

Understanding Drivers of Coronavirus Disease 2019 (COVID-19) Racial Disparities: A Population-Level Analysis of COVID-19 Testing Among Black and White Populations

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Background. Disparities in coronavirus disease 2019 (COVID-19) testing—the pandemic’s most critical but limited resource—may be an important but modifiable driver of COVID-19 inequities.

Methods. We analyzed data from the Missouri State Department of Health and Senior Services on all COVID-19 tests conducted in the St Louis and Kansas City regions. We adapted a well-established tool for measuring inequity—the Lorenz curve—to compare COVID-19 testing rates per diagnosed case among Black and White populations.

Results. Between 14/3/2020 and 15/9/2020, 606 725 and 328 204 COVID-19 tests were conducted in the St Louis and Kansas City regions, respectively. Over time, Black individuals consistently had approximately half the rate of testing per case than White individuals. In the early period (14/3/2020 to 15/6/2020), zip codes in the lowest quartile of testing rates accounted for only 12.1% and 8.8% of all tests in the St Louis and Kansas City regions, respectively, even though they accounted for 25% of all cases in each region. These zip codes had higher proportions of residents who were Black, without insurance, and with lower median incomes. These disparities were reduced but still persisted during later phases of the pandemic (16/6/2020 to 15/9/2020). Last, even within the same zip code, Black residents had lower rates of tests per case than White residents.

Conclusions. Black populations had consistently lower COVID-19 testing rates per diagnosed case than White populations in 2 Missouri regions. Public health strategies should proactively focus on addressing equity gaps in COVID-19 testing to improve equity of the overall response.

Keywords. COVID-19 testing; racial disparities; Lorenz curve; inequity; structural racism.

The impact of the coronavirus disease 2019 (COVID-19) pandemic has mirrored existing racial health disparities in the United States [1–4] and, even if not entirely unsurprising, demands additional explanation and urgent remedy. Over the last 6 months, epidemiologic studies have repeatedly shown greater burden of COVID-19 cases, hospitalizations, and mortality in minority communities [2–8]. This disparate impact likely results, in part, from social and economic inequities deeply embedded in American society. For example, overrepresentation of minorities in lower-wage service and essential occupations means greater exposure risks and less access to protective

measures (eg, no guaranteed sick leave) for many Black individuals. However, better understanding of the contribution of health systems behavior to COVID-19 disparities [4–10] can reveal immediately modifiable mechanisms and redirect ongoing public health efforts.

COVID-19 testing, in particular, is one of the most essential components of an effective COVID-19 public health response and represents an important potential mechanism for disparities [1, 2]. Adequate testing is essential for epidemic control as it facilitates early case detection, self-isolation, and prevention of onward transmission [11–16]. Furthermore, it enables accurate recognition of disease burden in communities, thereby contributing to appropriate responses from both the public health system and individuals (eg, mask wearing and social distancing) [17]. Although inequitable COVID-19 testing in already marginalized populations can magnify their risk for poor outcomes, few studies have examined the extent of disparities in COVID-19 testing [11–14, 18, 19] relative to the burden of disease.

We seek to deepen our understanding of health disparities in COVID-19 testing by examining testing equities explicitly in relation to disease burden over time and geography in the St

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Louis and Kansas City regions in Missouri. We used, in part, a tool from economics—the Lorenz curve—which is commonly used to visualize and quantify wealth- and income-based inequality in a population [20]. This novel application of an established methodology will enable quantification of the underlying inequities in COVID-19 testing to directly inform health policy solutions [20].

METHODS

Study Setting and Data

We sought to assess disparities in COVID-19 testing across 7 counties in the St Louis region (St Louis City, St Louis County, St Charles, Jefferson, Franklin, Lincoln, and Warren) and 4 counties in the Kansas City region (Jackson, Clay, Cass, and Platte). We used data from the Missouri State Department of Health and Senior Services on severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) polymerase chain reaction (PCR) or antigen tests conducted in Missouri. This is expected to contain near-complete data on all tests performed in the state, as reporting was mandated. This dataset contains test date, test type, test result, performing laboratory, patient age category, race, and zip code. We used data from the 2018 American Community Surveys to obtain sociodemographic and socioeconomic characteristics of individual zip codes.

Analyses

Our analyses are based on the premise that an equitable testing strategy is defined by a relative balance between the number of tests done and the overall disease burden in a community, rather than simply an equal number of tests done per person (ie, equal testing). Decreased testing rates relative to the number of cases identified generally indicates that testing is only occurring among symptomatic patients with a higher probability of disease. In contrast, higher test rates per case indicates testing is sufficiently widespread to be effective at also capturing asymptomatic and mild cases of COVID-19, which are a major driver of the pandemic [11–15, 21]. The World Health Organization (WHO) suggests that adequate testing levels are indicated by at least 10, and ideally 30, tests for every diagnosed case [11–15]. Based on these principles, we sought to assess disparities in COVID-19 testing and disease burden in several ways.

First, we estimated new COVID-19 tests and cases per day and the rate of COVID-19 testing per diagnosed case among Black and White individuals over time.

Second, we generated modified versions of Lorenz curves to assess the relative equity in the distribution of COVID-19 testing and disease burden across zip codes. Lorenz curves—originally developed by economists to graphically represent income equality—have more recently been leveraged as a tool for public health [20, 22, 23]. A Lorenz curve is generated by plotting the cumulative proportion of the total population

against the cumulative proportion of a resource or burden of disease after sorting values in ascending order. If the resource or burden is equitably distributed across the population, the curve will follow a straight line at a 45-degree angle. The curve becomes more convex with increasing inequity. We adapted this method to examine disparities in (1) the number of COVID-19 tests performed relative to the burden of diagnosed COVID-19 cases and (2) the gap between existing and adequate testing levels, which we define as the number of additional negative tests needed to achieve 20 tests per diagnosed case (based on WHO guidance) [14, 24, 25]. We used zip codes as the unit of analysis and generated Lorenz curves for both the early (14 March to 15 June) and later (16 June to 15 September) phases of the pandemic. We also calculated Gini coefficients—a measure of equality/inequality between 0 and 1, with 0 indicating perfect equality and 1 indicating perfect inequality—and Hoover indices—a metric that indicates what percentage of the resource would need to be reallocated in order to achieve an equitable distribution [26]. Last, we grouped zip codes into quartiles based on their position on Lorenz curves and assessed differences in zip code-level sociodemographic and socioeconomic characteristics using Kruskal-Wallis tests.

Third, we generated bubble plots to compare rates of COVID-19 testing for Black versus White residents living in the same zip code. For this analysis, we only considered zip codes whose populations were at least 1% Black and 1% White to avoid identifying extreme outliers from small denominators.

Last, we performed univariate and multivariable mixed-effects Poisson regression to identify individual-level (eg, race, age) and zip code-level (eg, racial makeup, health insurance coverage) factors independently associated with having a positive COVID-19 test. Zip code was included as random effect. We also assessed for an interaction between race and age, stratifying by time period. The effect of race and racism on health outcomes is mediated by (as opposed to confounded by) ecological structural factors such as socioeconomic status; thus, unadjusted analyses assess the overall association with race and racism while adjusted analyses can be thought to assess the contribution of systemic racism that still remains even when adjusting away the mediating effects of the measured ecological factors [1, 2, 27].

To account for missingness in race, patient zip code, and age variables, we performed multiple imputation using multivariate normal imputation methods ($n = 50$ imputations) and adaptive rounding of categorical variables [28–30]. Missingness was highly dependent on the test date, test result, and performing laboratory, and thus the missing-at-random assumption (ie, that missingness was random conditional on all the variables included in the imputation model [test date, test result, performing laboratory, race, zip code, age, and mortality]) required for unbiased imputation was very plausible in our setting [28–30].

Table 1. Characteristics of COVID-19 Testing

	Overall	St Louis	Kansas City	Black	White	14 March–15 June	16 June–15 September
Number of tests	934 929	606 725	328 204	89 695	273 058	210 056	724 873
Age category, ^a n (%)							
0–17 years	58 750 (6.3)	41 429 (6.8)	17 321 (5.3)	6524 (7.3)	19 251 (7.1)	8844 (4.2)	49 906 (6.9)
18–24 years	99 439 (10.7)	63 844 (10.6)	35 595 (10.9)	8224 (9.2)	25 081 (9.2)	13 805 (6.6)	85 634 (11.8)
25–49 years	354 350 (38.0)	218 687 (36.1)	135 663 (41.5)	34 339 (38.4)	85 619 (31.5)	74 230 (35.5)	280 120 (38.8)
50–64 years	209 438 (22.5)	136 616 (22.6)	72 822 (22.3)	23 137 (25.9)	63 503 (23.3)	53 486 (25.6)	155 952 (21.6)
65–74 years	101 007 (10.8)	66 483 (11.0)	34 524 (10.6)	10 316 (11.5)	38 533 (14.2)	29 167 (13.9)	71 840 (9.9)
75–84 years	59 529 (6.4)	40 972 (6.8)	18 557 (5.7)	4600 (5.1)	24 388 (9.0)	17 180 (8.2)	42 349 (5.9)
≥85 years	49 557 (5.3)	37 042 (6.1)	12 515 (3.8)	2364 (2.6)	15 773 (5.8)	12 582 (6.0)	36 975 (5.1)
Race, ^a n (%)							
Black	89 695 (23.1)	59 977 (24.5)	29 718 (20.6)	...	...	24 412 (27.8)	65 283 (21.7)
White	273 058 (70.2)	174 520 (71.4)	98 538 (68.2)	...	...	57 954 (65.9)	215 104 (71.4)
Other	26 360 (6.8)	10 028 (4.1)	16 332 (11.3)	...	...	5584 (6.3)	20 776 (6.9)
Median (IQR) days from testing to results ^a	2 (2, 5) (n = 929 193)	3 (2, 5) (n = 603 077)	2 (1, 4) (n = 326 116)	2 (1, 3) (n = 89 461)	2 (1, 3) (n = 272 240)	3 (2, 7) (n = 20 7557)	2 (2, 4) (n = 721 636)
Long-term-care facility, n (%)	94 068 (10.1)	60 513 (10.0)	33 555 (10.2)	4120 (4.6)	12 043 (4.4)	21 435 (10.2)	72 633 (10.0)
Test associated with known outbreak, n (%)	4826 (0.5)	1815 (0.3)	3011 (0.9)	1196 (1.3)	2820 (1.0)	2429 (1.2)	2397 (0.3)
Positive cases, n (%)	73 562 (7.9)	47 896 (7.9)	25 666 (7.8)	15 916 (17.7)	29 841 (10.9)	15 671 (7.5)	57 891 (8.0)
Died, n (%)	2040 (0.2)	1598 (0.3)	442 (0.1)	696 (0.8)	1168 (0.4)	1291 (0.6)	749 (0.1)
County, ^a n (%)							
St Louis region							
St Louis	26 1075 (31.5)	261 075 (50.1)	...	35 533 (40.8)	76 790 (29.1)	56 091 (30.6)	204 984 (31.7)
St Louis City	83 879 (10.1)	83 879 (16.1)	...	18 873 (21.7)	16 085 (6.1)	20 458 (11.2)	63 421 (9.8)
St Charles	86 440 (10.4)	86 440 (16.6)	...	2461 (2.8)	32 665 (12.4)	18 972 (10.4)	67 468 (10.5)
Jefferson	48 629 (5.9)	48 629 (9.3)	...	283 (0.3)	22 144 (8.4)	9908 (5.4)	38 721 (6.0)
Franklin	23 837 (2.9)	23 837 (4.6)	...	114 (0.1)	11 419 (4.3)	4997 (2.7)	18 840 (2.9)
Lincoln	10 913 (1.3)	10 913 (2.1)	...	157 (0.2)	4961 (1.9)	2131 (1.2)	8782 (1.4)
Warren	6440 (0.8)	6440 (1.2)	...	79 (0.1)	2719 (1.0)	1150 (0.6)	5290 (0.8)
Kansas City region							
Jackson	219 364 (26.5)	...	219 364 (71.3)	26 298 (30.2)	64 523 (24.5)	45 502 (24.8)	173 862 (26.9)
Clay	46 149 (5.6)	...	46 149 (15.0)	1915 (2.2)	17 258 (6.5)	13 504 (7.4)	32 645 (5.1)
Cass	21 773 (2.6)	...	21 773 (7.1)	511 (0.6)	7674 (2.9)	4699 (2.6)	17 074 (2.6)
Platte	20 405 (2.5)	...	20 405 (6.6)	770 (0.9)	7595 (2.9)	5868 (3.2)	14 537 (2.3)
Time period, n (%)							
14 March–15 June	210 056 (22.5)	132 558 (21.8)	77 498 (23.6)	24 412 (27.2)	57 954 (21.2)	...	...
16 June–15 September	724 873 (77.5)	474 167 (78.2)	250 706 (76.4)	65 283 (72.8)	215 104 (78.8)	...	...

Abbreviations: COVID-19, coronavirus disease 2019; IQR, interquartile range.

^aOverall missing values: Age category, 2859; Race, 545 816; Median days from testing to results, 5736; County, 106 025.

All analyses were conducted using Stata MP 16.1 (StataCorp) and R 3.2.4 (R Foundation for Statistical Computing). *P* values less than or equal to .05 were considered statistically significant.

RESULTS

Between 14 March 2020 and 15 September 2020, 606 725 total COVID-19 tests were conducted across 7 counties in the St Louis region (total population, 2 135 730: 19.2% Black, 74.6% White) and 328 204 were conducted across 4 counties in the Kansas City region (total population, 1 292 263: 15.1% Black, 76.5% White) (Table 1, Supplementary Tables 1 and 2).

COVID-19 Testing Disparities Over Time

In both regions, the number of COVID-19 tests per diagnosed case steadily increased until mid-June but began to decline after a new surge in cases beginning in mid-July (Figure 1). The rate of tests per case in the Black population consistently remained about half that of the White population until August. Even though the overall number of tests expanded steadily over time,

it increased more rapidly among the White population as opposed to the Black population (Figure 1).

COVID-19 Testing Disparities Across Zip Codes Using Lorenz Curves

Modified Lorenz curves depict the distribution of COVID-19 testing with respect to the number of diagnosed cases across zip codes (Figure 2, Table 2). Between 14 March and 15 June, zip codes in the quartile with the lowest rates of tests per case accounted for only 12.1% and 8.8% of all tests in the St Louis and Kansas City regions, respectively, but accounted for 25% of all cases in each region. These zip codes had higher proportions of Black residents, lower median incomes, higher rates of poverty, lower rates of health insurance coverage, a higher proportion of residents employed in the service sector, and a higher proportion of public transport users (Figure 2, Supplementary Tables 3 and 4). In contrast, zip codes with the highest rates of testing per case accounted for 45.3% and 45.2% of all tests, respectively, to diagnose a similar number of cases (ie, 25% of cases in the region). These zip codes tended to have a lower percentage of Black residents and be more socioeconomically

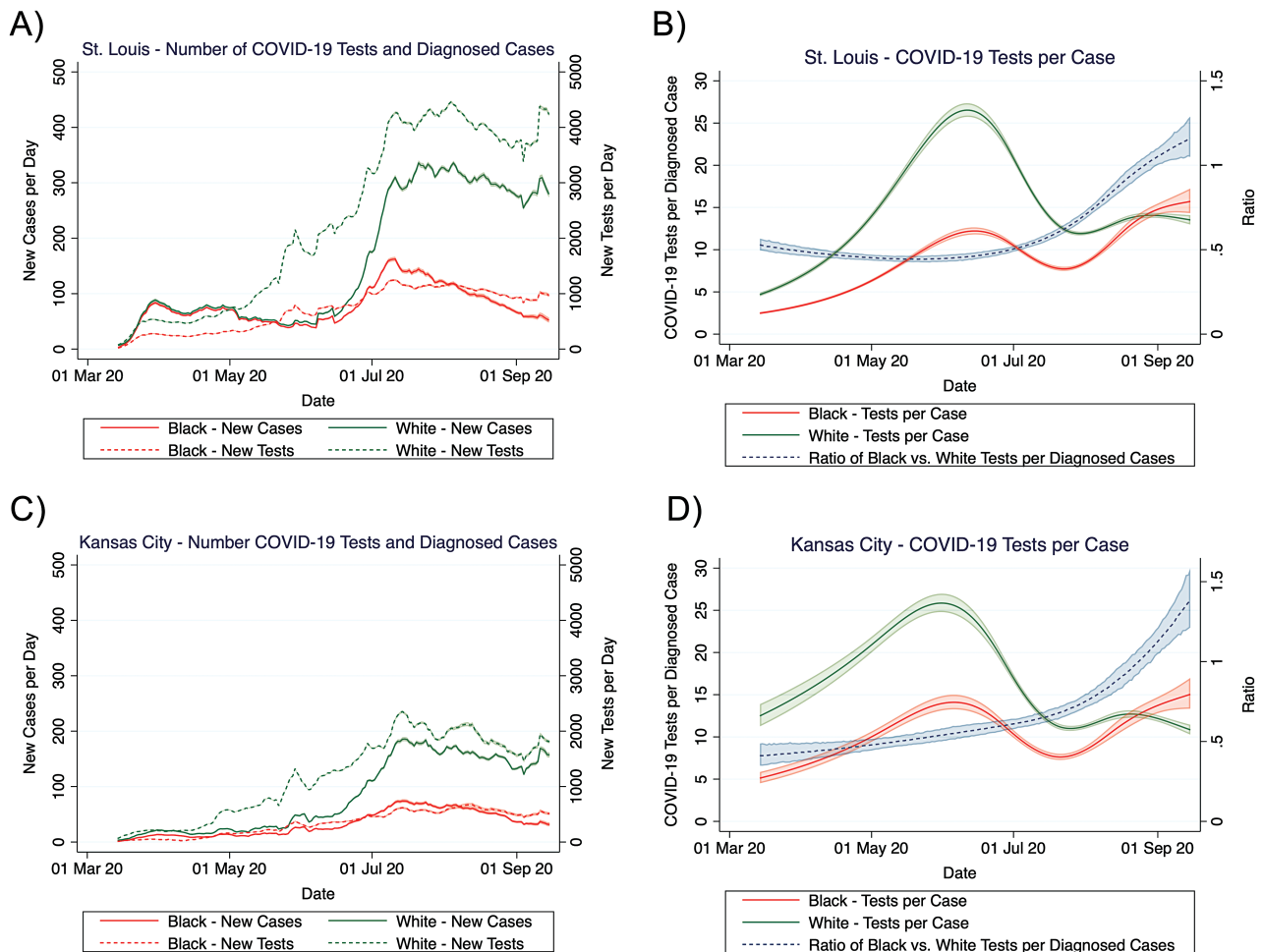


Figure 1. A–D, Number of COVID-19 tests, diagnosed cases, and tests per diagnosed case ratio among Black and White individuals over time. Estimates represent 7-day moving averages derived from multiply imputed datasets. Abbreviation: COVID-19, coronavirus disease 2019.

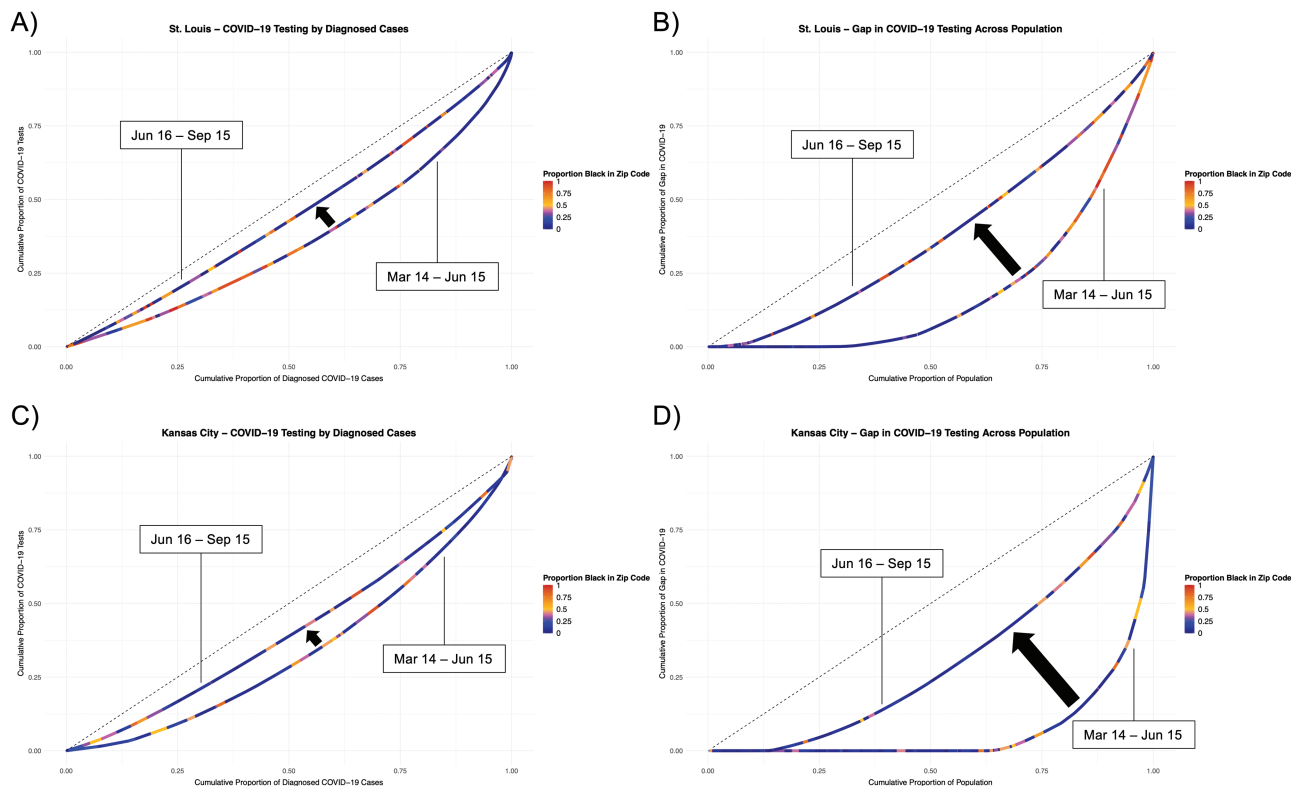


Figure 2. Lorenz curves of disparities in COVID-19 testing. This figure depicts modified Lorenz curves examining disparities in COVID-19 testing. The units of analysis are zip codes and they are color-coded by their overall racial makeup. Separate curves were generated for the periods between 14 March to 15 June and 16 June to 15 September. The dashed line represents equitable distribution where 50% of testing would be conducted in zip codes accounting for 50% of hospitalizations. Panels A and C depict Lorenz curves for the St Louis and Kansas City regions, respectively, measuring disparities in the distribution of COVID-19 tests relative to the diagnosed cases in a zip code. Panels B and D depict Lorenz curves for St Louis and Kansas City, respectively, examining the current gap in COVID-19 tests (ie, the number of additional negative tests needed to achieve 30 tests per diagnosed case) relative to the total population in a zip code. Abbreviation: COVID-19, coronavirus disease 2019.

advantaged (Figure 2, Supplementary Tables 3 and 4). Disparity patterns were similar although more extreme when considering the gap in testing to reach adequate levels across zip codes (ie, how many additional tests would be needed to achieve 20 tests per case) (Figure 2, Supplementary Tables 5 and 6).

In contrast to the earlier period, disparities in testing relative to cases were less apparent between 16 June and 15 September (Figure 2, Supplementary Tables 3–6). When tracking Gini coefficients over time, levels of testing disparities began to decline in mid-June, corresponding to a more rapid increase

in cases in the White as compared with the Black population (Figure 3).

COVID-19 Testing Disparities Within Zip Codes

Black individuals also had consistently lower rates of COVID-19 testing per case compared with White individuals residing in the same zip codes (Figure 4). This pattern was largely irrespective of the overall racial makeup of a zip code (ie, whether the zip codes were predominantly White or Black). Only 13 of 173 zip codes had a testing rate of greater than 20 tests per case

Table 2. Gini Coefficients and Hoover Indices by Region and Time Period

	Gini Coefficient		Hoover Index	
	14 March–15 June	16 June–15 September	14 March–15 June	16 June–15 September
St Louis				
Tests per case	0.281	0.110	0.203	0.076
Testing gap over population	0.619	0.243	0.471	0.165
Kansas City				
Tests per case	0.316	0.176	0.222	0.120
Testing gap over population	0.861	0.396	0.699	0.266

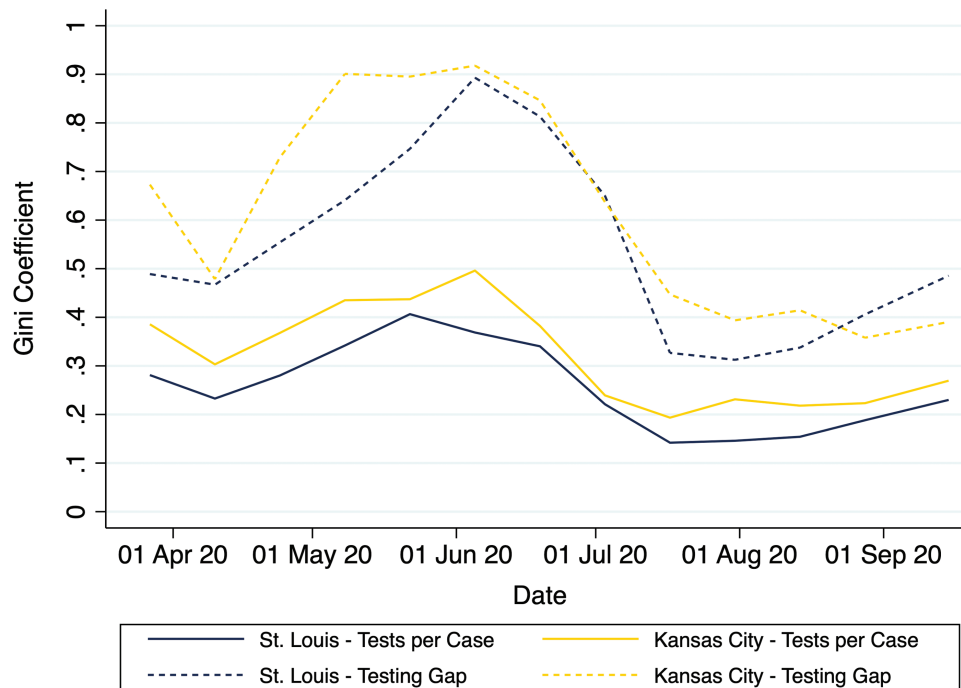


Figure 3. Temporal trends in COVID-19 testing disparities. This figure depicts trends in the Gini coefficients for 2 metrics over time in the St Louis and Kansas City regions: (1) COVID testing relative to diagnosed cases (solid line) and (2) gap in COVID-19 testing (ie, the number of additional negative tests needed to achieve 30 tests per diagnosed case) (dashed line). Gini coefficients were calculated on a biweekly basis from Lorenz curves generated for that time interval. Abbreviation: COVID-19, coronavirus disease 2019.

among Black residents, but 30 zip codes had this rate among its White residents.

Factors Associated With a Having Positive COVID-19 Test

In multivariable mixed-effects Poisson regression, Black race was one of the strongest factors associated with testing positive for COVID-19 (adjusted risk ratio [aRR], 1.60; 95% confidence interval [CI], 1.52–1.69) (Table 3). Additional risk factors included being 18 to 24 years old (aRR, 1.37; 95% CI, 1.31–1.44) as compared to age 24–49 and residing in a zip code with lower levels of insurance coverage (aRR, 1.15 per 10% increase in the uninsured; 95% CI, 1.04–1.26). In assessing interactions between race and age across time periods, Black race was consistently associated with lower rates of testing per case across age strata and time periods but these were lowest for older Black individuals in the earlier phases of the pandemic ($P < .001$ for interaction for both periods) (Figure 5).

DISCUSSION

Our analyses revealed consistent disparities in the rates of COVID-19 testing relative to COVID-19 disease burden between Black and White communities over time, across both the St Louis and Kansas City regions of Missouri, across zip codes within these regions, and even within zip codes. Overall, these results highlight the systemic inequities in one of the most

critical but limited resources for controlling the COVID-19 pandemic but one that is immediately actionable: COVID-19 testing.

A key premise of our analysis is that an equitable testing strategy is essential for a successful COVID-19 response and requires that testing be scaled up in proportion to the disease burden in an area, which is also in line with current WHO guidance [14, 24, 25]. Increases in the overall disease burden also affect this metric, but public health programs failing to adapt testing to meet this threshold will still run the risk of identifying only the most severe and symptomatic cases in a community while systematically missing more mild and asymptomatic cases. This ultimately has immense implications for disease control as transmission from asymptomatic individuals is a major driver of the pandemic [11–15, 21]. We find that, although the burden of COVID-19 disease has disproportionately affected Black communities more, rates of COVID-19 testing have also not been correspondingly scaled up relative to this increased disease burden. This finding remained consistent over time, across regions, and even within geographical areas.

First, despite overall expansion of testing, rates of COVID-19 tests per case among Black individuals consistently remained half that of White individuals for most of the pandemic, a finding that has also been demonstrated in other regions of the country [13, 18, 19]. Moreover, overall testing numbers actually increased more rapidly among White compared with Black individuals,

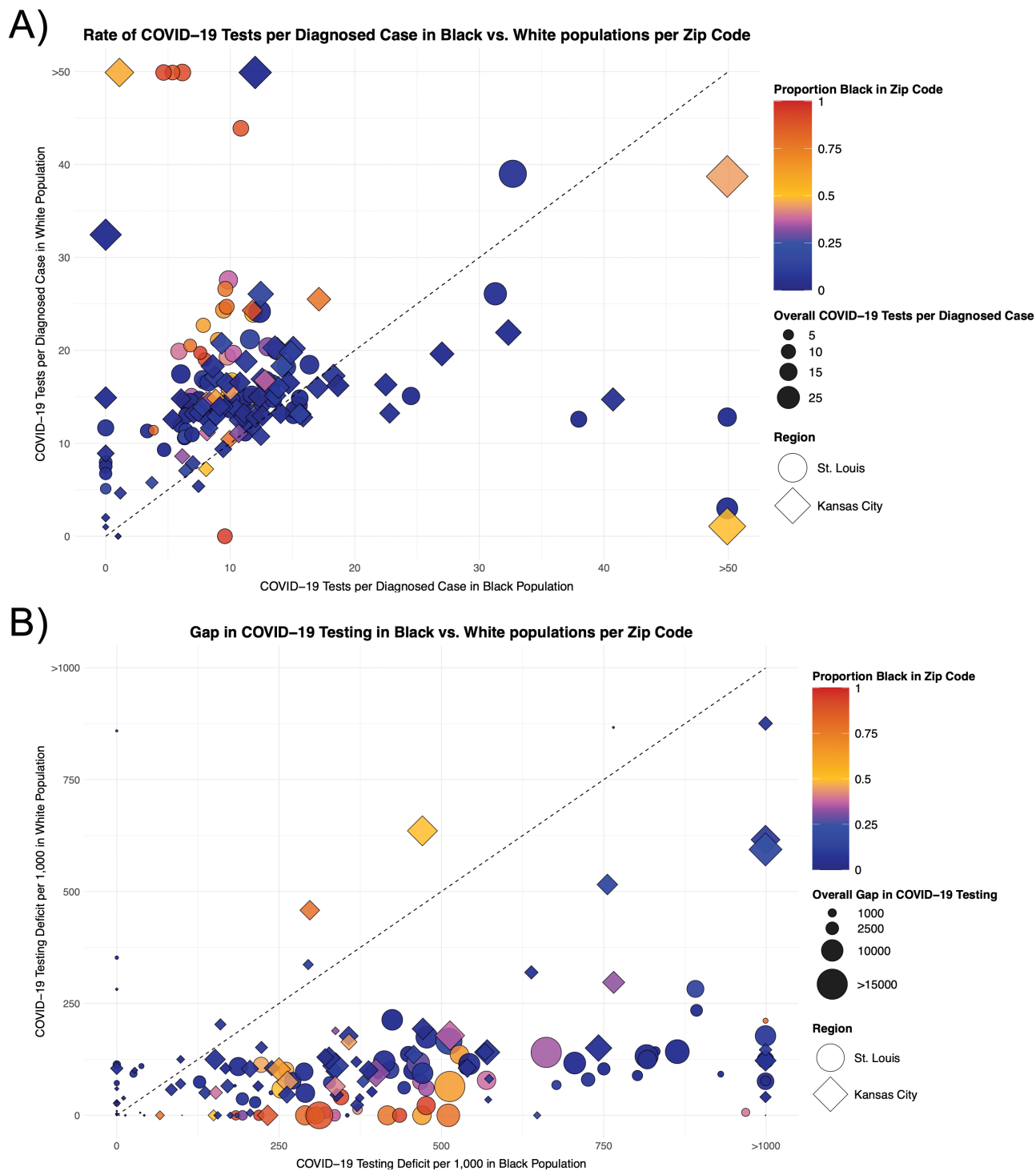


Figure 4. Disparities in COVID-19 testing among Black and White residents of the same zip code. This figure depicts testing rates per diagnosed case (A) and the gap in negative COVID-19 tests to reach 20 tests per case (B) in Black versus White residents of the same zip code. Each marker represents a single zip code in either the St Louis (bubble) or Kansas City (diamond) region. Markers are color-coded by the racial makeup of the zip code and sized by the absolute value of metric of interest (ie, rate of COVID-19 tests per case in panel A and the overall number of negative COVID-19 tests needed in panel B). The dashed line represents equitable testing distribution between Black and White residents. Zip codes falling above the dashed line in panel A or below it in panel B indicate that they decreased testing in Black as opposed to White residents (and vice versa). Abbreviation: COVID-19, coronavirus disease 2019.

with testing in Black populations always being far from the target necessary for optimizing infection control. Although disparities were reduced in later phases of the pandemic, this was

driven more by increased case counts among the White population rather than any increased testing in the Black population. Second, using modified Lorenz curves, the majority of zip codes

Table 3. Mixed-Effects Poisson Model of Individual- and Zip Code–Level Factors Associated With Having a Positive COVID-19 Test

	Unadjusted Risk Ratio (95% CI)	<i>P</i>	Adjusted Risk Ratio (95% CI)	<i>P</i>
Race				
Black	1.55 (1.52–1.58)	<.001	1.60 (1.52–1.69)	<.001
White	1 (ref)		1 (ref)	
Other	1.38 (1.33–1.42)		1.36 (1.29–1.43)	
Age category				
<18 years	1.03 (1.00–1.06)	<.001	.99 (.94–1.03)	<.001
18–24 years	1.35 (1.32–1.37)		1.37 (1.31–1.44)	
25–49 years	1 (ref)		1 (ref)	
50–64 years	.88 (.86–.89)		.87 (.84–.89)	
65–74 years	.73 (.71–.75)		.74 (.70–.78)	
75–84 years	.82 (.80–.85)		.87 (.81–.94)	
≥85 years	.85 (.82–.88)		.97 (.87–1.08)	
Long-term-care resident	.78 (.75–.80)	<.001	.79 (.66–.94)	.009
Zip code–level characteristics				
Percent Black, per 10% increase	1.00 (1.00–1.00)	.176	.98 (.96–1.00)	.023
Total population, per 10 000 increase	1.02 (1.01–1.02)	<.001	1.03 (1.01–1.05)	.006
Average household size, per 1 person increase	1.00 (1.00–1.00)	.03	1.00 (1.00–1.00)	.774
Median income, per \$10 000 increase	1.00 (1.00–1.00)	.013	1.00 (1.00–1.00)	.465
Percent below poverty line, per 10% increase	1.00 (1.00–1.00)	.03	... ^a	... ^a
Percent without health insurance, per 10% increase	1.22 (1.20–1.23)	<.001	1.15 (1.04–1.26)	.006
Percent in healthcare industry, per 10% increase	1.00 (1.00–1.00)	.086	1.00 (1.00–1.00)	.765
Percent in service industry, per 10% increase	1.00 (1.00–1.00)	.176	... ^a	... ^a
Region				
St Louis	1 (ref)	<.001	1 (ref)	.003
Kansas City	.91 (.89–.92)		.89 (.82–.96)	
Time period				
14 March–15 June	1 (ref)	<.001	1 (ref)	.297
16 June–15 September	1.05 (1.03–1.07)		1.06 (.95–1.17)	

Abbreviations: CI, confidence interval; COVID-19, coronavirus disease 2019; ref, reference value.

^aExcluded from multivariable model due to collinearity.

with a higher proportion of Black residents and lower health insurance coverage also had the lowest rates of testing per case and higher gaps between existing and adequate levels of testing as opposed to the zip codes with higher rates of testing, which were overwhelmingly White. Third, Black residents were more likely to have lower rates of tests per case even compared with White residents within the same zip code and this was irrespective of the overall racial makeup of that zip code level. Last, even in models adjusting for differences in individual-level characteristics and mediation of ecologic zip code–level characteristics, being Black was associated with a higher risk of testing positive for COVID-19 and thus having lower rates of tests per case. The lowest testing rates occurred in the most at-risk group: older Black individuals in the early pandemic phases when there was less knowledge about transmission prevention, limited access to testing, and no evidence-based treatments. Thus, our analyses demonstrate a pattern of COVID-19 testing disparities that, although changing, was pervasive regardless of time or geography and reflects aspects of both structurally and individually mediated racism [1]. Ultimately, these disparities may also be an important driver of the disparities in actual disease burden, a point of national concern.

The underlying etiologies for these consistent disparities in COVID-19 testing are likely severalfold, but, ultimately, are all manifestations of structural racism in our healthcare system and current society [1–4]. It is thus to be expected that these existing structural disparities in healthcare have permeated into the COVID-19 response as well [11, 12] and have only been exacerbated through mechanisms such as access to testing sites or funding allocation during the pandemic [31–35]. For example, North St Louis, a predominantly Black community that was one of the hardest hit in Missouri, did not have a single testing site several weeks into the pandemic [35]. It is also important to acknowledge that years of experience with structural racism in a historically discriminatory healthcare system has also garnered a significant yet appropriate level of mistrust of the healthcare system, which may lead those in Black communities to have a higher threshold for seeking out testing [4]. These potential drivers of testing disparities are layered onto the inequities that have led to an increased burden of disease in Black communities, which includes higher proportions of essential workers, less paid sick leave, lower ability to work from home, and living in more crowded settings and multigenerational households [4–6, 10].

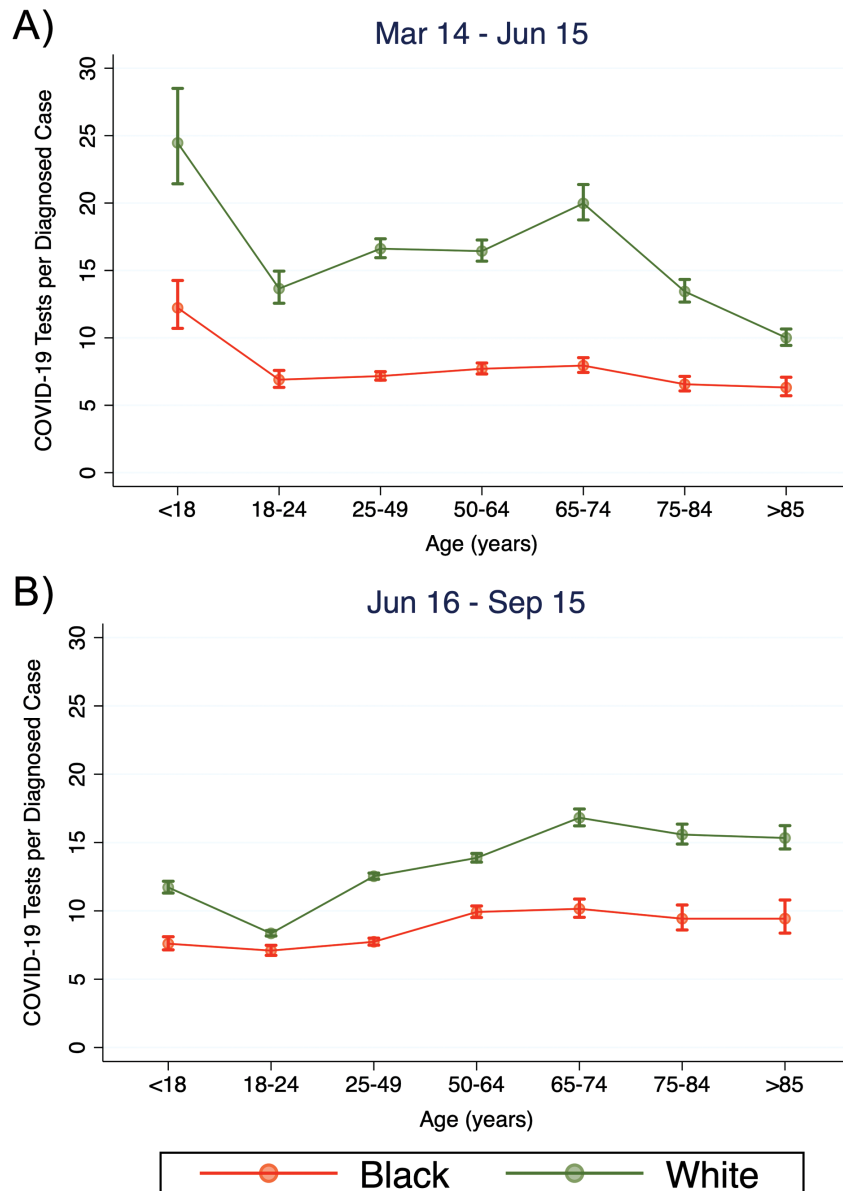


Figure 5. A, B, Adjusted age-stratified estimates of COVID-19 tests per diagnosed case. This figure represents age-stratified estimates of COVID-19 testing per case in models adjusted for differences in zip code-level characteristics. Estimates based on mixed-effects Poisson regression stratified by time period assessing an interaction between race and age and adjusted for long-term-care residency status, zip code-level characteristics, and region. For both periods, the *P* value for the interaction between race and age strata was <.001. Abbreviation: COVID-19, coronavirus disease 2019.

Addressing inequities in testing is an immediately actionable target in the short term but will likely require implementing proactive public health responses that move beyond the existing healthcare infrastructure to increase testing access. Our analyses show that, to date, there has been limited evidence of any adaptive or targeted strategies to increase testing in areas with a higher burden of disease. Going forward, however, it is essential for public health officials to consider more deliberate and targeted strategies. Targeted community-based testing campaigns in venues such as community centers and high-density residential spaces such as public housing, places of worship, or

transportation hubs could improve access to testing, particularly in communities that have suffered neglect by existing public health infrastructures to date [11, 12]. Saliva-based COVID-19 tests, which can easily be administered on a large scale, can make community-based testing campaigns significantly more feasible [36, 37]. Community-based approaches will also be essential for ensuring equitable access to COVID-19 vaccines once they are available. In designing these efforts, it is essential that public health officials actively engage the individual communities themselves in developing plans that take into account the layered levels of trauma that exist in these communities [3, 4]. Focusing

on implementing more equitable testing strategies should be an immediate priority but, ultimately, it must also be anchored by a long-term commitment to actively dismantle the underlying structural racism that gives rise to such health disparities.

This analysis also strongly compels routine monitoring using formal metrics to quantitatively track the equity of their distribution to inform adaptive testing strategies. Such metrics have been lacking but are a powerful tool because they can be used to identify and prioritize communities in most need, track improvements or worsening over time (particularly in response to interventions), compare different regions, and ultimately, provide a measure of accountability for healthcare systems' commitments to protecting health equity. Modified uses of Lorenz curves provide a straightforward method to do so. For example, tracking Gini coefficients and Hoover indices over time suggests that testing disparities have been easing in both the St Louis and Kansas City regions, but that this has more likely been driven by changes in disease patterns rather than strategic changes to testing efforts. They thus present a novel option for assessing inequities not only in testing but also for disease burden, ability to socially distance, and allocation of COVID-19 vaccines once they become available [4, 38, 39]. Ultimately, they can help develop roadmaps for building a more equitable COVID-19 response by identifying to whom, where, and how particular resources need to be targeted.

There are several limitations to our analysis. First, state reporting of COVID-19 tests was mandatory, but not all variables were reported consistently—race and, to a lesser extent, zip code in particular. Still, as this missingness was highly dependent on the test date, test result, and performing laboratory, multiple imputation would still yield unbiased results even with higher levels of missingness [28–30]. Second, we lacked data on hospitalizations from both regions, which may be a better reflection of regional disease burden since it is less affected by limitations in COVID-19 testing. Still, we did identify significant inequities in testing that we would expect to only be further amplified given that the number of diagnosed cases likely underestimates the true number of infections. Third, we had insufficient data to parse between potential drivers of these disparities, such as physical access, insurance coverage, test-seeking behavior, and differences in symptomatic versus asymptomatic testing. Last, the premise of our analyses is that “equitable” and “adequate” are defined in relation to the burden of disease in an area, but we acknowledge that this metric is also affected by the disease burden. Still, our approach is in line with WHO guidance [14, 24, 25], and we believe that our framing of equitable testing yields essential information for understanding how to optimize testing strategies going forward.

In conclusion, we characterize consistent disparities in COVID-19 testing across time, across regions, across zip codes, and even within zip codes. Our modified use of Lorenz curves provides straightforward methods to quantify and track these

disparities over time. COVID-19 testing is critical to an effective pandemic response, and these testing inequities may be one of the important drivers of the disproportionate impact of COVID-19 on minority communities in the United States. Further efforts should focus on proactive public health strategies to specifically address equity gaps in COVID-19 testing in order to improve the equity of the overall COVID-19 response.

Supplementary Data

Supplementary materials are available at *Clinical Infectious Diseases* online. Consisting of data provided by the authors to benefit the reader, the posted materials are not copyedited and are the sole responsibility of the authors, so questions or comments should be addressed to the corresponding author.

Notes

Disclaimer. The contents do not necessarily reflect the reviews and policies of the State of Missouri, nor does mention of trade names or commercial products constitute endorsement or recommendation for use. The funders had no role in the study design, data collection and analysis, decision to publish, or preparation of the manuscript.

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