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Observational Analysis for Predicting Initial Spikes in Testing Volume of Cohorts Inside and Outside of a Regional COVID-19 Screening Program

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ABSTRACT

Background : Containing the highly contagious SARs-CoV-2 pathogen requires a safe and effective screening program. This observational cohort study aims to analyze a regional testing center and identify factors predicting testing rates that direct supply and staffing needs.

Methods: A drive-through SAR-CoV-2 regional testing facility was created. A number of tests and positive results were collected for 18 months. Data for testing demand was compared to positive results, percent positive rates (PPR), known external factors, and county PPR. Dissimilarities were contrasted with dynamic time warping and a detailed agreement analysis. The Grainger's test was utilized to assess the degree of similarity.

Results: During the studied time, 44,877 tests were administered, resulting in 4,702 positives and a 10.48% PPR. Testing spikes occurred 4 times. Preceding month weekly fold-increases for testing (1.05+: p=0.0294) or weekly positives (1.05+: p=0.0294) predicted the "initial" spike in testing the following month, but PPR increases (1.15+: p=0.1160) did not. Similar increases in weekly testing (1.05+: p=0.0269), weekly positives (1.05+: p=0.0023), and PPR (1.15+: p=0.0063) predicted "any" spike in testing the following month. Testing center and county longitudinal PPRs demonstrated a dissimilarity rate of 44.16% (p<0.001) but correlated more during the Alpha variant surge.

Conclusions: Weekly testing and positive rate threshold increases predicted both "initial" and "any" peaks in testing, either due to COVID-19 variants or external pressures, 1 month in advance. Weekly PPR threshold measurements were not as reliable for initial spikes in testing. Similarity in PPR between testing center and county cohorts were seen beginning with the Alpha variant and ending at its vaccination-accelerated nadir. Understanding these factors allows for appropriate resource allocation for the remainder of this and future pandemics.

KEYWORDS

SARS-CoV-2, COVID-19, pandemic, testing volume, screening program, prediction factors

INTRODUCTION

The SARs-CoV-2, or COVID-19, is a coronavirus first identified following a pneumonia-like outbreak in Wuhan, China, in December 2019.[1] By March 2020, COVID-19 was classified a global pandemic.[2–5] Its transmission is essential to its virulence, generating[3] 2-fold more infectious particles than SARs-CoV-1[6-7] and heightened by an estimated 30-60% asymptomatic transmission rate.[6] Symptoms are variable, from asymptomatic to severe respiratory failure, and often include olfactory and gustatory loss, fever, cough, sore throat, rhinitis, headache, dyspnea, fatigue, gastrointestinal symptoms, myalgia, and hypoxia.[1,3,6] Severe morbidities include both ischemic and hemorrhagic strokes, as well as multi-organ failure.[3,6] Incubation after inoculation varies and ranges from 4-5 days to over 2 weeks.[6,8] Early diagnosis is the first step in preventing transmission to new hosts, but the proximity needed to screen these highly infectious individuals can endanger providers and other patients.[9]

An appropriate pandemic point-of-care testing protocol is essential to accurately identify infected patients, prevent transmission, conserve resources, and guide medical decisions.[10–12] Accurate surveillance requires both symptom history and reliable testing modalities. The most common testing modality of COVID-19 is real-time polymerase chain reaction testing,[13–16] which detects viruses from respiratory secretions within 6-8 hours.[14,17] Detecting only active virus narrows the testing window to the onset of symptoms and explains its high false negative rate (11%-40%).[10,14,15] Large-scale screening limits the spread by identifying greater percentages of asymptomatic or pre-symptomatic individuals.[11,12,15] This testing method requires sizable infrastructure and accurate, rapid point-of-care testing for maximal identification. To help facilitate this, governmental and other third-party payers initially helped finance the cost of testing. Nevertheless, even the broadest testing strategies miss infected individuals, limiting their surveillance.[11] As no established guidelines existed, we experienced barriers establishing widespread testing, including testing center location and scope of services provided, responsibility for the massive numbers of testing orders and result notification, and identification as well as qualification and supervision of various jobs within the team (registration, nursing, screeners). Since these issues were driven by need and often identified at the moment of crisis (Table 1), a blueprint for assessing the need for personnel and supplies in advance is essential moving forward in this and future pandemics.

In March 2020, the Marshall University School of Medicine's Department of Family and Community Health created a safe and effective COVID-19 screening program to minimize provider and patient exposure, ensure availability of testing, and limit supply utilization. This necessitated a prediction model for testing demand to drive resource allocation, but testing rate influencers within a pandemic are lacking. This project aims to identify factors by analyzing trends in testing, positive results, and positive percent rate (PPR) that predict testing volume and optimize resources for a regional testing center (RTC) during the COVID-19 pandemic.

METHODS

Data Collection

In this observational study, authors collected data on factors affecting facilities, staffing, and testing supplies longitudinally 18 months (March 2020 to August 2021) for an on-site drive-through RTC (Table 1). All numbers tested for the RTC cohort and positive results were monitored daily, stored on a spreadsheet, and PPRs were calculated. Data were plotted prospectively in weekly intervals (Figure 1). A similar retrospective search of the county cohort data was collected from the Center for Disease Control's Data Tracker to create longitudinal patterns of county weekly infection rates.18 Weekly data was compiled in monthly increments to determine the magnitude of the changes surrounding spikes in testing described as "initial" (first month of a surge) and "any" (each month with a surge). Factors influencing testing outside of infection rates were collected through local news reporting, including the governor's re-opening plan, holidays, vacation times, vaccination rollout, and waves of COVID. No funding was obtained for this study.

Data Analysis

We performed detailed comparisons between the time series data of PPR from tent and county. Dynamic time warping analysis (DTWA) displayed relative longitudinal dissimilarities between county and tent data and the points along the timeline when PPR are concordant. Magnitude differences over time are displayed by cumulative percentage plot, and Granger's test was used to assess the similarity of the county and tent time series. To confirm the longitudinal congruence patterns of these trends, a best-fitted time series model for county data with 95% confidence intervals based on

WEEK	START DATE	WHAT HAPPENED	RESULTANT CHANGE	RATIONALE
Week 1	March 2, 2020	First COVID-19 case reported in the state	Testing for SARs-COV-2 began inside the FMC for patients screening positive of COVID-19 symptoms (1 provider, 1 nurse, and 1 hallway. Provider and nurse changed every half day)	Limiting providers conserved PPE. Screening for symptoms conserved testing resources. Minimizing the providers, staff and facilities minimized exposure to employees and other patients
Week 0	March 9, 2020	Need to further decrease risk of exposure for staff and patients	Transitioned to in-car testing outside of medical center (Patient registration via telephone. Provider walked outside to screen and test patients at their car)	Increased demand for testing and worsening infection rates limited feasibility of testing in the FMC due to transmission risk to patients
Week 1	March 16, 2020	Increased testing rates	Temporary structures were created on the adjacent parking lot for drive-through testing	Multiple trips from FMC to the cars became impractical
Week 9	May 11, 2020	A second local testing site closed, and elective surgeries restarted	The hospital's Pre-Admission Testing department opened a separate pre-operative lane	Surgeries had been delayed due to not having COVID-19 test results in a timely manner
Weeks 10-13	May 18, 2020	Governor's reopening plan began	Spike in testing rates	Increased volume due to increased exposures and pre-employment testing requirements
Week 17	July 6, 2020	Testing numbers doubled to over 500 tests within 2 weeks	Hired first full-time LPN for the testing site	Time commitment required by nursing became problematic
Week 23	August 17, 2020	Constant strain of maintaining testing staffing and operations stretched clinic oversight capabilities	50% of the FMC's office manager's and social worker's time allocated to tent testing oversight	Formalized personnel management was needed due to growing numbers of employees
Week 24	August 24, 2020	Heat and storms became problematic, as the pandemic extended through the Summer	Created semi-permanent structures that housed supplies and equipment in the site's parking lot. Added on-site registration with designated on-site providers -and- First provider hired specifically for the testing center	As there was no end of the pandemic in site, a more permanent area was required to perform testing and house equipment.
Week 36	November 16, 2020	At the height of the pandemic, the extra work required at the testing center began wearing on providers and staff	Began weekly meetings to finalize schedules with department coordinator, nurse manager, occupational medicine, and research & development	Large interdisciplinary response needed to maintain day-to-day productivity
Weeks 39-40	December 7, 2020	Volume of testing demand hindered collection of all demographic and insurance data.	Hired first staff member to solely work the tent. -and- The hospital lab provided personnel and equipment.	Need for improved capturing of billing.
Week 46	January 25, 2021	Line congestion	Hired screeners (1.5 full time equivalent)	Collection of data from patients waiting to be tested became the rate limiting step
Week 49	February 22, 2021	Testing numbers decreased	Did not fill position vacated by an outgoing staff	The effects of an increasing vaccination rate caused testing demand to decrease
Weeks 67-69	June 2021	Testing numbers consistently under 100	Began making plans to discontinue drive-through testing and absorb this work in the FMC	
Week 70	August 2021	Testing numbers increased	Delayed plans to discontinue the drive-through testing and maintained current operations.	A spike in testing was attributed to a new variant (Delta).

TABLE 1. Longitudinal Development of a Regional Testing Facility, FMC (Family Medical Center)

Note: Demonstration of the developmental timeline for the testing center with contextual factors and rationale that necessitated the changes.
*FMC = family medical center, PPE = personal protective equipment

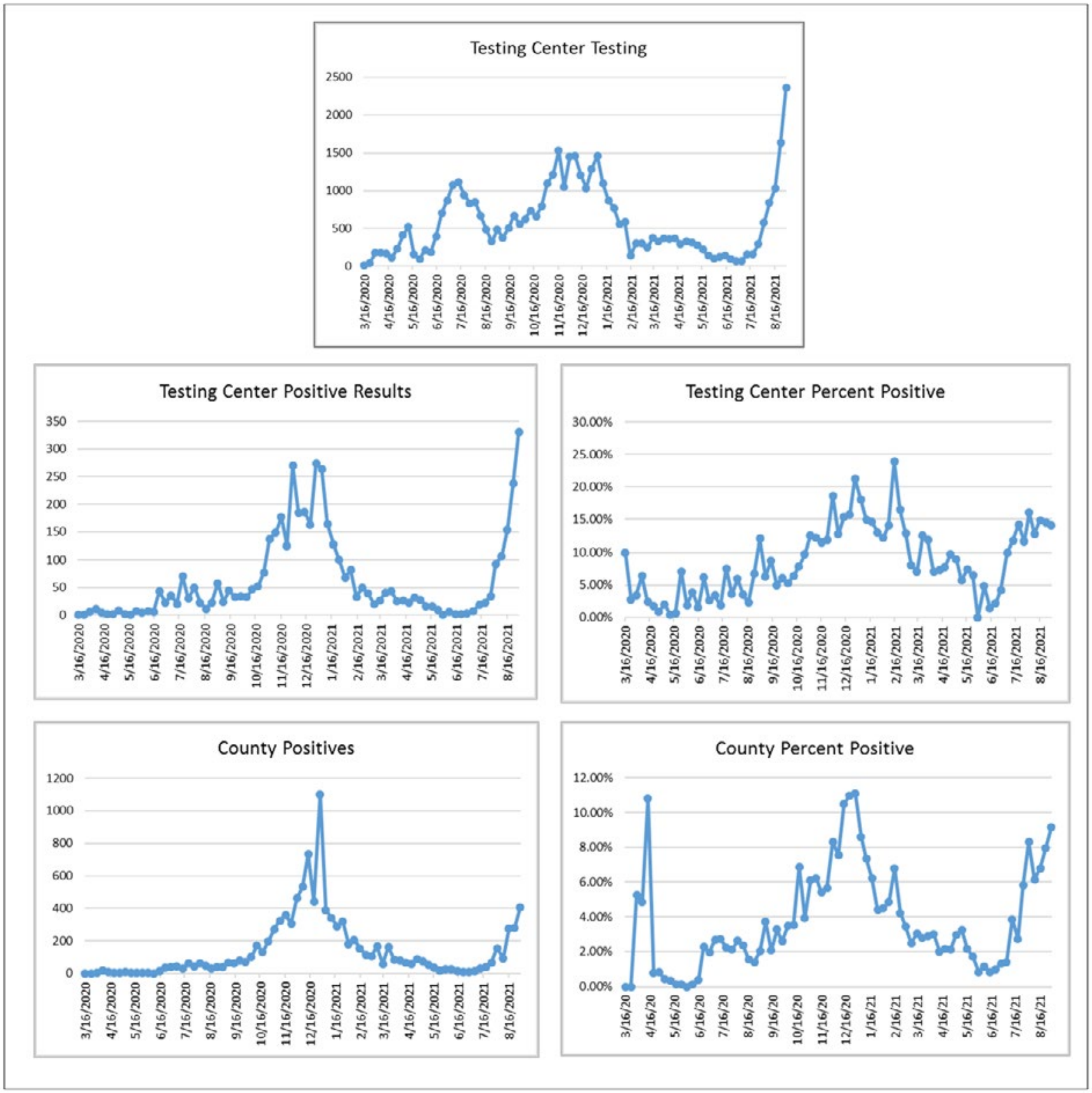

FIGURE 1. Longitudinal Display of Local and Regional Testing Center Results

Note: Longitudinal weekly trends of testing, positive results and percent positive calculations for testing center and county, in which the testing center resides. Testing and positive result data were collected from day-to-day operations for the testing center and from the CDC COVID data tracker18 for the county. These were utilized to calculate the percent positive rates (positive results divided by testing).

minimum Akaike Information Criterion (AIC) criteria was compared to tent data. A detailed agreement analysis was used to determine differences based on the direction of the previous week's trend. Weekly data was termed "agreement" for similar trends and "disagreement" for differing trends. A Wilcoxon signed rank test determined the significance of the agreement. Significance was defined as p<0.05. The Marshall University Institutional Review Board designated this project exempt and granted a limited IRB review approval.

RESULTS

The RTC cohort contained 44,877 tests administered over the 77 weeks studied, resulting in 4,702 positive results and a 10.48% PPR (Table 2). Longitudinal analysis (Figure 1) displays 4 distinct initial peaks: a 1.71-fold increase in weekly testing (174.00 to 298.25) in May 2020, a 2.1-fold increase (473.00 to 993.00) in July 2020, a 1.80-fold increase (704.5 to 1268.00) in November 2020, and a 7.49-fold (172.00 to 1287.60) in August 2021. The months preceding each of the 4 months displayed at least 1.05-fold increases weekly (p=0.1160). If all 6 peak months are considered, fold-increases in all 3 measures within the preceding months are significant: 1.05+ for weekly testing (p=0.0269) and weekly positives (p=0.0023), and 1.15+ for PPR (P=0.0063) (Table 3).

The DTWA indicates significant longitudinal differences between RTC and county cohorts (Figure 2A). Congruence occurred at the beginning and end of testing times, with county numbers higher, except for the downside of the spike from the alpha variant of COVID-19 until the delta spike. The cumulative percentage plot indicates that RTC PPR was greater compared to the county numbers, accelerating during times of higher infection rates (Figure 2B). Granger's test confirmed no causal association (< or >). Significant differences in both cycle and trend are seen in both data sets (Figure 2C), with 44.16% disagreement. The Wilcoxon signed rank test found no agreement between RTC and county PPR (p<0.001). Multi-week disagreement patterns are seen in weeks 7-11, 18-19, 26-31, 53-57,59-62, 71-72, and 76-77 (Figure 2D).

Month	Tests	Tests/ Week	Fold Increase	Positives	Positives/ Week	Fold Increase	% Positive	Fold Increase
March 2020	220	73.33		8	2.67		3.64%	
April 2020	696	174.00	2.37	19	4.75	1.78	2.73%	0.75
May 2020	1193	298.25	1.71	18	4.50	0.95	1.51%	0.55
June 2020	2365	473.00	1.59	82	16.40	3.64	3.47%	2.30
July 2020	3972	993.00	2.10	153	38.25	2.33	3.85%	1.11
August 2020	2807	561.40	0.57	164	32.80	0.86	5.84%	1.52
September 2020	2110	527.50	0.94	135	33.75	1.03	6.40%	1.10
October 2020	2818	704.50	1.34	209	52.25	1.55	7.42%	1.16
November 2020	6340	1268.00	1.80	856	171.20	3.27	13.50%	1.82
December 2020	4988	1247.00	0.98	808	202.00	1.18	16.20%	1.20
January 2021	4202	1050.50	0.84	655	163.75	0.81	15.59%	0.96
February 2021	1583	395.75	0.38	233	58.25	0.36	14.72%	0.94
March 2021	1627	325.40	0.82	170	34.00	0.58	10.45%	0.71
April 2021	1349	337.25	1.04	107	26.75	0.79	7.93%	0.76
May 2021	1054	210.80	0.63	69	13.80	0.52	6.55%	0.83
June 2021	427	106.75	0.51	13	3.25	0.24	3.04%	0.47
July 2021	688	172.00	1.61	83	20.75	6.38	12.06%	3.96
August 2021	6438	1287.60	7.49	920	184.00	8.87	14.29%	1.18
Totals	44877	582.82		4702	61.06		10.48%	

TABLE 2. Monthly Testing Numbers of the Regional Testing Center
Note: 18 month analysis of the average weekly fold increases from the previous month for rates of testing, positive results, and percent positive rate (PPR) for COVID-19. Shaded months represent months with spikes in testing. April 2020 was not counted as a peak as it was a result of the slow start up of March 2020 which only contained half of a month of data collection.

Fold Increase	Month Before *"Initial"* Peak (n = 4)		Chi Square	P Value*	Month Before *"Any"* Peak (n =6)		Chi Square	P Value*
Testing	Yes	No			Yes	No		
Less than 1.05	0 (0.0%)	9 (100.0%)			1 (11.1%)	8 (88.9%)		
1.05 or more	4 (50.0%)	4 (50.0%)		0.029	5 (62.5%)	3 (37.5%)	4.898	0.027
Positives	Yes	No			Yes	No		
Less than 1.05	0 (0.0%)	9 (100.00%			0 (0.0%)	9 (100.0%)		
1.05 or more	4 (50.0%)	4 (50.00%)		0.029	6 (75.0%)	2 (25.0%)		0.002
PPR	Yes	No			Yes	No		
Less than 1.15	1 (10.0%)	9 (90.0%)			1 (10.0%)	9 (90.0%)		
1.15 or more	3 (43.9%)	4 (57.1%)	2.471	0.116	5 (71.4%)	2 (28.6%)	7.481	0.006

TABLE 3. Analysis of the Prediction Trends in Testing, Positive Results, and Positive Percent Rate

Note: Analysis of the chance that fold increases of +1.05 in testing and +1.05+ in positives for months prior to both 'Initial' and 'Any' peaks in testing are predictive. Fold increases of 1.15+ in PPR is only predictive for 'Any' peak. An 'Initial' peak is defined as the first month of a testing surge. When the surge in testing lasts longer than a month, each month qualifies as 'Any' peak.
PPR = Positive Percent Rate
* Chi square or Fischer exact test.

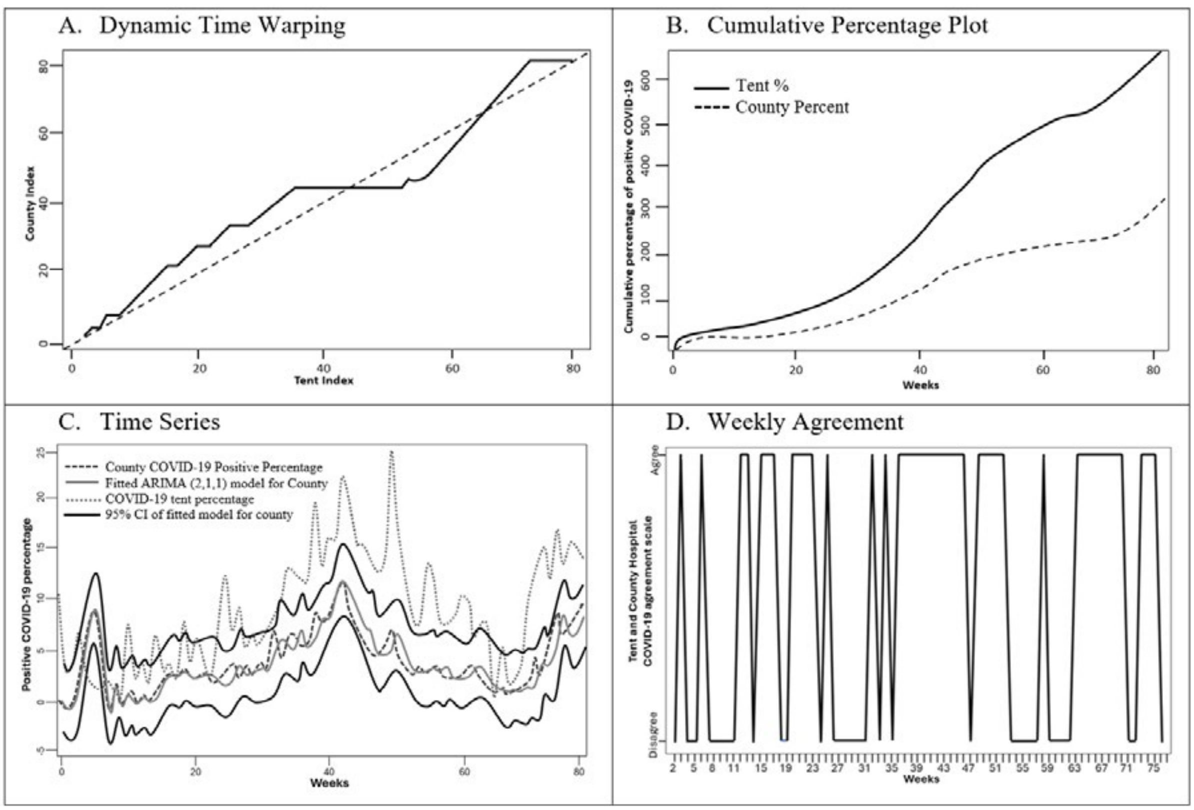

FIGURE 2: Comparative Analysis of Local and Regional Testing Center Percent Positive Rates
Note. Figures denote differences in testing center (tent) vs. (Cabell) county: A) Dynamic time warping indicates sequence alignment between county and testing center data with higher PPRs seen for the testing center during the Alpha variant. B) Cumulative percentage plot demonstrates the difference in magnitude of county% vs testing center%. C) Time series compares the weekly positive percentage rate of county vs testing center data with 95% confidence intervals [best fit county data is Autoregressive Integrated Moving Average (ARIMA)(2,1,1) with minimum AIC 313.34]. D) Weekly agreement pattern displays agreement or disagreement of change is positive percent rate of county vs testing center from the previous week.

DISCUSSION

The COVID-19 pandemic represents the largest medical crisis in recent memory. It left local, state, and national health services scrambling to provide the testing services necessary to identify and manage surges. Many health care systems utilized offsite testing, even drive-through arrangements, to manage resources and minimize the spread of infection to other patients and staff. Previous literature on this subject has analyzed this model; however, they were smaller operations[19,20] in countries with less medical infrastructure,[21] co-targeted testing of other pathogens,[22] or were offsite extensions of a hospital's emergency services.[20,22] Our experience of the continuous evolution of a process over time concurs that initial set-up, or mid-stream changes, were found to be the most problematic times.[23] Thankfully, a vast majority of patients felt they received similar care to services provided at indoor offices, and that this arrangement was convenient in previous literature.[24] The literature assessing forecasting of testing patterns is minimal. The vast majority of current research uses complex forecasting software, such as Univariate time series,[25] Bayesian time series,[26] ARIMA, Seasonal Autoregressive Integrated Moving Average (SARIMA), Prophet, [27,28] and Susceptible Exposed Infectious Recover (SEIR)29 to predict surges in cases with varying success levels. While positive COVID-19 cases are closely related to testing patterns, other non-infectious indications sometimes drive testing. As testing creates a demand for resources, there is value in predicting testing surges independent of positive cases.

Pattern analysis between RTC testing and both RTC and local positive rates longitudinally display similarities (Figure 1). Four peaks occurred across the 18 months studied, 2 of which correlated with known spikes in COVID-19 activity. Alpha variant weekly testing rose in late October 2020, peaked initially in November, and lasted through mid-February. The mid-July 2021 peak, caused by the arrival of the Delta variant, continued until data collection was halted. In each instance, the magnitude of fold increases in positives (3.27 and 8.87) outpaced testing (1.80 and 7.49) (Table 3). The other 2 weekly testing spikes correlate with external forces, tangential to the infection rather than from the infection itself. The April-May spike in testing (1.71-fold) occurred without an increase in positives (0.95-fold). It correlated with the resumption of the hospitals' elective surgeries, the closing of the second testing site, and the Governor's reopening plan. The June-July 2020 testing spike is larger and is associated with a comparable fold increase in positives (2.10 vs 2.33). This increase in testing was driven by local people returning from vacation, whose employers required negative screens to resume working. Unlike the April-May spike, increases in positive rates accompanied this testing increase as infection rates outside of the state were higher at the time.

Personnel and supply availability for periods of high weekly testing require a prediction method to make decisions and marshal resources. When data is analyzed for the weekly average in monthly intervals (Table 3), significant trends appear the month before initial peaks in testing. Fold-increases of 1.05+ in weekly testing (p=0.0294) and weekly positives (p=0.0294) are seen in the month directly preceding all 4 peaks. Weekly PPR of 1.15+ failed to predict an initial testing spike (p=0.1160). If we consider that peaks also occurred in December and January during the Alpha variant, then all 3 metrics are significant for the 6 preceding months: testing (1.05+: p=0.0269), positives (1.05+: p=0.0023), and PPR (1.15+: p=0.0063). PPR has been held as a standard measure for prediction,30 but our results demonstrate some limitations. While it can identify a month before a peak, it is less reliable in predicting the initial peak. The latter is more essential, as it necessitates a change in resource allocation instead of just maintaining existing resources. While longitudinal RTC cohort versus county cohort PPR disagreement occurs 44.16% of the time, the agreement does include a prolonged period during the Alpha variant's high community burden. Overall and longitudinal magnitude differences show that RTC serviced many outside the county.

The primary limitation of this study was data completeness, which was impacted by both the patient financial testing burden, which was partially ameliorated by third-party funding, and the availability of RTC testing times, which was limited to business hours. Also, smaller testing centers did siphon testing opportunities. Future research should analyze results in institutions of varying sizes and governance. Furthermore, future pandemics with differing infectivity patterns should be prospectively compared to results seen with SARS-CoV-2.

CONCLUSION

At times, testing is independent of positive cases. Predicting testing surges is valuable for resource management. Weekly testing and positive rate threshold increases predicted both "initial" and "any" peaks in testing, either due to COVID-19 variants or external pressures, 1 month in advance. Weekly PPR threshold measurements were not as reliable for initial spikes in testing. Similarity in PPR between testing center and county were seen beginning with the Alpha variant and ending at its vaccination-accelerated nadir. Understanding these factors allows for appropriate resource allocation for the remainder of this and future pandemics.

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