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

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**Background**

SARS-CoV-2 is the virus strain that causes Coronavirus Disease 2019 (COVID-19) which killed over 88 thousand people globally [1]. Patients with coronavirus infections have highly varied outcomes. Research also revealed that between 3% and 100% of verified cases, a larger percentage of coronavirus-infected individuals required ICU admission. Additionally, studies revealed that between 6% and 86% of hospitalized patients in critical care had a coronavirus infection, which was a very high rate of mortality [3].

The COVID pandemic has made health inequities worse, with underrepresented communities seeing greater rates of morbidity and mortality than the overall population [4]. 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 [5], [6]. Research by Zeng et al. (2022) 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 [7].

Soon after the virus genome was made public, tests to identify COVID-19 were created [8]. For clinical and public health applications, a wide range of COVID-19 tests are available. The point of care (POC), a central laboratory, or a community setting like a home, workplace, or school can all be used for testing [9].

The University of Illinois System's SHIELD Illinois (also referred to as "SHIELD") effort 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. During its time, SHIELD 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 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 provide 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 the COVID ICU admission rates. The process begins 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 are extracted. This step reduces the dataset to 147 zip codes, focusing on the areas most impacted by ICU admissions at Loyola. The next step involves filtering the dataset to focus exclusively on COVID-19 patients. Non-COVID patients are excluded from the dataset based on COVID-19 ICD-10 codes (Table 1), which are standardized codes used to identify and classify COVID-19 cases. The final dataset includes only COVID-19 patients from the 147 selected zip codes, spanning the same 2020-2023 timeframe. This refined dataset is 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 [13], [14] | Contact with and (suspected)exposure to COVID-19 |
| M35.81 [14], [15], [16] | Multisystem Inflammatory Syndrome (MIS) |
| J12.82 [13], [14] | Pneumonia due to Coronavirus disease 2019 |
| U07.1 [13], [14], [15], [16], [17], [18], [19] | COVID-19 |
| U09.9 [15], [16] | Post-COVID-19 condition, unspecified |
| B97.29 [18], [19] | Other Coronavirus as the cause of disease classified elsewhere |
| J20.8 [19] | Acute bronchitis confirmed as due to COVID-19 |
| J22 [19] | Lower or acute respiratory infection due to COVID-19 |
| J98.8 [19] | Respiratory infection due to COVID-19 |
| J80 [19] | Acute Respiratory Distress Syndrome (ARDS) due to COVID-19 |

The primary objective of this study is to assess whether the number or effective presence of SHIELD test centers has a mitigating effect on COVID-19 ICU admission rates, particularly in more disadvantaged zip codes, during the different waves of the COVID-19 pandemic. These waves include the Alpha wave (March 2021- June 2021), Delta wave (August 2021-November 2021) [10], and Omicron wave (December 2021-March 2022) [11].

Effective Number of SHIELD Centers:

*Number of SHIELD centers per zip code per month*: The total number of SHIELD centers operating in each zip code each month is obtained. However, this number can be misleading as it may not represent how many of them “effectively” served the zipcode in which they are located. Therefore, we calculated the effective number of SHIELD test centers in each month as follow:

{HOW DID YOU CALCULATE IT AND HOW THEY ARE RELATED TO EACH OTHER}

**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 comprises 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. This standardization facilitates fair comparisons across zip codes, highlighting the relative burden of severe COVID-19 cases in different areas.
* *NUMBER OF SHIELD CENTER*:
* that actively served each zip code. It reflects the actual accessibility and utilization of SHIELD testing facilities within a given area, providing a more accurate measure of the centers’ impact on the local population.
* *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 number and 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, and December 2021 to March 2022 for the Omicron wave. The model included fixed effects such as the number of SHIELD centers per zip code per month, the 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 shied centers that are located in this zip code. compares 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.

**General Trend**

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 the number and effective number of test centers have evolved during the different COVID-19 waves (Figure 3).

A graph with lines and numbers

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**Figure 3:** Trends in COVID ICU admission rates and SHIELD test center across zip codes over time

According to these results, the COVID ICU admission rate exhibits distinct peaks corresponding to the three major COVID-19 waves. During the Alpha wave there is a sharp increase in the COVID ICU admission rate, peaking in March 2021. This indicates a significant burden on ICUs during this early period of the pandemic. The Delta wave, occurring sees the ICU admission rate rise again, reaching its highest point in October 2021. This suggests another period of severe strain on healthcare resources. The Omicron wave also shows an elevated COVID ICU admission rate, peaking in January 2022, though this peak is slightly lower compared to the Delta wave. The rate remains high for a more sustained period during Omicron before gradually declining.

The orange bars represent the average number of SHIELD test centers, which significantly increased during the Alpha wave and reached their peak during the Delta wave. This reflects an expansion in testing capacity in response to the rising number of COVID-19 cases. The number of SHIELD centers remains high through the Omicron wave but begins to decrease after March 2022, indicating a reduction in testing capacity as the severity of the pandemic diminished.

The green bars show the effective number of SHIELD centers, which closely follows the trend of the total number of centers. This indicates that most of the available centers were actively serving their communities. During the Alpha wave, the number of effective centers gradually increases and remains high throughout the Delta wave, peaking in effectiveness during this period to meet the high demand for testing. After the Omicron wave, starting in March 2022, there is a noticeable decline in the effective number of SHIELD centers, corresponding with the general scale-back of testing efforts.

**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. Each model tests different combinations of predictors, including the number of SHIELD test centers, the effective number of test centers, the ADI category, specifically focusing on “More Disadvantaged” areas, and interaction terms between SHIELD centers and ADI.

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

|  |  |  |  |
| --- | --- | --- | --- |
| **Model** | **Predictors** | **Estimates** | **Significance Level** |
| **Alpha Wave** | | | |
| **1** | SHIELD Test Centers | -0.00302 |  |
| **2** | Effective Number of Test Centers | -0.00542 |  |
| **3** | ADI (More Disadvantaged) | 0.00873 |  |
| **4** | SHIELD Test Centers:ADI (More Disadvantaged) | 0.00224 |  |
| **5** | Effective Number of Test Centers:ADI (More Disadvantaged) | 0.00403 |  |
| **Delta Wave** | | | |
| **1** | SHIELD Test Centers | 0.00021 |  |
| **2** | Effective Number of Test Centers | 0.00004 |  |
| **3** | ADI (More Disadvantaged) | 0.01622 | **\*** |
| **4** | SHIELD Test Centers:ADI (More Disadvantaged) | -0.00202 |  |
| **5** | Effective Number of Test Centers:ADI (More Disadvantaged) | -0.00247 |  |
| **Omicron Wave** | | | |
| **1** | SHIELD Test Centers | -0.00206 |  |
| **2** | Effective Number of Test Centers | -0.00249 |  |
| **3** | ADI (More Disadvantaged) | 0.02097 | **\*** |
| **4** | SHIELD Test Centers:ADI (More Disadvantaged) | -0.00388 |  |
| **5** | Effective Number of Test Centers:ADI (More Disadvantaged) | -0.00594 | **\*** |

During the Alpha wave, the estimates for the number of SHIELD test centers and the effective number of test centers in Models 1 and 2 are negative, suggesting a potential reduction in COVID ICU admission rates associated with the presence of more test centers. However, these effects are not statistically significant. In Model 3, the ADI variable shows a positive estimate (0.873%), indicating a potential increase in ICU admissions in more disadvantaged areas, though this result is also not statistically significant. The interaction terms in Models 4 and 5 suggest small positive effects when combining SHIELD test centers with ADI, but neither interaction is statistically significant, indicating no substantial difference in the impact of SHIELD centers across socio-economic contexts during the Alpha wave.

During the Delta wave, Model 3 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.

Finally, during the Omicron wave, Model 3 shows a positive and statistically significant estimate (*p* < 0.1), indicating that more disadvantaged zip codes experienced higher COVID ICU admission rates compared to less disadvantaged areas. Additionally, Model 5 reveals that an increase in the effectiveness 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 rate in these disadvantaged areas is currently 6.33%. Therefore, enhancing the effectiveness of SHIELD centers by one unit would reduce the average COVID ICU rate to 5.83% in these regions.

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 ICU admission rates one month later, considering different COVID-19 waves.

**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** | SHIELD Test Centers | 0.0009 |  |
| **2** | Effective Number of Test Centers | 0.00251 |  |
| **3** | ADI (More Disadvantaged) | 0.00885 |  |
| **4** | SHIELD Test Centers:ADI (More Disadvantaged) | 0.00151 |  |
| **5** | Effective Number of Test Centers:ADI (More Disadvantaged) | -0.00083 |  |
| **Delta Wave** | | | |
| **1** | SHIELD Test Centers | -0.00102 |  |
| **2** | Effective Number of Test Centers | -0.00149 |  |
| **3** | ADI (More Disadvantaged) | 0.01622 | **\*** |
| **4** | SHIELD Test Centers:ADI (More Disadvantaged) | -0.00176 |  |
| **5** | Effective Number of Test Centers:ADI (More Disadvantaged) | -0.00259 |  |
| **Omicron Wave** | | | |
| **1** | SHIELD Test Centers | -0.00178 |  |
| **2** | Effective Number of Test Centers | -0.00287 | **\*** |
| **3** | ADI (More Disadvantaged) | 0.02097 | **\*** |
| **4** | SHIELD Test Centers:ADI (More Disadvantaged) | -0.00311 |  |
| **5** | Effective Number of Test Centers:ADI (More Disadvantaged) | -0.00447 |  |

During the Delta wave, Model 3 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. Although Models 4 and 5 show negative estimates for the interaction between the number of SHIELD test centers and the effective number of SHIELD test centers with ADI, respectively, these effects are not statistically significant.

In the Omicron wave, Model 2 indicates a negative and statistically significant estimate (-0.287%, *p* < 0.1) for the effective number of SHIELD test centers, suggesting a significant reduction in COVID ICU admissions one month after an increase in the effectiveness of SHIELD centers. With the current average COVID ICU rate at 4.77%, this decrease would lower the rate to 4.49% one-month post-testing. Additionally, Model 3 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. However, Models 4 and 5 do not show statistically significant results, despite the negative estimates for the COVID ICU admission rate.

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.

|  |  |  |  |
| --- | --- | --- | --- |
| **Model** | **Predictors** | **Estimates** | **Significance Level** |
| **Alpha Wave** | | | |
| **1** | SHIELD Test Centers | -0.00062 |  |
| **2** | Effective Number of Test Centers | -0.00154 |  |
| **3** | ADI (More Disadvantaged) | 0.00885 |  |
| **4** | SHIELD Test Centers:ADI (More Disadvantaged) | -0.00023 |  |
| **5** | Effective Number of Test Centers:ADI (More Disadvantaged) | -0.00806 |  |
| **Delta Wave** | | | |
| **1** | SHIELD Test Centers | -0.00109 |  |
| **2** | Effective Number of Test Centers | -0.00199 | **\*** |
| **3** | ADI (More Disadvantaged) | 0.01622 | **\*** |
| **4** | SHIELD Test Centers:ADI (More Disadvantaged) | -0.0018 |  |
| **5** | Effective Number of Test Centers:ADI (More Disadvantaged) | -0.00313 |  |
| **Omicron Wave** | | | |
| **1** | SHIELD Test Centers | -0.00194 |  |
| **2** | Effective Number of Test Centers | -0.00236 |  |
| **3** | ADI (More Disadvantaged) | 0.02097 | **\*** |
| **4** | SHIELD Test Centers:ADI (More Disadvantaged) | -0.00464 |  |
| **5** | Effective Number of Test Centers:ADI (More Disadvantaged) | -0.00678 | \* |

During the Delta wave, Model 2 presents a negative and statistically significant estimate (-0.199%, *p* < 0.1) for the effective number of SHIELD test centers, indicating a significant reduction in the COVID ICU admission rate two months after an increase in the effectiveness of these centers. The data shows that the average COVID ICU 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 rate to 3.94% two months post-testing during this wave. Also, Model 3 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. While Models 4 and 5 display negative estimates for the interaction between the number of SHIELD test centers and the effective number of SHIELD test centers with ADI, these effects are not statistically significant.

In Omicron wave, Model 3 shows a positive and statistically significant estimate (2.097, *p* < 0.1) for the ADI (More Disadvantaged), suggesting that more disadvantaged areas experienced significantly higher ICU admission rates two months after testing. Also, Model 5 presents a negative estimate (-0.678%, *p* < 0.1) for the interaction between the effective number of SHIELD test centers and ADI, suggesting a one-unit increase in the effectiveness of SHIELD centers in more disadvantaged ADI areas, two months after testing during the OMICRON wave would reduce the rate from 6.33% to 5.66% in these zip codes.

**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 admissions.

During the Alpha and Delta waves, the presence of SHIELD centers alone did not significantly lower COVID ICU admissions, indicating that simply having more centers available was not enough. However, during the Omicron wave, the data 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 admissions. This suggests that the effectiveness of testing 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 admissions 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 (i.e., how well they served the communities they were intended to help). 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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