. Studies indicate significant disparities in infection prevalence

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and health outcomes based on socioeconomic status, race, and geographic location (Singh et al., 2021). These disparities are further compounded by differences in healthcare access and occupational exposure risks.

State-level variations in COVID-19 burden demonstrate that structural determinants play a critical role in shaping health outcomes. For example, areas with limited healthcare infrastructure and higher poverty rates tend to experience disproportionately higher disease burdens. These findings support the need for multilevel analytical frameworks that integrate structural and spatial determinants.

### Health System and Economic Impacts

Long COVID has also been associated with substantial economic consequences, including workforce reduction and productivity loss. Economic analyses estimate that millions of individuals may be unable to return to work due to persistent symptoms (Bach, 2022). These impacts further reinforce the importance of understanding geographic disparities in disease burden.

Additionally, broader assessments of pandemic-related costs highlight the long-term strain on healthcare systems and labor markets (Bruns & Teran, 2022). These structural pressures contribute indirectly to disparities in post-acute health outcomes.

### Research Gaps

Despite growing literature on Long COVID, several gaps remain:

- Lack of integrated multilevel frameworks combining individual and structural determinants
- Insufficient spatial analysis of metropolitan vs. state-level disparities
- Limited longitudinal surveillance systems
- Inadequate policy translation of epidemiological findings

National research planning efforts have acknowledged these limitations, emphasizing the need for improved coordination and methodological innovation (Abbasi, 2022). This

study addresses these gaps by proposing a structured multilevel analytical framework.

## METHODOLOGY

### Study Design

This study adopts a conceptual and analytical framework development approach based on synthesis of existing epidemiological, clinical, and socioeconomic literature. The objective is not primary data collection but the construction of a multilevel analytical model for assessing geographic disparities in Long COVID outcomes.

### Framework Development Approach

The proposed framework integrates three analytical levels:

1. Individual Level: Infection severity, symptom persistence, comorbidities
2. Community Level: Socioeconomic status, population density, healthcare access
3. Structural Level: State health policy, surveillance capacity, economic conditions

This hierarchical structure enables systematic evaluation of how determinants at different levels interact to produce geographic disparities in health outcomes.

### Data and Evidence Integration

The framework is informed by synthesis of national surveillance data and peer-reviewed literature, including CDC reports and population-level surveys (CDC, 2022; U.S. Census Bureau, 2022). These sources provide evidence of spatial variability in COVID-19 outcomes and healthcare utilization patterns.

Additionally, conceptual insights from Long COVID research planning documents highlight the importance of coordinated data systems for monitoring post-acute conditions (Abbasi, 2022). These insights inform the structural component of the framework.

### Analytical Structure

The model employs a multilevel perspective consistent with spatial epidemiology principles. Geographic disparities are conceptualized as outcomes of nested determinants:

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- Level 1 (Individual): Biological response variability
- Level 2 (Contextual): Community vulnerability indices
- Level 3 (Structural): Policy and healthcare system variation

This structure allows for interpretation of both within-region and between-region variability in Long COVID outcomes.

### RESULTS

The synthesis of existing epidemiological and policy literature reveals a pronounced geographic heterogeneity in post-acute COVID-19 conditions across the United States. At the state level, Long COVID prevalence demonstrates systematic clustering in regions characterized by socioeconomic disadvantage, lower healthcare access, and higher baseline comorbidity burden. This pattern is consistent with broader COVID-19 inequity trends observed during earlier phases of the pandemic (Singh et al., 2021).

One of the central findings is that Long COVID is not uniformly distributed but instead reflects layered structural and contextual determinants. States in the Southeast and parts of the Southwest exhibit higher reported symptom persistence and severity, while metropolitan regions with stronger healthcare infrastructure demonstrate comparatively lower symptom burden. This aligns with national surveillance interpretations that emphasize uneven disease burden across jurisdictions (CDC, 2022).

A second key observation is the divergence between infection prevalence and post-acute symptom persistence. While infection rates may be high across multiple states, the progression to Long COVID appears more strongly associated with socioeconomic vulnerability and healthcare access constraints than with infection incidence alone. This suggests that post-acute outcomes are mediated by systemic conditions rather than purely biological exposure.

Economic and occupational impacts further reinforce these disparities. Evidence indicates that Long COVID contributes to substantial workforce disengagement, with millions

affected by reduced labor participation (Bach, 2022). These effects are disproportionately concentrated in regions with already fragile labor markets, amplifying geographic inequality.

Additionally, health system preparedness varies significantly across states, influencing both diagnosis rates and long-term management of post-COVID conditions. Regions with stronger surveillance infrastructure are more likely to identify and document Long COVID cases, whereas under-resourced areas may underreport burden, thereby masking true prevalence variability. National research planning documents highlight that such inconsistencies reflect broader limitations in Long COVID monitoring systems (Abbasi, 2022).

Overall, the findings indicate that geographic disparities in Long COVID are driven by a convergence of structural inequality, healthcare system variability, and socioeconomic stressors, rather than isolated epidemiological factors.

### DISCUSSION

#### Interpretation of Findings

The observed geographic disparities in Long COVID outcomes underscore the importance of adopting a multilevel analytical perspective. The results suggest that post-acute COVID-19 conditions cannot be fully understood through individual-level clinical factors alone. Instead, they emerge from interactions between biological vulnerability, community-level socioeconomic conditions, and structural health system capacity.

This interpretation aligns with broader pandemic research indicating that COVID-19 outcomes are deeply stratified by social determinants of health (Singh et al., 2021). The persistence of these disparities into the post-acute phase suggests that Long COVID functions as a continuation of pandemic-era inequities rather than a distinct clinical phenomenon.

#### Theoretical Implications

The proposed multilevel framework contributes to spatial epidemiology by integrating structural determinants into post-viral condition analysis. Traditional biomedical models of Long COVID emphasize symptomatology and individual clinical history;

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however, this study demonstrates the necessity of embedding these within broader geographic and institutional contexts.

From a theoretical standpoint, Long COVID can be conceptualized as a multi-layered outcome shaped by:

- Biological susceptibility (immune response variability)
- Social exposure risk (occupational and housing conditions)
- Structural health system performance (access, surveillance, and continuity of care)

This layered model expands existing frameworks by explicitly incorporating geographic stratification as a core analytic dimension.

### Policy and Practical Implications

The findings have significant implications for health policy design. First, resource allocation strategies must account for geographic heterogeneity in post-acute COVID-19 burden. States and metropolitan areas with higher vulnerability indices require targeted investment in rehabilitation services and long-term care infrastructure.

Second, surveillance systems require standardization to ensure consistent identification of Long COVID across jurisdictions. Current inconsistencies in reporting may lead to systematic underestimation of disease burden in underserved regions. National-level planning efforts emphasize the need for improved coordination, though implementation remains incomplete (Abbasi, 2022).

Third, workforce policies must incorporate Long COVID as a structural labor market factor. Economic evidence indicates that productivity losses are concentrated in regions already experiencing economic fragility (Bach, 2022), reinforcing the need for integrated health-economic policy responses.

### Limitations

This study is limited by its reliance on secondary literature synthesis rather than primary empirical datasets. As a result,

quantitative estimation of regional effect sizes is not provided. Additionally, variability in definitions of Long COVID across studies introduces interpretive heterogeneity.

Another limitation is the absence of granular individual-level data linked to geographic identifiers, which restricts precise multilevel statistical validation. Finally, evolving definitions of post-acute COVID-19 conditions may influence the consistency of comparative findings over time.

Despite these limitations, the framework offers a structured conceptual foundation for future empirical modeling.

## CONCLUSION

This study developed a multilevel analytical framework for assessing geographic disparities in post-acute COVID-19 conditions across U.S. states and metropolitan regions. The findings demonstrate that Long COVID is shaped by interconnected individual, community, and structural determinants, resulting in significant spatial inequality in symptom burden and health outcomes.

The analysis highlights that geographic disparities are not merely reflections of infection patterns but are deeply embedded in socioeconomic inequality and health system variability. These findings reinforce the need for coordinated national research strategies, particularly given ongoing concerns regarding the adequacy of Long COVID research planning and surveillance systems (Abbasi, 2022).

Future research should focus on integrating real-time surveillance data with multilevel modeling approaches to quantify regional disparities more precisely. Strengthening data infrastructure and harmonizing definitions across jurisdictions will be critical for improving policy responsiveness.

Ultimately, the proposed framework contributes to advancing spatial health analytics and provides a foundation for more equitable post-pandemic health system planning.

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