**Evaluate the effectiveness of SHIELD Illinois COVID testing program in underrepresented zip codes**

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**Abstract**

This study underscores the pivotal role of the SHIELD testing program in managing the COVID-19 pandemic, particularly through the concept of the “effective number” of test centers, those actively serving their communities. While the overall number of SHIELD test centers increased during major pandemic waves, it was the proportion of these centers effectively serving their respective zip codes that significantly impacted the reduction of COVID ICU admission rates. During the Alpha and Delta waves, the mere presence of SHIELD test centers did not markedly lower COVID ICU admission rates. However, during the Omicron wave, a higher proportion of effectively serving centers, especially in more disadvantaged areas, was associated with a statistically significant reduction in COVID ICU admission rates. Lag analysis further revealed that increases in the effective number of SHIELD test centers led to sustained decreases in COVID ICU admission rates over time, particularly in socioeconomically disadvantaged communities. These findings highlight the necessity of not only maintaining the number of testing centers but also ensuring their strategic deployment and efficient operation to meet the evolving demands of the pandemic. The success of the SHIELD program hinged on the effective placement of centers in areas most in need, which is vital for controlling the virus’s spread and reducing severe outcomes. This study provides insight for public health officials to make more informed decisions in mitigating the outcome of future pandemics.

**Background**

SARS-CoV-2 is the virus strain that causes Coronavirus Disease 2019 (COVID-19) which killed over 7 million people globally [1]. Patients with coronavirus infections have highly varied outcomes. Research revealed that ICU admission was necessary for between 3% and 100% of confirmed cases, with mortality rates reaching as high as 86% among those admitted [2].

The COVID pandemic has made health inequities worse, with underrepresented communities seeing greater rates of morbidity and mortality than the overall population [3]. According to earlier research, socioeconomic risk factors like food insecurity, homelessness, and poverty can also have a negative impact on people’s health during a pandemic [4-5]. Zeng et al., [6] revealed that low vaccination rates in some Chicago zip codes were linked to greater COVID mortality rates, aggravating already-existing racial and ethnic differences in death rates.

Soon after the virus genome was made public, tests to identify COVID-19 were created [7]. The University of Illinois System’s SHIELD Illinois (also referred to as “SHIELD”) aims to provide the cutting-edge saliva-based COVID-19 test to K–12 schools, colleges, universities, businesses, and the public throughout the state of Illinois. Testing for SHIELD started in the fall of 2020 and expanded quickly. In the fall of 2020, SHIELD processed less than 5,000 tests; by May 2021, it processed 85,500 tests; and by January 2022, it processed slightly under 900,000 tests. In May 2022, SHIELD cleared the 6-million-test level, and in February 2023, it surpassed the 7-million-test threshold. SHIELD Illinois is a statewide initiative offering free COVID testing to all residents. While the program has successfully increased testing rates across Illinois, its effectiveness in improving COVID outcomes in underserved communities remains unclear. The program has amassed extensive data on testing, encompassing the number and types of tests conducted, test results, and demographic information of those tested. This presents a unique opportunity to gain a comprehensive understanding of the impact of SHIELD Illinois on the health of underrepresented communities in Chicago, especially when combined with data from the Chicago Department of Public Health and Electronic Health Records.

Our aim is to evaluate the relation between the number of SHIELD test centers on COVID-19 ICU admission rates across the different COVID-19 waves (i.e., Alpha, Delta, and Omicron). We further analyze the impact of the geospatial determinants of health factors including the socioeconomic status in zip code level on the effectiveness of the number of SHIELD centers. We particularly focus on a large academic hospital which serves a diverse population with highly different socioeconomic status in the western suburbs of Chicago. By addressing this aim, our study provides insight for public health officials to make more informed decisions in mitigating the outcome of future pandemics.

**Methods**

**Study Design and Population**

We utilized datasets from the ICU at Loyola University Chicago, covering the period from January 2020 to December 2023. Figure 1 illustrates the data filtration process used to refine the ICU dataset for the study, focusing on COVID ICU admission rates. The process began with an initial dataset comprising ICU admissions from 585 zip codes, collected between 2020 and 2023. From this dataset, the top 25% of zip codes with the highest frequency of patients served by Loyola Hospital were selected, reducing the dataset to 147 zip codes and concentrating on the areas most impacted by ICU admissions at Loyola. The next step involved filtering the dataset to include only COVID-19 patients, excluding non-COVID patients based on COVID-19 ICD-10 codes (Table 1), which are standardized codes used to identify and classify COVID-19 cases. The final dataset included only COVID-19 patients from the 147 selected zip codes, spanning the same 2020-2023 timeframe. This refined dataset was then used for further analysis in the study.

A flowchart of datasets

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**Figure 1**: Data Filtration Diagram

**Table1:** ICD-10 codes related to the COVID-19

|  |  |
| --- | --- |
| **COVID related ICD-10 code** | **Description** |
| Z11.52 [8-9] | Contact with and (suspected)exposure to COVID-19 |
| M35.81 [9-11] | Multisystem Inflammatory Syndrome (MIS) |
| J12.82 [8-9] | Pneumonia due to Coronavirus disease 2019 |
| U07.1 [8-14] | COVID-19 |
| U09.9 [10-11] | Post-COVID-19 condition, unspecified |
| B97.29 [13-14] | Other Coronavirus as the cause of disease classified elsewhere |
| J20.8 [14] | Acute bronchitis confirmed as due to COVID-19 |
| J22 [14] | Lower or acute respiratory infection due to COVID-19 |
| J98.8 [14] | Respiratory infection due to COVID-19 |
| J80 [14] | Acute Respiratory Distress Syndrome (ARDS) due to COVID-19 |

The total number of SHIELD centers operating in each zip code each month was recorded. However, this figure can be misleading, as it may not accurately represent how many of these centers “effectively” served the zip codes in which they were located. Therefore, we calculated the effective number of SHIELD test centers each month as follows:

First, a matrix was constructed with zip codes as columns and testing center IDs as rows. For each date between February 2021 and December 2022, the total number of samples collected by each testing center in every zip code was computed. Next, the proportion of samples collected by each testing center within a zip code, relative to the total number of samples collected by that center, was calculated. Finally, these proportions were aggregated for each zip code to determine the effective number of SHIELD test centers serving that area.

**Data Description**

We sourced the data from the ICU at Loyola University Chicago Hospital. After filtering the data, we had a total of 147 zip codes between January 2020 and December 2023 across Illinois. Figure 2 illustrates the geographical distribution of all these zip codes with COVID-19 patients who were frequently served by Loyola Hospital. The highlighted areas, primarily concentrated around the Chicago metropolitan region and extending to various surrounding areas, represent the zip codes where Loyola Hospital’s ICU services were most utilized for treating COVID-19 patients during this period.

A map of a city

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**Figure 2:** Distribution of 147 zip codes with COVID patients frequently served by Loyola hospital

The dataset comprised various variables essential for analyzing the impact of SHIELD test centers on COVID ICU admissions rate across different zip codes. Below is a brief description of each variable included in the dataset:

* *Zip code*: The dataset includes 147 unique zip codes across Illinois, where Loyola University Chicago Hospital frequently treated COVID-19 patients.
* *Timespan (Feb 2021 - Dec 2022)*: The time period covered in the dataset to focus on the impact of SHIELD center interventions and closures on ICU admission rates.
* *Total COVID ICU admission per zip code per month*: The total number of COVID-19 ICU admissions recorded each month for each zip code. This variable helps assess the severity and frequency of COVID-19 cases requiring intensive care.
* *Zip code population*: The population of each zip code
* *COVID ICU admission rate*: This rate measures ICU admissions for COVID-19 per zip code, adjusted for population size. It is calculated by dividing the total COVID-19 ICU admissions by the zip code’s population and then multiplying by 100,000 to standardize the rate per 100,000 people.
* *Effective number of SHIELD test centers*: The effective number of testing sites that actively served each zip code.
* *ADI Category*: The Area Deprivation Index (ADI) score categorizes zip codes into “Less Disadvantaged” (scores 1 through 4) and “More Disadvantaged” (scores 5 through 9) based on socioeconomic factors. This variable is used to explore disparities in ICU admissions and the impact of SHIELD centers in different socioeconomic contexts.

**Statistical Analysis**

We investigated the association between the effective number of SHIELD test centers and the COVID ICU admission rate by employing a linear mixed-effects regression model. The analysis utilized data from March 2021 to June 2021 for the Alpha wave, August 2021 to November 2021 for the Delta wave [15], and December 2021 to March 2022 for the Omicron wave [16]. The model included fixed effects such as effective number of SHIELD centers per zip code per month and ADI category. To account for the clustering of the monthly COVID ICU admission rate, we incorporated a zip code-level random intercept.

Additionally, we conducted robustness checks using lag analysis to assess the impact of SHIELD testing on the COVID ICU admission rate across different waves. Specifically, we examined the effects with one-month and two-month lags to determine whether the timing of testing influenced subsequent COVID ICU admissions.

All analyses were conducted using R statistical software version 2024.04.1 (R Project for Statistical Computing). The data analysis period spanned from March 1, 2024, to August 9, 2024.

**Results**

We considered the effective number of SHIELD center that served the zip code, instead of just the number of SHIELD centers that are located in this zip code. Figure 3 compares the average number of SHIELD test centers and the average effective number of SHIELD test centers across all zip codes over time. The root mean square error (RMSE) between them is 0.94, indicating a close alignment between these two metrics. While some variations exist, this small RMSE suggests that the centers were generally effective in their operations relative to their number.

A graph showing the value of a wave

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**Figure 3:** Trends of SHIELD test centers and effective number of SHIELD centers over time for all zip codes

To begin our analysis, we examined the overall trends in the COVID ICU admission rate and the availability of SHIELD test centers across all zip codes over the study period. This preliminary analysis provides insight into how both the rate of COVID ICU admissions and effective number of test centers have evolved during the different COVID-19 waves (Figure 4). The chart presents an analysis of the relationship between the average effective number of SHIELD test centers and the average COVID ICU admission rates across different zip codes, categorized by their level of deprivation using the ADI. The green bars represent the average effective number of SHIELD test centers in less disadvantaged areas, while the orange bars indicate the same in more disadvantaged areas. The green and orange lines track the average COVID ICU admission rates in less and more disadvantaged areas, respectively. The data reveals that during the pandemic’s peaks, specifically the Delta and Omicron waves, the effective number of SHIELD test centers increased significantly in both more and less disadvantaged areas. However, less disadvantaged areas consistently had a higher number of effective test centers throughout the observed period. Despite this, the COVID ICU admission rates were generally higher in more disadvantaged zip codes, particularly during the Delta and Omicron waves. This trend suggests that more disadvantaged areas experienced a greater burden of severe COVID-19 cases, even as the number of SHIELD centers increased.

A graph of green and orange lines

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**Figure 4:** Trends in COVID ICU admission rates and SHIELD test center across zip codes over time

**Linear Mixed-Effect Regression Model**

Tables 2 provide a summary of regression models examining the relationship between SHIELD test centers and COVID ICU admission rates during the Alpha, Delta, and Omicron waves. During the Delta wave, model 2 presents a positive estimate (1.622%) for the more disadvantaged ADI, which is statistically significant at the *p* < 0.1 level. This suggests that these zip codes experienced higher COVID ICU admission rates, reflecting a socio-economic disparity in the burden of severe COVID-19 cases. For the Omicron wave, model 2 shows a positive and statistically significant estimate (2.097%, *p* < 0.1), indicating that more disadvantaged zip codes experienced higher COVID ICU admission rates compared to less disadvantaged areas. Additionally, model 3 reveals that an increase in the effective number of SHIELD centers in more disadvantaged ADI areas is associated with a 0.5% reduction in the COVID ICU admission rate (*p* < 0.1). Our data indicates that the average COVID ICU admission rate in more disadvantaged zip codes is currently 6.33%. Therefore, enhancing the effectiveness of SHIELD centers by one unit would reduce the average COVID ICU admission rate to 5.83% in these areas.

**Table 2**: Impact of SHIELD test centers and ADI on COVID ICU admission rates

|  |  |  |  |
| --- | --- | --- | --- |
| **Model** | **Predictors** | **Estimates** | **Significance Level** |
| **Alpha Wave** | | | |
| **1** | Effective Number of Test Centers | -0.00542 |  |
| **2** | ADI (More Disadvantaged) | 0.00873 |  |
| **3** | Effective Number of Test Centers:ADI (More Disadvantaged) | 0.00403 |  |
|  |  |  |  |
| **Delta Wave** | | | |
|  | | | |
| **1** | Effective Number of Test Centers | 0.00004 |  |
| **2** | ADI (More Disadvantaged) | 0.01622 | **\*** |
| **3** | Effective Number of Test Centers:ADI (More Disadvantaged) | -0.00247 |  |
|  |  |  |  |
| **Omicron Wave** | | | |
|  | | | |
| **1** | Effective Number of Test Centers | -0.00249 |  |
| **2** | ADI (More Disadvantaged) | 0.02097 | **\*** |
| **3** | Effective Number of Test Centers:ADI (More Disadvantaged) | -0.00594 | **\*** |

Table 3 presents the results of a regression analysis examining the impact of SHIELD test centers and ADI on COVID ICU admission rates with a one-month lag. This lag analysis aims to determine how COVID-19 testing influences COVID ICU admission rates one month later, considering different COVID-19 waves. During the Delta wave, model 2 presents a positive and statistically significant estimate (1.622%, *p* < 0.1) for the more disadvantaged zip codes, indicating that these areas experienced significantly higher COVID ICU admission rates one month after testing.

In the Omicron wave, model 1 indicates a negative and statistically significant estimate (-0.287%, *p* < 0.1) suggesting a significant reduction in COVID ICU admissions one month after an increase in the effective number of SHIELD test centers. With the current average COVID ICU admission rate at 4.77%, this decrease would lower the rate to 4.49% one-month post-testing. Additionally, Model 2 presents a positive and statistically significant estimate (2.097%, *p* < 0.1) for the more disadvantaged zip codes, indicating that these areas experienced significantly higher COVID ICU admission rates one month after testing.

**Table 3**: Impact of SHIELD test centers and ADI on COVID ICU admission rates (one-month lag)

|  |  |  |  |
| --- | --- | --- | --- |
| **Model** | **Predictors** | **Estimates** | **Significance Level** |
| **Alpha Wave** | | | |
| **1** | Effective Number of Test Centers | 0.00251 |  |
| **2** | ADI (More Disadvantaged) | 0.00885 |  |
| **3** | Effective Number of Test Centers:ADI (More Disadvantaged) | -0.00083 |  |
|  |  |  |  |
| **Delta Wave** | | | |
|  | | | |
| **1** | Effective Number of Test Centers | -0.00149 |  |
| **2** | ADI (More Disadvantaged) | 0.01622 | **\*** |
| **3** | Effective Number of Test Centers:ADI (More Disadvantaged) | -0.00259 |  |
|  |  |  |  |
| **Omicron Wave** | | | |
|  | | | |
| **1** | Effective Number of Test Centers | -0.00287 | **\*** |
| **2** | ADI (More Disadvantaged) | 0.02097 | **\*** |
| **3** | Effective Number of Test Centers:ADI (More Disadvantaged) | -0.00447 |  |

Table 4 displays the findings of a regression analysis that investigates the influence of SHIELD test centers and ADI on COVID ICU admission rates with a two-month delay. During the Delta wave, model 1 presents a negative and statistically significant estimate (-0.199%, *p* < 0.1) indicating a significant reduction in the COVID ICU admission rate two months after an increase in the effective number of SHIELD test centers. The data shows that the average COVID ICU admission rate during the Delta wave is currently 4.14%. Therefore, improving the effectiveness of SHIELD centers by one unit would reduce the average COVID ICU admission rate to 3.94% two-month post-testing during this wave. Also, model 2 shows a positive and statistically significant estimate (1.622%, *p* < 0.1) for the more disadvantaged zip codes, suggesting that these areas experienced significantly higher COVID ICU admission rates two months after testing. In Omicron wave, model 2 shows a positive and statistically significant estimate (2.097, *p* < 0.1) for the more disadvantaged zip codes, suggesting that these experienced significantly higher COVID ICU admission rates two months after testing. Also, model 3 presents a negative estimate (-0.678%, *p* < 0.1) for the interaction between the effective number of SHIELD test centers and more disadvantaged zip codes, suggesting a one-unit increase of SHIELD test centers in these areas would reduce the COVID ICU admission rate from 6.33% to 5.66% two months after testing.

**Table 4**: Impact of SHIELD test centers and ADI on COVID ICU admission rates (two-month lag)

|  |  |  |  |
| --- | --- | --- | --- |
| **Model** | **Predictors** | **Estimates** | **Significance Level** |
| **Alpha Wave** | | | |
|  |  |  |  |
| **1** | Effective Number of Test Centers | -0.00154 |  |
| **2** | ADI (More Disadvantaged) | 0.00885 |  |
| **3** | Effective Number of Test Centers:ADI (More Disadvantaged) | -0.00806 |  |
|  |  |  |  |
| **Delta Wave** | | | |
|  | | | |
| **1** | Effective Number of Test Centers | -0.00199 | **\*** |
| **2** | ADI (More Disadvantaged) | 0.01622 | **\*** |
| **3** | Effective Number of Test Centers:ADI (More Disadvantaged) | -0.00313 |  |
|  |  |  |  |
| **Omicron Wave** | | | |
|  | | | |
| **1** | Effective Number of Test Centers | -0.00236 |  |
| **2** | ADI (More Disadvantaged) | 0.02097 | **\*** |
| **3** | Effective Number of Test Centers:ADI (More Disadvantaged) | -0.00678 | \* |

**Conclusion**

The results of this study highlight the critical role that the SHIELD testing program played in managing the COVID-19 pandemic, with particular emphasis on the proportion of these centers that were actively serving communities, the “effective number” of SHIELD test centers. While the overall number of SHIELD test centers increased during major waves of the pandemic, it was the proportion of centers that were effectively serving their respective zip codes that had a significant impact on reducing COVID ICU admission rate.

During the Alpha and Delta waves, the effective number of SHIELD test centers alone did not significantly lower COVID ICU admission rate. However, during the Omicron wave, the results revealed that when a higher proportion of SHIELD centers actively served their communities, particularly in more disadvantaged areas, there was a statistically significant reduction in COVID ICU admission rate. This suggests that the effectiveness of number of testing centers was crucial in mitigating severe COVID-19 outcomes. The lag analysis further supports this conclusion, showing that an increase in the effective number of SHIELD centers led to sustained reductions in COVID ICU admission rates over time, particularly in socio-economically disadvantaged areas. This underscores the importance of not only maintaining the number of testing centers but also ensuring that these centers are strategically deployed and effectively utilized to meet the evolving demands of the pandemic.

In summary, the findings suggest that the success of the SHIELD testing program depended not just on the quantity of testing centers, but on their effectiveness, specifically how well they are strategically placed in areas where they are most needed, based on factors like socio-economic conditions and how efficiently they operate to maximize their impact. This strategic deployment and effective utilization are necessary to ensure that all communities, especially those that are more disadvantaged, have adequate access to testing resources, which is vital for controlling the spread of the virus and reducing severe outcomes.

Future public health strategies should focus on optimizing the deployment and operation of testing centers, particularly in vulnerable communities, to maximize their impact on reducing severe health outcomes during a pandemic.

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