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# Regional Availability of Mechanical Embolectomy for Acute Ischemic Stroke in California, 2009 to 2010

Jay Chol Choi, MD, PhD; Renee Y. Hsia, MD, MSc; Anthony S. Kim, MD, MAS

***Background and Purpose***—We sought to assess the geographic proximity of patients with stroke in California to centers that performed specific threshold volumes of mechanical embolectomy procedures each year.

***Methods***—We identified all patients who were hospitalized for acute ischemic stroke at all nonfederal acute care hospitals in California from 2009 to 2010, and all hospitals that performed any mechanical embolectomy procedures by case volume during the same period, using nonpublic data from the Office of Statewide Health Planning and Development. We computed geographic service areas around each hospital on the basis of prespecified ground transport distance thresholds. We then calculated the proportion of hospitalized patients with stroke who lived within service areas for centers that performed a low volume and high volume of mechanical embolectomy procedures each year.

***Results***—During the 2-year study period, 15% (53/360) of hospitals performed at least 1 mechanical embolectomy for acute stroke, but only 19% (10/53) performed >10 cases per year. Most hospitalized patients with stroke (94%) lived within a 2-hour transport time (65 miles) to a hospital that performed ≥1 procedure during the 2-year period. Approximately 93% of the patients with stroke who received mechanical embolectomy lived within 20 miles from an embolectomy-capable hospital compared with 7% of those who lived >20 miles.

***Conclusions***—In California, most patients with stroke lived within reasonable ground transport distances from centers that performed ≥1 mechanical embolectomy in a 2-year period. The probability of receiving mechanical embolectomy for acute ischemic stroke was associated with living in close geographic proximity to these hospitals.   (***Stroke***. 2015;46:762-768. DOI: 10.1161/STROKEAHA.114.007735.)

**Key Words:** endovascular procedures ■ geographic location ■ stroke

At present, available data suggest that the efficacy and risks of reperfusion therapies for acute ischemic stroke are time-sensitive and that delivering time-sensitive interventions requires complex coordination efforts and organized systems of care.[1–5] The ability to deliver a time-sensitive intervention such as mechanical embolectomy depends on the availability of skilled interventionalists and hospitals with interventional teams that have sufficient experience and infrastructure to effectively coordinate the delivery of these complex interventions. Although Interventional Management of Stroke III failed to demonstrate efficacy for endovascular therapy after intravenous tissue-type plasminogen activator compared with intravenous tissue-type plasminogen activator alone,[6] a shorter time from symptom onset to treatment was associated with better outcomes. However, recent results from the Multicenter Randomized Clinical Trial of Endovascular Treatment for Acute Ischemic Stroke in the Netherlands (MR CLEAN) trial, which showed a clear benefit for intraarterial therapy for patients with acute stroke within 6 hours of symptom onset,[7] and ongoing clinical trials to assess efficacy in the

context of more stringent onset-to-treatment time goals may make the goal of optimizing access to timely intraarterial therapy particularly relevant.[8,9] Because higher procedural volume has been associated with shorter in-hospital treatment delays and lower mortality,[10,11] there may be a trade-off between increasing geographic access to specialized interventions, such as mechanical embolectomy, by either having many low-volume endovascular-capable hospitals or a more regionalized system with only more experienced, high-volume hospitals.

From 2004 to 2009, >13 000 endovascular treatments for acute stroke were performed in the United States, and the proportion of patients who underwent the treatment has been steadily increasing.[12] Recent reports suggest that 82% to 95% of US population had access to hospitals capable of delivering endovascular therapy within a 50- to 65-mile radius,[13,14] but procedural volumes were not specifically assessed. Geographic access to centers by actual case volume rather than by the availability of neurointerventionist has not been well characterized. In the present study, we sought to assess the geographic access of patients with stroke in California to centers that performed

mechanical embolectomy cases, as well as to centers that performed a certain threshold volume cases each year with the idea that such information could be useful to plan for the type of infrastructure that may needed to be developed to deliver time-sensitive treatments, particularly in light of the results from the MR CLEAN study[7] and as additional data on mechanical embolectomy or other such specialized stroke interventions becomes available from ongoing clinical trials.

## Methods

### Study Design

We conducted a retrospective cohort study linking clinical information to detailed street-level geographic data. This study was approved by the local institutional review board and the California Health and Human Services Agency's Committee for the Protection of Human Subjects.

### Data Sources

The Office of Statewide Health Planning and Development maintains comprehensive data on all hospital discharges from all 542 nonfederal hospitals that are licensed within California. Hospital-level information (location, hospital size, teaching hospital status, and trauma center designation) was obtained from the 2010 Office of Statewide Health Planning and Development Hospital Utilization Data.

### Identification of Hospital Discharges, Patients, and Procedures

We identified all hospital discharges for ischemic stroke from all nonfederal acute care hospitals in California from 2009 to 2010. Hospitalizations for acute ischemic stroke were identified using a previously validated algorithm based on the *International Classification of Disease, Clinical Modification,* 9th revision (ICD-9 CM) codes 433×1, 434×1, or 436, after excluding discharges with traumatic brain injury (800–804, 850–854) or rehabilitation care (V57) as the primary ICD-9-CM code.[15] The subset of these hospitalizations where mechanical embolectomy was used were identified using ICM-9 CM code 39.74,[12,16] which has been in use by reporting hospitals since January 2007. For the patient-level analyses, we excluded discharges without a record linkage number, and multiple hospital discharges for the same patient (using the unique record linkage number).

For each hospital, to estimate overall procedural experience with neuroangiographic procedures, we also captured data on the following related procedures: injection or infusion of thrombolytic agent (99.10)[17]; arteriography of cerebral arteries (88.41)[18]; and coil embolization of head and neck vessels (39.72).[19]

We abstracted demographic characteristics of each patient (age, sex, race, ethnicity, and ZIP code and county of residence), characteristics of the index admission (admission day [weekday versus weekends, including national holidays], admission source [emergency department or not; transfer from another hospital], disposition [home, other hospital, rehabilitation, skilled nursing facility, died, or other]), and discharge codes for medical comorbidities (hypertension, diabetes mellitus, coronary artery disease, congestive heart failure, chronic obstructive pulmonary disease, chronic kidney disease, hyperlipidemia, smoking, and atrial fibrillation) for each hospitalization for stroke. For the rural-urban classification, we used the 2013 US Department of Agriculture continuum codes, which are based on the county.[20] We classified hospitals according to whether the average annual hospital volume of mechanical embolectomy cases during the study period was <10 or ≥ 10 per year, as suggested as the minimum number for qualification by the Neurovascular Coalition and its participating societies, including the Society of NeuroInterventional Surgery, American Academy of Neurology, American Association of Neurological Surgeons/Cerebrovascular Section, and Society of Vascular & Interventional Neurology.[21]

### Ground Transport Distance and Service Area Maps

For the geographic analysis, we limited our analysis to patients with an available in-state ZIP code. We used ground transport distance thresholds of 20, 65, 115, 165, and 200 miles which correspond to estimated ground transport times of 1, 2, 3, 4, and 5 hours, as suggested by previous studies.[13,22] Using ZIP code centroids, we developed service area maps that encompassed all accessible streets within a specified transport distance from each hospital using network analysis software. With these maps, we developed a combined service area map for hospitals that performed ≥1 mechanical embolectomy during the study period, as well as for the subset of hospitals with a high mechanical embolectomy case volume (≥10). Using these service area maps, we also estimated the proportion of patients with stroke and mechanical embolectomy who lived within each transport distance threshold. Finally, we calculated the proportion of patients with stroke treated with mechanical embolectomy as a function of ground transport distance between the patient's residence and a hospital that performed mechanical embolectomy. For all geographic analyses, we used ArcGIS (Version 10.2.1; Esri, Redlands, CA).

### Statistical Analysis

Baseline characteristics of patients with acute stroke who received mechanical embolectomy versus those who did not were compared using Student $t$ test, Wilcoxon rank-sum test, or Fisher exact test, according to variable type. For the hospitals that performed at least 1 mechanical embolectomy during the study period, we compared hospital characteristics by annual volume of mechanical embolectomy procedures (high-versus low-volume). For all analyses, a $P$ value of ≤0.05 was defined as statistically significant; all tests were 2-sided. Statistical analyses were performed using Stata 13 (StataCorp LP, College Station, TX).

## Results

We identified 104 721 hospital discharges for acute ischemic stroke in California during 2009 to 2010. This corresponded to 86 092 individual patients who were hospitalized for acute ischemic stroke at 360 acute care hospitals in California from 2009 to 2010 after applying the study's inclusion criteria. Of these, 636 (0.7%) received mechanical embolectomy during the index hospitalization for stroke.

Demographic characteristics of the cohort as well as a comparison of patients with stroke who received mechanical embolectomy and those who did not are provided in Table 1. More than two thirds (70%) of patients were >65 years and most (83%) lived in metropolitan areas with a population of ≥1 million. In-hospital mortality was 8%, and 34% were discharged home. Patients with stroke treated with mechanical embolectomy were significantly younger, more likely to have atrial fibrillation, but less likely to have diabetes mellitus, chronic lung disease, chronic kidney disease, and a smoking history. Only one fifth (19.8%) of patients with stroke treated with mechanical embolectomy had been transferred from another facility (Table 1).

At the hospital level, 53 of 360 acute care hospitals in California (14.7%) had performed at least 1 mechanical embolectomy for acute stroke during the 2-year study period. The median annual endovascular case volume was 3.5 (interquartile range 1.0–8.5). Most hospitals (43; 81.1%) performed <10 mechanical embolectomies per year; 10 hospitals (18.8%) performed ≥10 procedures per year (Figure 1). Overall, more than half (56%) of these procedures were performed at hospitals that performed ≥10 procedures per year. Most hospitals that performed mechanical embolectomy (96%) were in metropolitan areas, 45% of these hospitals were designated as trauma centers, and 25% were teaching hospitals. Metropolitan

**Table 1.    Characteristics of Patients Hospitalized for Acute Ischemic Stroke in California Stratified by Treatment With Mechanical Embolectomy, 2009 to 2010**

| Characteristics | Mechanical Embolectomy (n=636) | No Mechanical Embolectomy (n=85 456) | P Value |
|---|---|---|---|
| Age at admission, y (SD) | 69 (±16) | 72 (±15) | <0.001 |
| Male sex, n (%) | 319 (50.2) | 40 992 (47.9) | 0.27 |
| Ethnicity, n (%) | | | <0.001 |
| Hispanic | 85 (13.4) | 15 412 (18.0) | |
| Non-Hispanic | 539 (84.8) | 69 236 (81.0) | |
| Unknown | 12 (1.9) | 805 (0.9) | |
| Race, n (%) | | | <0.001 |
| White | 439 (69.0) | 58 440 (68.4) | |
| Black | 39 (6.1) | 8789 (10.3) | |
| Asian/Pacific Islander | 79 (12.4) | 8554 (10.0) | |
| Other or unknown | 79 (12.4) | 9673 (11.3) | |
| County of residence, n (%) | | | 0.52 |
| Metropolitan | 598 (94.0) | 80 415 (94.1) | |
| ≥1 million population | 545 (88.8) | 62 324 (75.1) | |
| 250 000 to 1 million | 46 (7.5) | 14 992 (18.1) | |
| <250 000 population | 7 (1.1) | 3099 (3.7) | |
| Non-metropolitan | 16 (2.5) | 2596 (3.0) | |
| Not available | 22 (3.5) | 2445 (2.9) | |
| Comorbidities, n (%) | | | |
| Hypertension | 384 (60.4) | 52 295 (61.2) | 0.68 |
| Diabetes mellitus | 148 (23.3) | 30 827 (36.1) | <0.001 |
| Coronary artery disease | 172 (27.0) | 22 733 (26.6) | 0.78 |
| Congestive heart failure | 112 (17.6) | 14 030 (16.4) | 0.42 |
| Chronic obstructive lung disease | 78 (12.3) | 13 285 (15.6) | 0.02 |
| Chronic kidney disease | 27 (4.3) | 5899 (6.9) | 0.01 |
| Hyperlipidemia | 284 (44.7) | 41 496 (48.6) | 0.05 |
| Atrial fibrillation | 307 (48.3) | 21 844 (25.6) | <0.001 |
| Smoking | 103 (16.2) | 20 628 (24.1) | <0.001 |
| Source of admission, n (%) | | | <0.001 |
| Admitting hospital's emergency department | 510 (80.2) | 74 939 (87.7) | |
| Transferred from another facility | 126 (19.8) | 10 514 (12.3) | |
| Discharge disposition, n (%) | | | <0.001 |
| Home | 70 (11.0) | 29 505 (34.5) | |
| Other hospital | 92 (14.5) | 3324 (3.9) | |
| Rehabilitation | 153 (24.1) | 10 232 (12.0) | |
| Skilled nursing facility | 125 (19.7) | 22 292 (26.1) | |
| Died | 147 (23.1) | 6653 (7.8) | |
| Other | 49 (7.7) | 13 450 (15.7) | |

hospital location, hospital bed size, trauma center designation, and teaching hospital status did not significantly differ between high- (≥10 procedures per year) and low-volume hospitals.

High-volume hospitals also had higher volumes of patients receiving thrombolytic stroke therapy and coil embolization for aneurysms (P<0.05). However, the overall annual volume of patients with stroke did not significantly differ between low- and high-volume hospitals. A higher volume of mechanical embolectomy cases at the hospital level was not associated with a significant difference in the unadjusted mortality rates for those treated with mechanical embolectomy (Table 2). Overall, the proportion of patients who received mechanical embolectomy among all patients with stroke was greater during the week than during weekends and holidays (0.79% versus 0.61%; P=0.006). This difference was not observed for high-volume centers (6.1% versus 6.0%; P=0.51).

Among the 84 063 patients with stroke with available California ZIP codes, most (94%) lived within a 2-hour ground
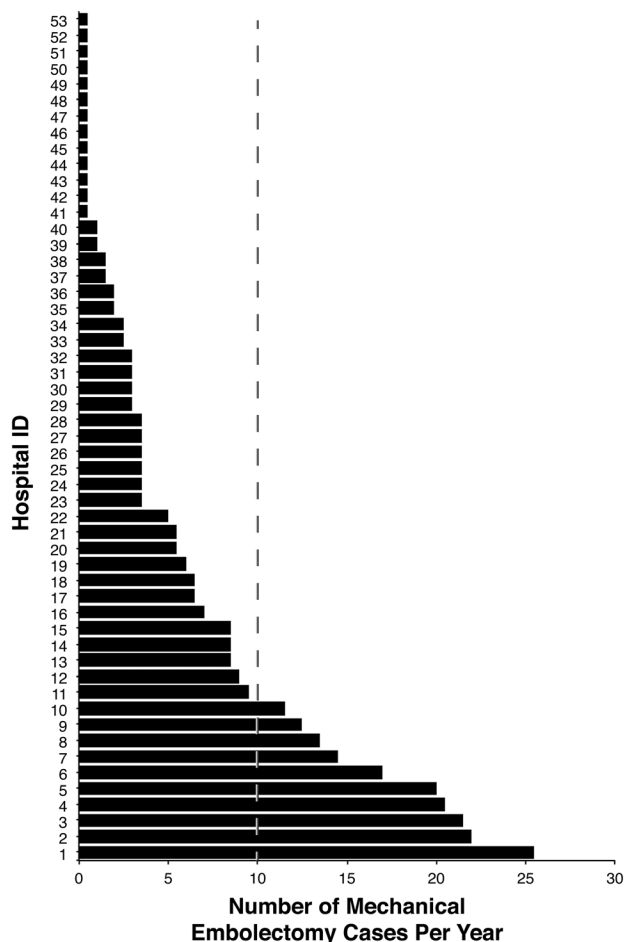
**Figure 1.** Average annual volume of mechanical embolectomy cases among 53 hospitals that performed mechanical embolectomy for acute stroke in California, 2009 to 2010. Vertical gray line indicates an annual volume of 10 cases per year. ID indicates identification.

transport time (65 miles) to a hospital that performed ≥1 procedure during the 2-year study period. Patients with stroke had more limited access to high-volume hospitals (70%), assuming a 2-hour ground transport time, but still >95% of patients with stroke still lived within a 4-hour ground transport distance (Table 3 and Figure 2).

For the subset of 603 patients with mechanical embolectomy with available California ZIP codes, 93% lived within a 20-mile ground transport distance from a hospital that performed at least 1 mechanical embolectomy over 2 years compared with 7% of those who lived >20 miles. As a result, the proportion of patients with stroke treated with mechanical embolectomy decreased from 0.9% for those who lived within 20 miles of a hospital that had performed at least 1 procedure over 2 years to 0.2% for >20 miles ($P<0.001$, $\chi^2$ test). A similar trend was also observed when considering only high-volume centers (1.2% within 20 miles versus 0.4% >20 miles; $P<0.001$; $\chi^2$ test).

## Discussion

Most patients with stroke in California lived within reasonable ground transport distances to hospitals that performed at least 1 mechanical embolectomy procedure from 2009 to 2010. However, the proportion of patients with stroke treated

with mechanical embolectomy decreased sharply for patients who lived beyond a 20-mile ground transport distance from these hospitals. Mechanical embolectomy was used in 0.7% of acute ischemic stroke hospitalizations in California from 2009 to 2010 and more than half of the procedures were done at hospitals that performed ≥10 procedures per year.

Previous reports have suggested that most of the US population had access to endovascular-capable hospitals within ≈2-hour ground transport time using survey data on the practice locations of active neurointerventionalists across United States.[13,14] However, our present analysis shows that if only high-volume centers are considered, this access decreases considerably (39% for 1-hour ground transport distance and 70% for a 2-hour ground transport distance), although >95% of patients with stroke still lived within 4-hour transport distance to a high-volume center. However, most patients with stroke treated with mechanical embolectomy lived within a 1-hour transport distance to the treating hospital and few lived >20 miles of a hospital that had performed this intervention at least once during the 2-year period. This may reflect the challenges of being able to quickly transfer patients from outlying areas for mechanical embolectomy; only 20% of patients treated with mechanical embolectomy were transferred from other hospitals in present analysis.

A recent retrospective study reported that interhospital transfer delays are associated with worse outcomes for patients receiving endovascular stroke interventions.[23] Specifically, the delay for patients transferred from >60 miles approached 1 hour, and this delay was associated with worse outcomes. Given the results of MR CLEAN and as additional data evaluating the efficacy of specialized and time-sensitive interventions become available, it may become particularly relevant to improve access to these treatments for patients who live far away from specialized centers that are able to deliver these interventions. A regional acute stroke system—similar to those already implemented for cardiac care and trauma and potentially including a robust air transport network—may be necessary to minimize the time delay during transfer of the patients with stroke.

Our study did not find a clear relationship between the volume of mechanical embolectomy cases performed annually and patient outcomes. However, our study has limited ability to evaluate for such volume-outcome relationships because there are likely to be other important differences in patients selected for mechanical embolectomy at each center (eg, time to reperfusion, stroke severity, infarct volume and location, or hemorrhagic transformation) that could influence outcomes but were not available to be included in our analysis. Nevertheless, present thresholds for the procedural volumes that may be required to maintain technical proficiency for this and other acute stroke interventions, as have been put forward by professional organizations, are largely based on expert opinion and would benefit from additional data moving forward, particularly given how few centers or practitioners in California would meet these thresholds.

In the United States, the proportion of hospitals that performed mechanical embolectomy for patients with acute ischemic stroke to hospitals treating patients with acute stroke was 5.6% nationwide and 7.6% in the West.[10] In our study, of 360 acute care hospitals in California, 53 hospitals (15%) performed at least 1 mechanical embolectomy during the 2-year

**Table 2. Characteristics of California Hospitals That Performed <10 Mechanical Embolectomies for Acute Stroke per Year Compared With Those That Performed ≥10 per Year, 2009 to 2010**

| | Low-Volume Hospitals (<10 per Year; n=43) | High-Volume Hospitals (≥10 per Year; n=10) | P Value |
|---|---|---|---|
| Urban/rural location | | | 0.71 |
| Metropolitan | 41 (95.4) | 10 (100) | |
| ≥1 million population | 34 (79.1) | 10 (100) | |
| 250 000 to 1 million | 6 (14.0) | 0 (0) | |
| <250 000 population | 1 (2.3) | 0 (0) | |
| Non-metropolitan | 2 (4.7) | 0 (0) | |
| Hospital size | | | 0.81 |
| Small (1–100 beds) | 2 (4.7) | 0 | |
| Medium (101–300 beds) | 29 (67.4) | 6 (60.0) | |
| Large (>300 beds) | 12 (27.9) | 4 (40.0) | |
| Trauma center designation | 17 (39.5) | 7 (70.0) | 0.16 |
| Teaching hospital status | 9 (20.9) | 4 (40.0) | 0.24 |
| Hospital ownership | | | |
| Non-profit | 38 (88.4) | 8 (80.0) | 0.48 |
| For profit | 5 (11.6) | 2 (20.0) | |
| No. of patients and procedures | | | |
| Annual volume of patients with acute ischemic stroke | 265±113 | 301±89 | 0.35 |
| Proportion of patients who received mechanical embolectomy, % (interquartile range) | 0.9 (0.3–2.3) | 6.2 (5.1–7.9) | <0.001 |
| Annual thrombolytic case volume | 17±11 | 33±10 | <0.001 |
| Annual cerebral angiogram volume | 124 (51–200) | 144 (124–199) | 0.23 |
| Annual coil embolization volume | 10 (1–25) | 28 (17–72) | 0.02 |
| In-hospital mortality for mechanical embolectomy cases, % | 20 (0–44) | 23 (17–30) | 0.82 |

Data are No. (%), mean ± SD, or median (interquartile range).

period. Because the proportion of patients who received mechanical embolectomy was similar to nationwide estimates (0.6% in 2009),[12] a greater proportion of hospitals may offer mechanical embolectomy in California than in other regions. Moreover, the proportion of high-volume hospitals (≥10 procedures per year) was lower (18.8%) in California than nationwide (26.4%),[10] which may reflect greater number of lower-volume centers offering treatment and relatively fewer transfers for mechanical embolectomy in California, although there is no clear evidence-based threshold for the number of procedures required to maintain technical proficiency for acute endovascular stroke treatment.

A weekend effect for performing mechanical embolectomy was only found for low-volume hospitals in the present analysis, which might reflect a limitation in 24/7 availability because of staffing. As regional plans to deliver time-sensitive and specialized stroke treatments become more systematized, there will continue to be a tension between developing more centralized systems with a limited geographic reach and more distributed access at a higher number of lower-volume centers.

**Table 3. Number and Percentage of Patients With Acute Stroke (n=84 063) and Mechanical Embolectomy (n=603) Who Live Within Each Various Ground Transport Distances From California Hospitals That Offer Mechanical Embolectomy, 2009 to 2010**

| | For All Centers Performing Mechanical Embolectomy | | For High-Volume Centers (≥10 per Year) Only | |
|---|---|---|---|---|
| | Patients With Acute Ischemic Stroke | Patients With Mechanical Embolectomy | Patients With Acute Ischemic Stroke | Patients With Mechanical Embolectomy |
| 1 h (20 miles) | 62 918 (74.8) | 559 (92.7) | 32 529 (38.7) | 388 (64.3) |
| 2 h (65 miles) | 79 230 (94.3) | 594 (98.5) | 58 861 (70.0) | 542 (89.9) |
| 3 h (115 miles) | 83 107 (98.9) | 602 (99.8) | 71 814 (85.4) | 572 (94.9) |
| 4 h (165 miles) | 83 409 (99.2) | 602 (99.8) | 79 920 (95.1) | 597 (99.0) |
| 5 h (200 miles) | 83 857 (99.8) | 602 (99.8) | 82 304 (97.9) | 602 (99.8) |

Data are No. (%).
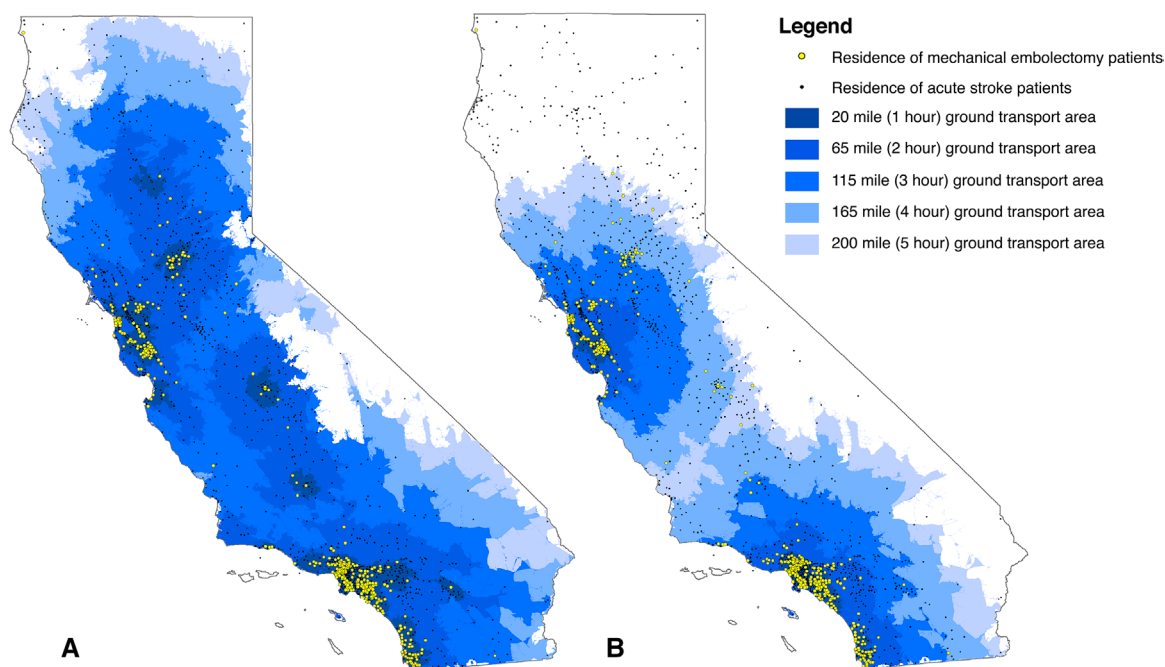
**Figure 2.** Service area maps by ground transport distance thresholds to (**A**) any hospital that performed mechanical embolectomy hospitals in 2009 to 2010 and (**B**) to only hospitals that performed ≥10 mechanical embolectomy procedures per year in 2009 to 2010.

Finally, although unadjusted mortality rates were higher among patients with embolectomy compared with other patients with stroke, we suspect that this may reflect that patients referred for embolectomy were more likely to have a large-vessel occlusion and more severe strokes, although the level of clinical detail to directly assess this possibility was not available to us from this data source.

Our study has several limitations. First, although previous studies have used ICD-9 CM code 39.74 for identifying endovascular procedures for acute stroke, the sensitivity and specificity of this approach have not been validated.[10,12,16] However, we used data from 2009 to 2010, well after the introduction of this code in 2007, to mitigate the impact of secular changes in coding practices over time. Although endovascular treatment for acute ischemic stroke usually includes not only mechanical embolectomy but also intra-arterial thrombolysis, we could not specifically identify intra-arterial thrombolysis cases because ICD codes do not reliably distinguish between intravenous thrombolysis and intra-arterial thrombolysis.[17] Second, because the calculated ground transport time was based on only the length of the street-level routes, the actual transport time might be different because of traffic conditions or elevation of the roads, and the potential for air transport to expedite care was not taken into account. Third, the transport distance from the patient's residence to hospitals used ZIP code centroids because the exact address of each patient was not available, and the acute stroke may have occurred at work or at places other than the patient's residence. Finally, although there is a strong association between faster onset-to-treatment times and better outcomes for intravenous thrombolysis,[24] there may be complex effects of collaterals on time and outcome for the type of large-vessel strokes that may be amenable to mechanical embolectomy in particular. Therefore, a focus on time alone may not be sufficiently nuanced to inform the regional organization of stroke care moving forward. We also did not study cross-border coverage in this study because we included only patients with California ZIP codes.

In conclusion, most patients with stroke in California lived within reasonable ground transport distances from hospitals that performed ≥1 mechanical embolectomy from 2009 to 2010. Although only high-volume stroke centers are considered, the accessibility to these centers sharply decreased. Patients who lived within 20 miles in one of these centers were more likely to receive mechanical embolectomy. A more systematized approach to regional stroke care may be required to shorten the time delay from symptom onset to treatment for future acute stroke interventions.

## Disclosures

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