


## ORIGINAL RESEARCH

## Neurology

# The relationship between stroke system organization and disparities in access to stroke center care in California

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**Abstract**

**Background:** There are significant racial and ethnic disparities in receipt of reperfusion interventions for acute ischemic stroke. Our objective was to determine whether there are disparities in access to stroke center care by race or ethnicity that help explain differences in reperfusion therapy and to understand whether interhospital patient transfer plays a role in improving access.

**Methods:** Using statewide administrating data including all emergency department and hospital discharges in California from 2010 to 2017, we identified all acute ischemic stroke patients. Primary outcomes of interest included presentation to primary or comprehensive stroke center (PSC or CSC), interhospital transfer, discharge from PSC or CSC, and discharge from CSC alone. We used hierarchical logistic regression modeling to identify the relationship between patient- and hospital-level characteristics and outcomes of interest.

**Results:** Of 336,247 ischemic stroke patients, 55.4% were non-Hispanic White, 19.6% Hispanic, 10.6% non-Hispanic Asian/Pacific Islander, and 10.3% non-Hispanic Black. There was no difference in initial presentation to stroke center hospitals between groups. However, adjusted odds of reperfusion intervention, interhospital transfer and discharge from CSC did vary by race and ethnicity. Adjusted odds of interhospital transfer were lower among Hispanic (odds ratio [OR] 0.94, 95% confidence interval [CI] 0.89 to 0.98) and non-Hispanic Asian/Pacific Islander patients (OR 0.84, 95% CI 0.79 to 0.90) and odds of discharge from a CSC were lower for Hispanic (OR 0.91, 95% CI 0.85 to 0.97) and non-Hispanic Black patients (OR 0.74, 95% CI 0.67 to 0.81).

**Conclusions:** There are racial and ethnic disparities in reperfusion intervention receipt among stroke patients in California. Stroke system of care design, hospital resources, and transfer patterns may contribute to this disparity.

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**KEYWORDS**

disparities, ischemic stroke, reperfusion, stroke center, thrombolysis

## 1 | INTRODUCTION

### 1.1 | Background

As a leading cause of long-term disability, early and appropriate intervention is critical to optimize stroke patient outcomes. For eligible patients, reperfusion with alteplase or endovascular thrombectomy (EVT) is associated with reduced post-stroke disability and in some cases mortality.<sup>1-3</sup> In addition, regardless of eligibility for acute reperfusion interventions, receipt of care at a stroke center hospital is also associated with significantly improved patient outcomes.<sup>4</sup>

Yet access to high-quality acute ischemic stroke care varies, especially for racial and ethnic minorities. Prior work has shown lower receipt of alteplase among Black patients, whether cared for in a stroke center hospital or not,<sup>5</sup> as well as lower rates of EVT.<sup>6</sup> Prior work has also shown variation in alteplase receipt by geographic and hospital factors including region, rurality, teaching status, and stroke center status<sup>7</sup>; that a non-trivial proportion of the population lives > 60 miles from an alteplase-capable hospital<sup>8</sup>; and that non-White patients less often present to EVT-capable hospitals.<sup>6</sup>

### 1.2 | Importance

Access to reperfusion interventions and to high-quality stroke care depends in part on the site of initial presentation, which itself is closely connected to where patients live. Yet emergency department (ED) and hospital openings and closures may be more influenced by market forces than by a centralized determination of need or consideration of optimal allocation of resources for a population.<sup>9-11</sup> Thus, in order to achieve a system of care in which stroke patients are appropriately allocated and matched with the resources required for their care, interhospital transfer is an important strategy.<sup>12</sup> Although interhospital transfer of stroke patients has been increasing over time,<sup>13,14</sup> it is not clear whether this change has been accompanied by changes in access to stroke center care across all racial and ethnic groups.

### 1.3 | Goals of this investigation

Our primary objective was to determine whether there are disparities in access to stroke center care by race and ethnicity that may help explain differences in reperfusion intervention receipt, and to understand whether interhospital patient transfer plays a role in improving access. Because we need to capture population level encounters for patients of all ages (not just elderly Medicare patients) and track transfers between hospitals, neither Medicare nor registry sources, such as Get with the Guidelines-Stroke are adequate. We, therefore,

conducted these analyses in a statewide all payer claims database suitable for the objective.

## 2 | METHODS

### 2.1 | Data source and population

We used non-public data maintained by the California Office of Statewide Health Planning and Development,<sup>15</sup> which include all ED and hospital discharges from all non-federal, acute care hospitals licensed in California. We identified all encounters for acute ischemic stroke from January 2010 to December 2017 using primary discharge diagnosis codes (International Classification of Diseases, Ninth Revision, Clinical Modification [ICD-9-CM], Tenth Revision [ICD-10-CM], and Medicare Severity Diagnosis Related Groups [MS-DRG]) based on a previously described strategy.<sup>16</sup> This study was approved by the local institutional review board.

### 2.2 | Outcomes of interest

Outcomes of interest were presentation to a primary or comprehensive stroke center hospital (PSC or CSC), interhospital transfer, discharge from a stroke center hospital (PSC or CSC), and discharge from a CSC. Records were linked for the identification of interhospital transfer using a previously described strategy; we used discharge disposition indicating transfer in combination with records from 2 different EDs or hospitals on the same or consecutive dates.<sup>13,16</sup> Hospital stroke center status was based on Joint Commission and local emergency medical services certification in 2017.<sup>17</sup> We used certification in the final year of our sample because we felt this was the most accurate reflection of a hospital's stroke-related resources and expertise, regardless of which year the hospital achieved designation. We examined hospital stroke center status using both PSC and CSC designations.

To understand the relationship between these outcomes of interest and patients' access to reperfusion interventions, we also examined alteplase receipt and EVT. Alteplase receipt was identified using ICD-9- and ICD-10-PCS codes, Current Procedural Terminology codes, and MS-DRG codes.<sup>16</sup> EVT receipt was identified using ICD-9-PCS, ICD-10-PCS, or MS-DRG codes.<sup>16</sup>

### 2.3 | Other variables of interest

Patient-level variables of interest included age, sex, race or ethnicity, year of presentation, insurance status, and Charlson comorbidity

index (CCI) score. Race or ethnicity based on OSPHD documentation was categorized as non-Hispanic White, non-Hispanic Black, Hispanic, non-Hispanic Asian or Pacific Islander, other, and not reported. Patient insurance status was categorized as private, Medicare, Medicaid, other, or self-pay/uninsured. A Charlson comorbidity index was derived for each patient based on medical history variables that were identified by ICD-9-CM and ICD-10 coding.<sup>18</sup>

In addition to stroke center status, hospital-level variables of interest for initial and discharging hospitals included urban versus rural location, hospital annual stroke volume, and hospital payer mix. Urban versus rural location was based on urban influence codes.<sup>19</sup> Hospital payer mix was based on proportion of stroke patients with Medicaid or who were self-pay.

## 2.4 | Analyses

We used descriptive statistics to characterize the overall population and *t*-tests, chi-square, and analysis of variance as appropriate to examine bivariate relationships between variables of interest and our outcomes. For each of the outcomes of interest, we used hierarchical logistic regression modeling in order to account for the patient- and hospital-level covariates of interest described previously. We examined a series of models with covariates chosen a priori based on scientific evidence and our hypotheses of interest, with a random intercept for initial hospital of presentation. Finally, to examine whether inter-hospital transfer mediated the relationship between race or ethnicity and odds of discharge from a stroke center hospital, we tested race or ethnicity-by-transfer status interactions in the models examining discharge from PSC or CSC and discharge from CSC. When interactions were not significant (ie,  $P > 0.05$ ), they were removed from the model for ease of interpretation.

## 3 | RESULTS

### 3.1 | Overall population

There were 336,247 acute ischemic stroke patients in our overall sample, of whom 186,444 (55.4%) were non-Hispanic White, 66,016 (19.6%) were Hispanic, 35,784 (10.6%) were non-Hispanic Asian/Pacific Islander, 34,596 (10.3%) were non-Hispanic Black, and 13,407 (4.0%) were other or unknown. Half (50.7%) were female. Most patients had Medicare insurance (65.3%) followed by private (19.9%), Medicaid (12.2%), and self-pay (2.6%). Patient and hospital characteristics are outlined in Table 1.

#### 3.1.1 | Initial presentation to a stroke center hospital (PSC or CSC)

The majority of patients initially presented to a stroke center hospital: 84,083 (25%) to a CSC, 193,659 (57.6%) to a PSC, and 58,505

### The Bottom Line

The Bottom Line: This study examined whether the configuration of stroke systems of care contribute to racial and ethnic disparities in access to high-quality stroke care. The results suggest that differences in transfer and in discharge from comprehensive stroke centers may contribute to differential receipt of reperfusion interventions.

(17.4%) to a hospital with acute stroke ready or no certification. Odds of presentation to a stroke center hospital did not vary by race or ethnicity in unadjusted or adjusted analyses (Table eS4). Only patients initially presenting to a rural hospital had lower odds of presenting to a stroke center hospital in unadjusted and adjusted analysis (adjusted odds ratio [aOR] 0.001, 95% confidence interval [CI] 0.001 to 0.005).

### 3.2 | Receipt of alteplase

Of the full sample, 31,248 (9.3%) received alteplase. In bivariate comparisons, alteplase receipt was less frequent among Hispanic, non-Hispanic Asian or Pacific Islander, and non-Hispanic Black patients (Table eS1). After accounting for patient- and hospital-level characteristics, race or ethnicity remained significantly associated with likelihood of alteplase receipt, with lower odds among Hispanic (aOR 0.87, 95% CI 0.84 to 0.90), non-Hispanic Asian/Pacific Islander (aOR 0.80, 95% CI 0.76 to 0.83), and non-Hispanic Black (aOR 0.78, 95% CI 0.74 to 0.81) relative to White patients (Table eS2; Figure 1). Adjusted odds were also lower for patients with Medicaid insurance, for patients presenting to non-stroke center hospitals and for patients presenting to hospitals with higher proportion of Medicaid and self-pay patients.

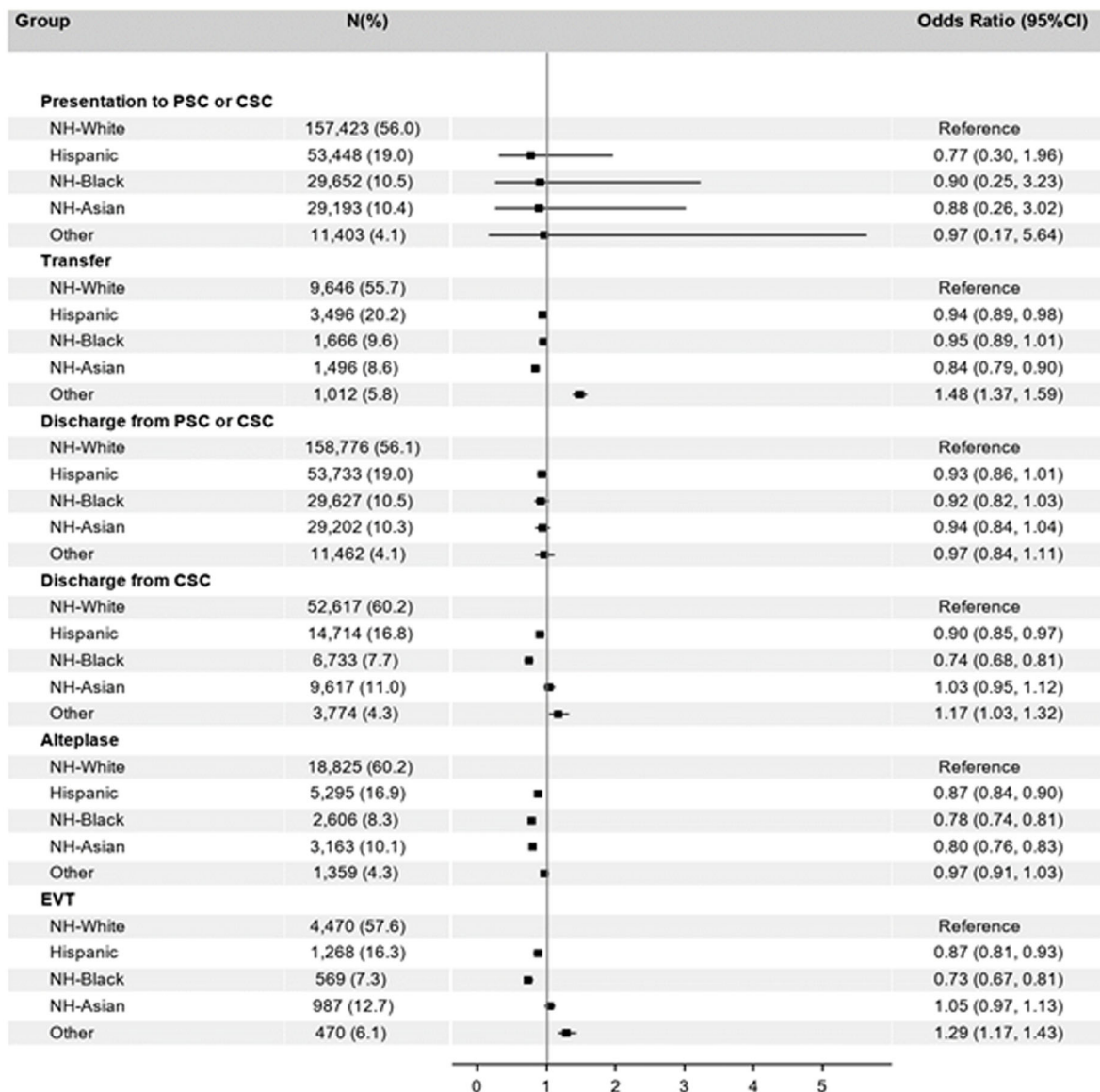
### 3.3 | Receipt of EVT

EVT was performed in 7764 patients (2.3%). In bivariate comparisons, EVT receipt was more frequent among patients who were White and non-Hispanic Asian/Pacific Islander and less frequent among Hispanic and non-Hispanic Black patients (Table eS1). After accounting for patient- and hospital-level characteristics, race and ethnicity remained significantly associated with likelihood of EVT receipt, with lower odds of receipt among Hispanic patients (aOR 0.87, 95% CI 0.82 to 0.94) and non-Hispanic Black patients (aOR 0.73, 95% CI 0.67 to 0.81), and higher odds among those with other or unknown race or ethnicity (aOR 1.29, 95% CI 1.17 to 1.43; Table eS3) relative to White patients. Adjusted odds were lower for patients presenting to non-CSCs (ie, PSCs and non-stroke center hospitals).

**TABLE 1** Patient characteristics and outcomes

	Overall (N = 336,247)	NH-White (N = 186,444)	Hispanic (N = 66,016)	NH-Black (N = 34,596)	NH-Asian (N = 35,784)	Other (N = 13,407)
<b>Age, years</b>						
<45	12,153 (3.6%)	4479 (2.4%)	3845 (5.8%)	2017 (5.8%)	1253 (3.5%)	559 (4.2%)
45-64	87,519 (26.0%)	38,430 (20.6%)	22,203 (33.6%)	13,883 (40.1%)	9117 (25.5%)	3886 (29.0%)
65-79	117,208 (34.9%)	64,161 (34.4%)	23,049 (34.9%)	11,960 (34.6%)	13,107 (36.6%)	4931 (36.8%)
80-89	86,493 (25.7%)	56,069 (30.1%)	13,202 (20.0%)	5069 (14.7%)	9162 (25.6%)	2991 (22.3%)
> = 90	32,874 (9.8%)	23,305 (12.5%)	3717 (5.6%)	1667 (4.8%)	3145 (8.8%)	1040 (7.8%)
<b>Gender</b>						
Female	170,455 (50.7%)	96,019 (51.5%)	31,397 (47.6%)	18,572 (53.7%)	18,030 (50.4%)	6437 (48.0%)
Male	165,792 (49.3%)	90,425 (48.5%)	34,619 (52.4%)	16,024 (46.3%)	17,754 (49.6%)	6970 (52.0%)
<b>Year of presentation</b>						
2010	39,036 (11.6%)	22,835 (12.2%)	6995 (10.6%)	4018 (11.6%)	3829 (10.7%)	1359 (10.1%)
2011	40,359 (12.0%)	23,344 (12.5%)	7314 (11.1%)	4135 (12.0%)	4131 (11.5%)	1435 (10.7%)
2012	40,262 (12.0%)	22,938 (12.3%)	7639 (11.6%)	4095 (11.8%)	4159 (11.6%)	1431 (10.7%)
2013	40,830 (12.1%)	23,028 (12.4%)	7942 (12.0%)	4058 (11.7%)	4273 (11.9%)	1529 (11.4%)
2014	42,294 (12.6%)	23,234 (12.5%)	8480 (12.8%)	4404 (12.7%)	4493 (12.6%)	1683 (12.6%)
2015	44,577 (13.3%)	24,131 (12.9%)	9159 (13.9%)	4604 (13.3%)	4780 (13.4%)	1903 (14.2%)
2016	44,650 (13.3%)	23,956 (12.8%)	9083 (13.8%)	4550 (13.2%)	5059 (14.1%)	2002 (14.9%)
2017	44,239 (13.2%)	22,978 (12.3%)	9404 (14.2%)	4732 (13.7%)	5060 (14.1%)	2065 (15.4%)
<b>Insurance</b>						
Medicare	219,724 (65.3%)	134,488 (72.1%)	37,089 (56.2%)	18,744 (54.2%)	21,592 (60.3%)	7811 (58.3%)
Private	66,754 (19.9%)	35,721 (19.2%)	12,927 (19.6%)	7608 (22.0%)	7730 (21.6%)	2768 (20.6%)
Medicaid	41,051 (12.2%)	12,548 (6.7%)	13,493 (20.4%)	7103 (20.5%)	5517 (15.4%)	2390 (17.8%)
Self	8718 (2.6%)	3687 (2.0%)	2507 (3.8%)	1141 (3.3%)	945 (2.6%)	438 (3.3%)
<b>Charlson comorbidity index</b>						
Median (Q1-Q3)	3.00 (2.00-4.00)	3.00 (2.00-4.00)	3.00 (2.00-4.00)	3.00 (2.00-5.00)	3.00 (2.00-4.00)	3.00 (2.00-4.00)
<b>Alteplase receipt</b>						
Yes	31,248 (9.3%)	18,825 (10.1%)	5295 (8.0%)	2606 (7.5%)	3163 (8.8%)	1359 (10.1%)
No	304,999 (90.7%)	167,619 (89.9%)	60,721 (92.0%)	31,990 (92.5%)	32,621 (91.2%)	12,048 (89.9%)
<b>Endovascular thrombectomy receipt</b>						
Yes	7764 (2.3%)	4470 (2.4%)	1268 (1.9%)	569 (1.6%)	987 (2.8%)	470 (3.5%)
No	328,483 (97.7%)	181,974 (97.6%)	64,748 (98.1%)	34,027 (98.4%)	34,797 (97.2%)	12,937 (96.5%)
<b>Interhospital transfer</b>						
Yes	17,316 (5.1%)	9646 (5.2%)	3496 (5.3%)	1666 (4.8%)	1496 (4.2%)	1012 (7.5%)
No	318,931 (94.9%)	176,798 (94.8%)	62,520 (94.7%)	32,930 (95.2%)	34,288 (95.8%)	12,395 (92.5%)
<b>Initial hospital</b>						
ASRH/None	55,128 (16.4%)	29,021 (15.6%)	12,568 (19.0%)	4944 (14.3%)	6591 (18.4%)	2004 (14.9%)
PSC	196,199 (58.3%)	106,224 (57.0%)	39,373 (59.6%)	23,096 (66.8%)	19,742 (55.2%)	7764 (57.9%)
CSC	84,920 (25.3%)	51,199 (27.5%)	14,075 (21.3%)	6556 (19.0%)	9451 (26.4%)	3639 (27.1%)
<b>Discharging hospital</b>						
ASRH/None	53,447 (15.9%)	27,668 (14.8%)	12,283 (18.6%)	4969 (14.4%)	6582 (18.4%)	1945 (14.5%)
PSC	195,345 (58.1%)	106,159 (56.9%)	39,019 (59.1%)	22,894 (66.2%)	19,585 (54.7%)	7688 (57.3%)
CSC	87,455 (26.0%)	52,617 (28.2%)	14,714 (22.3%)	6733 (19.5%)	9617 (26.9%)	3774 (28.1%)

Abbreviations: ASRH, acute stroke ready hospital; CSC, comprehensive stroke center; NH, non-Hispanic; PSC, primary stroke center; Q1, quartile 1; Q3, quartile 3.



**FIGURE 1** Adjusted odds of stroke center presentation, transfer, stroke center discharge and reperfusion interventions, by patient race/ethnicity. Abbreviations: CI, confidence interval; CSC, comprehensive stroke center; EVT, endovascular thrombectomy; NH, non-Hispanic; PSC, primary stroke center

### 3.4 | Interhospital transfer

Of the 336,247 patients in the overall sample, 17,316 (5.1%) were transferred between hospitals. In bivariate comparisons, interhospital transfer was more frequent among non-Hispanic White patients, Hispanic patients, and patients with unknown race or ethnicity (Table eS1). After accounting for patient- and hospital-level characteristics, race or ethnicity remained associated with interhospital transfer, with decreased odds among Hispanic patients (aOR 0.94, 95% CI 0.89 to 0.98) and non-Hispanic Asian or Pacific Islander patients (aOR 0.84, 95% CI 0.79 to 0.90) and increased odds among those with other or unknown race or ethnicity (aOR 1.48, 95% CI 1.37 to 1.59) when compared to White patients (Table 2). Adjusted odds of interhospital transfer were higher for patients with increased CCI, patients presenting

to rural hospitals, and for patients with Medicaid, private, and self-pay insurance (relative to Medicare insurance). Adjusted odds were lower for patients presenting to hospitals with higher stroke volumes.

### 3.5 | Discharge from stroke center hospital

Of the 336,247 patients in the overall sample, 279,146 (83.0%) were discharged from a PSC or CSC hospital: 192,582 (57.3%) from a PSC, and 86,564 (25.7%) from a CSC. In bivariate comparisons, discharge from a stroke center was more frequent among non-Hispanic White patients and was less frequent among Hispanic and non-Hispanic Asian or Pacific Islanders patients (Table eS1). In the adjusted model, including an interaction to evaluate whether transfer mitigated the

**TABLE 2** Odds of interhospital transfer in unadjusted and adjusted analyses

	Unadjusted		Adjusted for patient characteristics		Adjusted for patient characteristics and hospital stroke center status		Adjusted for all patient and hospital characteristics	
	Unadjusted OR	95% CI	Adjusted OR	95% CI	Adjusted OR	95% CI	Adjusted OR	95% CI
Age, years								
<45	1.36	(1.26–1.47)	1.43	(1.32–1.55)	1.43	(1.32–1.55)	1.43	(1.32–1.55)
45–64	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
65–79	0.99	(0.95–1.03)	2.01	(1.92–2.11)	2.01	(1.92–2.11)	2.01	(1.92–2.11)
80–89	0.83	(0.79–0.87)	1.89	(1.79–2.00)	1.89	(1.79–2.00)	1.89	(1.80–2.00)
90+	0.56	(0.53–0.60)	1.35	(1.25–1.46)	1.35	(1.35–1.46)	1.35	(1.25–1.46)
Female gender	1.23	(1.19–1.27)	1.09	(1.06–1.13)	1.09	(1.06–1.13)	1.09	(1.06–1.13)
Race/ethnicity								
Non-Hispanic White	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Non-Hispanic Black	1.03	(0.97–1.09)	0.95	(0.89–1.01)	0.95	(0.89–1.01)	0.95	(0.89–1.01)
Non-Hispanic Asian/Pacific islander	0.90	(0.84–0.95)	0.84	(0.79–0.90)	0.84	(0.79–0.90)	0.84	(0.79–0.90)
Hispanic	0.99	(0.94–1.03)	0.93	(0.89–0.98)	0.93	(0.89–0.98)	0.94	(0.89–0.98)
Other/unknown	1.60	(1.49–1.72)	1.48	(1.37–1.59)	1.48	(1.37–1.59)	1.48	(1.37–1.59)
Year of presentation								
2010	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
2011	1.08	(1.01–1.16)	1.08	(1.00–1.16)	1.08	(1.00–1.16)	1.08	(1.00–1.16)
2012	1.25	(1.16–1.34)	1.26	(1.17–1.35)	1.26	(1.17–1.35)	1.26	(1.17–1.36)
2013	1.32	(1.23–1.41)	1.31	(1.22–1.41)	1.32	(1.22–1.41)	1.32	(1.22–1.41)
2014	1.34	(1.25–1.44)	1.36	(1.26–1.46)	1.36	(1.27–1.46)	1.36	(1.27–1.46)
2015	1.52	(1.42–1.63)	1.53	(1.43–1.64)	1.53	(1.43–1.64)	1.53	(1.43–1.64)
2016	1.68	(1.57–1.79)	1.63	(1.53–1.75)	1.64	(1.53–1.76)	1.64	(1.53–1.76)
2017	1.73	(1.62–1.85)	1.69	(1.58–1.81)	1.69	(1.58–1.81)	1.70	(1.58–1.82)

(Continues)



**TABLE 2** (Continued)

	Unadjusted		Adjusted for patient characteristics		Adjusted for patient characteristics and hospital stroke center status		Adjusted for all patient and hospital characteristics	
	Unadjusted OR	95% CI	Adjusted OR	95% CI	Adjusted OR	95% CI	Adjusted OR	95% CI
<b>Insurance status</b>								
Medicare	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Medicaid	1.12	(1.06–1.19)	1.74	(1.63–1.86)	1.73	(1.62–1.85)	1.74	(1.62–1.85)
Private insurance	4.50	(4.34–4.66)	6.69	(6.41–6.97)	6.69	(6.42–6.98)	6.71	(6.43–6.99)
Self-pay	2.25	(2.06–2.45)	4.46	(4.06–4.90)	4.47	(4.06–4.91)	4.47	(4.07–4.92)
Charlson comorbidity index	1.15	(1.14–1.16)	1.22	(1.20–1.23)	1.22	(1.20–1.23)	1.22	(1.20–1.23)
<b>Stroke center status</b>								
ASRH/None	1.70	(1.34–2.14)			2.07	(1.62–2.65)	0.84	(0.64–1.09)
PSC	Ref	Ref			Ref	Ref	Ref	Ref
CSC	0.72	(0.51–1.01)			0.72	(0.50–1.04)	1.17	(0.84–1.64)
Initial presentation to rural	2.67	(1.78–4.00)					1.76	(1.20–2.57)
Payer mix (proportion of Medicaid/self-pay)	1.00	(0.99–1.01)					1.00	(0.99–1.01)
<b>Average annual stroke volume</b>								
<60	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
60–120	0.48	(0.37–0.63)					0.40	(0.30–0.54)
120–240	0.32	(0.25–0.41)					0.24	(0.18–0.33)
>240	0.24	(0.18–0.31)					0.16	(0.11–0.23)

Abbreviations: ASRH, acute stroke ready hospital; CI, confidence interval; CSC, comprehensive stroke center; OR, odds ratio; PSC, primary stroke center. All hospital-level variables refer to first hospital of presentation.

association between race or ethnicity and discharge from a PSC or CSC, we found that among non-transferred patients, Hispanic, non-Hispanic Black, non-Hispanic Asian or Pacific Islander, and patients of other or unknown race or ethnicity all had increased odds of discharge from a PSC or CSC, relative to White patients. However, the effect of interhospital transfer varied by race or ethnicity. Among Non-Hispanic White patients and patients of other/unknown race or ethnicity, interhospital transfer was associated with significantly increased odds of discharge from a PSC or CSC. The relationship was similar but with a less pronounced effect size among Hispanic and non-Hispanic Asian/Pacific Islander patients. However, among Non-Hispanic Black patients, interhospital transfer was associated with a decreased odds of discharge from a PSC or CSC (Table 3).

We also examined discharge from CSC alone, again including an interaction for race or ethnicity and transfer status. In adjusted analysis, we found that Hispanic and non-Hispanic Black patients had lower odds of discharge from a CSC in the absence of transfer. Among all patients, interhospital transfer led to increased odds of discharge from a PSC or CSC. The relationship between transfer and odds of discharge from a CSC did vary by race or ethnicity, with all patients experiencing greatly improved access to CSC care with transfer (Table 4).

#### 4 | LIMITATIONS

This study has important limitations. Our data are from a single state and may not be generalizable to other settings. However, California is a populous and diverse state representing over 10% of the US population. Our data through 2017 are also relatively old, with respect to the ongoing advanced in evidence for EVT,<sup>3,20,21</sup> and changes in evidence and eligibility time windows for EVT may have had differential impact on different patient groups, which may have reduced or widened racial and ethnic disparities. In addition, we chose to use these data because it gives the ability to link patients across emergency and inpatient data sources to track patients across all hospitals (except federal institutions) in the state. Other limitations of the data include that we lacked a measure of stroke severity (ie, National Institutes of Health Stroke Scale), lacked contraindications or time-based clinical data to determine patients' eligibility for reperfusion interventions, and data on ambulance transport, which may contribute to reperfusion delivery and have previously been shown to vary by race or ethnicity.<sup>22-24</sup> We also lacked data on patient language preference, though the contribution of language to acute stroke care is not clear.<sup>25-27</sup> Finally, there may have been unmeasured differences between groups that were unable to be accounted for in our analysis.

#### 5 | DISCUSSION

In this large, representative state database, we found variation in access to stroke center care by race and ethnicity. In particular, in

**TABLE 3** Odds of discharge from primary or comprehensive stroke center hospital in adjusted analysis, including interaction for race/ethnicity and transfer

	Adjusted for all patient and hospital characteristics	
	Adjusted OR	95% CI
Age, years		
<45	1.41	(1.20–1.65)
45–64	Ref	Ref
65–79	0.88	(0.80–0.96)
80–89	0.84	(0.76–0.92)
90+	0.79	(0.70–0.90)
Female gender	1.00	(0.94–1.06)
Year		
2010	Ref	Ref
2011	1.09	(0.97–1.23)
2012	1.17	(1.04–1.32)
2013	1.43	(1.27–1.60)
2014	1.35	(1.20–1.52)
2015	1.51	(1.35–1.70)
2016	1.58	(1.40–1.77)
2017	1.74	(1.54–1.95)
Race/ethnicity and transfer		
Non-Hispanic White, not transferred	Ref	Ref
Non-Hispanic White, transferred	14.89	(13.40–16.54)
Non-Hispanic Black, not transferred	1.45	(1.28–1.65)
Non-Hispanic Black, transferred	0.64	(0.47–0.89)
Non-Hispanic Asian/Pacific Islander, not transferred	1.30	(1.16–1.47)
Non-Hispanic Asian/Pacific Islander, transferred	1.67	(1.20–2.33)
Hispanic, not transferred	1.14	(1.04–1.25)
Hispanic, transferred	6.27	(5.33–7.38)
Other/unknown, not transferred	1.21	(1.02–1.42)
Other/unknown, transferred	16.93	(13.61–21.07)
Insurance		
Medicare	ref	ref
Medicaid	0.84	(0.75–0.93)
Private insurance	0.87	(0.80–0.95)
Self-pay	0.69	(0.58–0.82)
Charlson comorbidity index	0.97	(0.95–0.99)

(Continues)



**TABLE 3** (Continued)

	Adjusted for all patient and hospital characteristics	
	Adjusted OR	95% CI
Payer mix (proportion of Medicaid/self-pay) of initial hospital	0.92	(0.88–0.95)
Initial presentation to rural	0.01	(0.002–0.05)

Abbreviations: CI, confidence interval; OR, odds ratio.

All hospital-level variables refer to first hospital of presentation; payer mix defined as proportion of patients with Medicaid or self-pay insurance.

the absence of transfer Hispanic and non-Hispanic Black patients had lower odds of discharge from a CSC. Interestingly, this finding could not be attributed to differential access based on where patients live, given that initial presentation to a stroke center did not vary by race or ethnicity. Instead, our results suggest that differential transfer patterns may contribute to disparities in access, as we found lower odds of interhospital transfer among Hispanic patients, and that although interhospital transfer was strongly associated with improved access to CSC-level care, the relationship between transfer and access was modified by patient race or ethnicity and White patients experienced the strongest benefit from transfer. Concerningly, among non-Hispanic Black patients, transfer was associated with decreased odds of stroke center care.

We also found that the payer mix at a patient's initial hospital of presentation was associated with odds of stroke center access— with lower odds of stroke center discharge among patients presenting to hospitals with greater proportion of Medicaid and self-pay patients. This finding may suggest that transfer patterns and the organization of the stroke system of care are configured in a way that reinforces differential access to high-quality care based on relative privilege. As spatial justice is increasingly recognized as a critical component of building equitable systems of care, it will be important to examine the role of transfer patterns and the structure of the hospital network created by interhospital transfers in reinforcing or perpetuating disparities in patient access to high-quality acute stroke care.<sup>28</sup> Strategies from network science may prove valuable.<sup>29,30</sup>

Our findings also reinforce prior literature, as we found that stroke patients from racial or ethnic minority groups in California had lower odds than White patients of receiving reperfusion interventions.<sup>31–34</sup> This was true for both receipt of alteplase and EVT. Our findings are also consistent with prior work highlighting urban-rural disparities in access to acute stroke care<sup>35,36</sup> that are likely contributing to known rural disparities in stroke patient outcomes.<sup>37</sup> This is particularly so given that areas with less access to stroke center care tended to have higher representation of older Americans, Native American population, medically uninsured patients, low median annual income, and low population density.<sup>36</sup> Prior work has also highlighted important geographic gaps and disparities in access.<sup>38–40</sup> These factors will be

**TABLE 4** Odds of comprehensive stroke center discharge, including interaction for race/ethnicity and transfer

	Adjusted for all patient and hospital characteristics	
	Adjusted OR	95% CI
Age, years		
<45	1.37	(1.21–1.55)
45–64	Ref	Ref
65–79	0.93	(0.86–1.00)
80–89	0.84	(0.77–0.91)
90+	0.79	(0.71–0.88)
Female gender	0.93	(0.88–0.97)
Year		
2010	Ref	Ref
2011	0.99	(0.89–1.10)
2012	1.07	(0.97–1.19)
2013	1.20	(1.08–1.33)
2014	1.21	(1.09–1.34)
2015	1.60	(1.44–1.76)
2016	1.65	(1.49–1.82)
2017	1.80	(1.63–1.99)
Race/ethnicity and transfer		
Non-Hispanic White, not transferred	Ref	Ref
Non-Hispanic White, transferred	17.85	(16.39–19.44)
Non-Hispanic Black, not transferred	0.77	(0.69–0.85)
Non-Hispanic Black, transferred	12.6	(10.50–15.12)
Non-Hispanic Asian/Pacific Islander, not transferred	1.13	(1.03–1.25)
Non-Hispanic Asian/Pacific Islander, transferred	14.06	(11.64–16.98)
Hispanic, not transferred	0.85	(0.78–0.91)
Hispanic, transferred	20.84	(18.51–23.47)
Other/unknown, not transferred	1.05	(0.90–1.22)
Other/unknown, transferred	16.93	(13.61–21.07)
Insurance		
Medicare	Ref	Ref
Medicaid	0.94	(0.85–1.04)
Private insurance	0.77	(0.72–0.83)
Self-pay	1.38	(1.19–1.60)

(Continues)

**TABLE 4** (Continued)

	Adjusted for all patient and hospital characteristics	
	Adjusted OR	95% CI
Charlson comorbidity index	0.92	(0.90–0.93)
Payer mix (proportion of Medicaid/self-pay) of initial hospital	0.95	(0.92–0.98)
Initial presentation to rural	0.05	(0.01–0.18)

Abbreviations: CI, confidence interval; OR, odds ratio.

All hospital-level variables refer to first hospital of presentation; Payer mix defined as proportion of patients with Medicaid or self-pay insurance.

important to address in order to move toward more equitable access to acute stroke care in the United States.

There are several important implications of our findings. The lower rates of reperfusion interventions and discharge from a CSC hospital among patients from racial and ethnic minority groups have important implications for the organization of stroke systems of care. Although there will always be variation in where patients live and where strokes occur relative to the location of hospital resources, certain strategies can be considered in the configuration of stroke systems to mitigate the disparities in access demonstrated in our findings. Ideally, a system would provide bespoke solutions for each patient scenario, matching patients to the level of resources appropriate for their needs. For example, among patients transported by ambulance, the use of prehospital triage protocols and applications of decision modeling tools may serve as important – and ideally unbiased – guides in identification of patients potentially eligible for interventions in the prehospital setting and ensuring transport to appropriate facilities (whether PSC or CSC).<sup>41–44</sup> In addition to the prehospital setting, we may also be strategic in supporting resources for hospitals. A prior study by Mullen et al demonstrated the use of simulation modeling as a tool to selectively convert primary stroke centers to comprehensive stroke center hospitals in a way that would optimize patient access.<sup>45</sup> At the same time, however, it would be crucial to balance the need for more geographic access with the potential unintended consequence of decreased quality, given the well-documented relationship between volume and outcomes.<sup>46–48</sup> Finally, telestroke is another important tool that may be used to bring neurological expertise to patients at hospitals that would not otherwise have the necessary in-hospital resources<sup>49</sup> and has been shown to improve stroke patients' receipt of reperfusion interventions and post-stroke outcomes.<sup>50</sup> Rather than longer prehospital transports to already crowded CSCs, for the right subset of patients, access to expertise via telestroke through their local ED may enable patients to receive care closer to home and remain in their communities.

As choice of transfer destination and receipt of care at a stroke center have been directly associated with better outcomes for stroke patients,<sup>4,51</sup> optimizing interhospital patient transfers is another important component of improved stroke systems of care. Previous

work has suggested that choice of stroke patient transfer destination is associated with many factors, including hospital affiliation, and that stroke patients are not always transferred to high-quality hospitals.<sup>13,52</sup> Thus, improving choice of patient transfer destinations may represent an opportunity to improve the stroke system of care.<sup>53</sup> Improved identification of patients eligible for transfer and improved door-in/door-out times for transfer also represent opportunities for improvement.<sup>54</sup>

We report racial and ethnic disparities in receipt of disability-reducing reperfusion interventions among stroke patients in California and identify components of the stroke system of care that may contribute to these disparities. This includes differences in interhospital transfer and in discharge from comprehensive stroke center hospitals. However, further work is necessary to fully understand factors contributing to disparities in access to high-quality stroke care. This presents an important opportunity to improve prehospital and interhospital transfer systems to mitigate disparities in access and improve post-stroke patient outcomes.

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#### AUTHOR CONTRIBUTIONS

KSZ, LHS, and CAC conceived the study. RYH provided data access. KSZ, MES and MJR designed the statistical approach. SL and ZY performed the analyses. All authors contributed to interpretation of the results. KSZ drafted the manuscript, and all authors contributed to critical revisions of the manuscript.

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#### SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

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