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Endovascular Thrombectomy after Large-Vessel Ischemic Stroke: Utilization, Outcomes, and Readmissions across the United States

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Conflicts of interest are listed at the end of this article.

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Background: Following publication of trials demonstrating the efficacy of thrombectomy, societal guidelines were revised in 2015 to recommend this procedure for large-vessel stroke.

Purpose: To evaluate real-world thrombectomy rates, adverse events, outcomes, and readmissions across the United States in the 2 years after large-scale adoption of thrombectomy for acute stroke.

Materials and Methods: In this retrospective study, the authors queried the National Inpatient Sample and Nationwide Readmissions Database for patients undergoing thrombectomy between 2016 and 2017. Thrombectomy rates were compared by using the χ^2 test. Adjusted risk ratios (aRRs) were obtained for factors affecting routine discharge, mortality, and readmission by using multivariable Poisson regression with clustering at the hospital level.

Results: There were 290 460 admissions (mean age, 70.5 years ± 14.2 [standard deviation]; 148 620 women) for internal carotid or middle cerebral artery stroke; 30 835 (10.6%) of these patients underwent thrombectomy. Thrombectomy rates were lower in patients aged 90 years or older (1815 of 24 090 patients, 7.5%), Black patients (4280 of 43 365 patients, 9.9%), patients with the lowest income (8520 of 85 905 patients, 9.9%), and those treated in West South Central division hospitals (2695 of 34 355 patients, 7.8%) ($P < .001$ for all). The inpatient mortality rate was 12.1% (3740 of 30 835 patients), and 19.1% of patients (5900 of 30 835) were discharged to home. In adjusted analyses, routine discharge was less likely in patients aged 90 years or older (aRR: 0.12; 95% CI: 0.09, 0.16; $P < .001$) and octogenarians (aRR: 0.37; 95% CI: 0.33, 0.41; $P < .001$). Patients aged 90 years or older (aRR: 1.78; 95% CI: 1.48, 2.14; $P < .001$), octogenarians (aRR: 1.76; 95% CI: 1.51, 2.06; $P < .001$), Asians and/or Pacific Islanders (aRR: 1.21; 95% CI: 1.06, 1.39; $P = .005$), and those treated in teaching (aRR: 1.20; 95% CI: 1.07, 1.34; $P = .001$) or West South Central division (aRR: 1.35; 95% CI: 1.14, 1.60; $P < .001$) hospitals had a higher risk of death. Following discharge, 18.9% of patients (3449 of 18 274) were readmitted within 90 days.

Conclusion: Rates and outcomes of thrombectomy are affected by demographic, socioeconomic, and hospital-related factors. Fewer than one-fifth of patients are discharged to home, nearly one-fifth are readmitted within 90 days, and mortality and outcomes may be less favorable than in published trials.

Online supplemental material is available for this article.

Each year approximately 795 000 people experience a new or recurrent stroke, the fifth leading cause of death and the most common source of permanent disability in the United States. Ischemic stroke is responsible for 87% of all strokes (1). The first endovascular clot retrieval device was approved by the U.S. Food and Drug Administration in 2004, and endovascular treatment of patients with stroke evolved substantially during the next decade (2). In 2015, investigators in five multicenter randomized controlled clinical trials (3–7) reported a marked benefit for endovascular thrombectomy in the management of acute ischemic stroke (AIS) secondary to large-vessel occlusion. Shortly thereafter, the American Heart Association–American Stroke Association guidelines for management of AIS were revised to recommend endovascular thrombectomy in selected patients with proximal anterior circulation occlusion who presented within 6 hours from the time last known to be well (8). The impact of this landmark change in acute stroke management remains less studied at the population level. We therefore used the most recently available (2016–2017) National Inpatient Sample (NIS) and Nationwide Readmissions Database (NRD) data sets to examine real-world thrombectomy rates, adverse events, inpatient outcomes, and readmissions across the United States in the 2 years following large-scale adoption of thrombectomy in AIS.

Materials and Methods

Databases

The NIS database and NRD contain all-payer data on hospital inpatient stays from states participating in the Healthcare Cost and Utilization Project (HCUP) sponsored by the Agency for Healthcare Research and Quality

Abbreviations

AIS = acute ischemic stroke, APR-DRG = All Patient Refined Diagnosis Related Groups, aRR= adjusted risk ratio, ECI = Elixhauser comorbidity index, HCUP = Healthcare Cost and Utilization Project, HERMES = Highly Effective Reperfusion Evaluated in Multiple Endovascular Stroke Trials, ICA = internal carotid artery, MCA = middle cerebral artery, NIS = National Inpatient Sample, NRD = Nationwide Readmissions Database

Summary

Use of thrombectomy increased in the United States after it became standard treatment for ischemic stroke in 2015, yet disparities in rates and outcomes exist and adverse events and readmissions are not uncommon.

Key Results

- Among 290 460 patients admitted for internal carotid or middle cerebral artery stroke, the thrombectomy rate for carotid or middle cerebral artery ischemic stroke in 2016–2017 was 10.6%.
- Thrombectomy rates were lower in patients aged 90 years or older (7.5%), Black patients (9.9%), patients with the lowest income (9.9%), and those treated in West South Central division hospitals (7.8%) ($P < .001$ for all).
- The inpatient mortality rate was 12%; patients aged 90 years or older ($P < .001$), octogenarians ($P < .001$), Asians and/or Pacific Islanders ($P = .005$), and those treated in West South Central division hospitals ($P < .001$) had a higher risk of death.

and the U.S. Department of Health and Human Services. In its current format, the NIS is a 20% stratified sample of discharge records from all hospitals participating in the HCUP and includes more than 7 million inpatient stays each year, consisting of discharge data from 4584 hospitals in 48 states and the District of Columbia, covering more than 97% of the U.S. population in 2017 (9).

The 2017 NRD contains all discharges from 28 states, which are geographically dispersed and account for 60% of the total U.S. resident population and 58.2% of all U.S. hospitalizations (10).

For this retrospective study, annual NIS and NRD data sets from 2016 and 2017 were obtained from the HCUP Central Distributor (Rockville, Md). To produce national estimates, discharge weights provided by the Agency for Healthcare Research and Quality website were used (11). HCUP databases lack unique patient identifiers and therefore are exempt from institutional review board review and informed consent under the Health Insurance Portability and Accountability Act (12).

Patient Selection

International Classification of Diseases, 10th Revision, Clinical Modification codes were used to define medical diagnoses and inpatient procedures (Table E1 [online]), as well as adverse events (Table E2 [online]). Analysis was restricted to adult patients with internal carotid artery (ICA) or middle cerebral artery (MCA) stroke (Appendix E1 [online]), corresponding to American Heart Association–American Stroke Association guidelines for thrombectomy eligibility (8). The total number of comorbidities was analyzed by using the Elixhauser comorbidity index (ECI) score (minimum = 0, maximum = 29) (13). The All Patient Refined Diagnosis Related Groups (APR-DRG) classification system was used to classify the severity of illness and risk of mortality.

Definitions and End Point Variables

Thrombectomy was defined as mechanical thrombectomy of the anterior cerebral circulation (ie, intracranial artery, common carotid artery, and ICA), and stroke was defined as cerebral infarction due to thrombosis, embolism, or unspecific occlusion or stenosis of vessels. Measured outcomes included adverse events during hospitalization, discharge disposition, and 30- and 90-day readmissions after discharge. Discharge disposition was classified as routine discharge (typically to home), nonroutine discharge (discharge to short-term hospital, inpatient rehabilitation facility, intermediate care facility, skilled nursing facility, or hospice), or death (14). Reasons for readmissions were grouped by using the HCUP single-level Clinical Classifications Software (versions 2016 and 2017), a classification scheme that enables individual International Classification of Diseases codes to be classified according to clinical similarities. Diagnoses for readmission with frequencies lower than 2% were grouped as "other." Hospital geographic divisions were defined as per the NIS (9).

Comparison of NIS Cohort and Clinical Trials

To assess the differences between real-world NIS data and the five multicenter randomized controlled clinical trials, we compared patient characteristics of the NIS data with data from the published patient-level meta-analysis of the five trials (the Highly Effective Reperfusion Evaluated in Multiple Endovascular Stroke Trials [HERMES] collaboration) (15).

Statistical Analysis

In addition to frequency and percentage, age-standardized incidence rates of ICA and/or MCA stroke and mechanical thrombectomy were estimated by using U.S. census data from 2016 and 2017. These estimates were standardized to the census population of 2010 (16).

Student t and χ^2 tests were used in between-group comparisons for continuous and categorical variables, respectively. For post hoc comparisons, cellwise residual analysis with Bonferroni correction was performed. Regression analysis was used to determine factors associated with undergoing thrombectomy as well as postthrombectomy outcomes, including in-hospital mortality, routine discharge, and 30- and 90-day readmissions. Modified Poisson regression was used instead of logistic regression to enable estimation of risk ratios with high precision for binary data (17). Poisson regression was performed by using generalized estimating equations and clustering at the hospital level on patient and hospital characteristics, and adjusted risk ratios (aRRs) were obtained. For analysis of factors associated with outcome after thrombectomy and with readmission after thrombectomy, all available factors were first entered into univariable analysis, and only those with $P < .15$ were subsequently entered into multivariable regression in order to then obtain aRRs for outcome and for readmission after thrombectomy. For analysis of factors associated with performance of thrombectomy, all preprocedural factors were entered directly into multivariable analysis without any prior selection to permit derivation of risk ratios adjusted for all possible covariates, owing to concern that we could not safely eliminate any variable as potentially extraneous to this analysis.

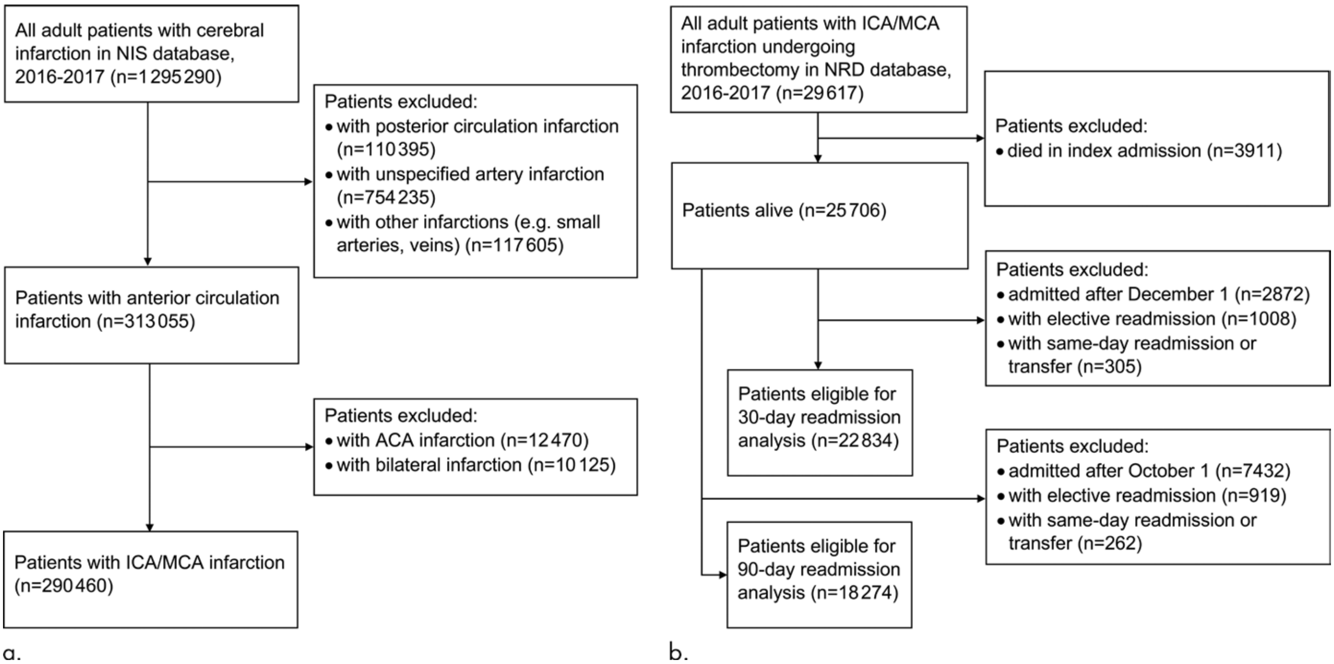

Figure 1: Flowcharts of patients selected for analysis from **(a)** National Inpatient Sample (NIS) database and **(b)** Nationwide Readmissions Database (NRD). ACA = anterior cerebral artery, ICA = internal carotid artery, MCA = middle cerebral artery.

Because the HCUP Data Use Agreement prohibits the reporting of 10 or fewer observations, details were suppressed in results tables as appropriate. Statistical analysis was performed with software (SPSS for Windows, version 26; IBM). $P < .05$ was considered to indicate a statistically significant difference.

Results

Impact across Patient Demographics, Hospital Characteristics, and Divisions

There were 1 295 290 admissions of adult patients for ischemic stroke during 2 years (2016–2017), of whom 36 255 (2.8%) underwent thrombectomy. Of all ischemic strokes, 290 460 (22.4%) were due to ICA and/or MCA infarction (mean patient age ± standard deviation, 70.5 years ± 14.2; 148 620 women), with 30 835 patients (10.6%; 95% CI: 10.5, 10.7) undergoing thrombectomy. Patients with posterior circulation (n = 110 395), unspecified artery (n = 754 235), anterior cerebral artery (n = 12 470), and bilateral (n = 10 125) or other infarctions such as small arteries or veins (n = 117 605) were excluded from the study (Fig 1).

Age-adjusted incidence rates of ICA and/or MCA infarction and thrombectomy were 51.4 and 5.0 persons per 100 000 adults, respectively, in 2016, and 56.4 and 6.4 persons per 100 000 adults, respectively, in 2017. However, thrombectomy rates were not uniform and were affected by patient (Table 1) and hospital (Table 2) characteristics. Thrombectomy rates were lower in patients aged 90 years or older (1815 of 24 090 patients [7.5%], $P < .001$), Black patients (4280 of 43 365 patients [9.9%], $P < .001$) and Native Americans (80 of 1325 patients [6.0%], $P < .001$), patients with the lowest quartile household income (8520 of 85 905 patients [9.9%], $P < .001$), patients on Medicaid (2740 of 27 290 patients [10.0%], $P < .001$), and those admitted electively (1115 of 14 340 patients [7.8%], $P < .001$). Thrombectomy rates were higher in women (16 140 of 148 620 patients [10.9%], $P < .001$), patients younger than 50 years (3205 of 23 735 patients [13.5%], $P < .001$), and those with private insurance (6690 of 53 710 patients [12.5%], $P < .001$) or the highest quartile household income (6665 of 56 190 patients [11.9%], $P < .001$). Similarly, thrombectomy rates were lower in small (1240 of 33 405 patients [3.7%], $P < .001$) and nonteaching (3205 of 65 540 patients [4.9%], $P < .001$) hospitals and higher in government-owned (4385 of 34 340 patients [12.8%], $P < .001$) hospitals. Geographic variations were also noted, with the highest overall number of strokes (62 990 [21.7%]) and thrombectomies (6995 [22.7%]) occurring in the South Atlantic division, and the highest and lowest rates of thrombectomy occurring in the Pacific (4630 of 35 965 [12.9%], $P < .001$) and West South Central (2695 of 34 355 [7.8%], $P < .001$) division hospitals, respectively (Fig 2).

Multivariable analysis, adjusting for all patient-related factors (age, sex, income, health insurance, comorbidities, and severity) and hospital-related factors (size, ownership, division, and teaching status), revealed independent differences in likelihood of undergoing thrombectomy across multiple factors (Fig 3). Patients aged 90 years or older (aRR: 0.67; 95% CI: 0.63, 0.71; $P < .001$), Black patients (aRR: 0.88; 95% CI: 0.85, 0.91; $P < .001$), and those admitted electively (aRR: 0.68; 95% CI: 0.64, 0.72; $P < .001$) had the lowest likelihood of undergoing thrombectomy (Fig 3). Native Americans also had a lower likelihood of undergoing thrombectomy (aRR: 0.73; 95% CI: 0.60, 0.90; P = .003), but represented only 0.3% of the population (80 of 30 835 patients). Women (aRR: 1.10; 95% CI: 1.08, 1.12; $P < .001$), those with the highest quartile household income (aRR: 1.29; 95% CI: 1.25, 1.34; $P < .001$) or private (aRR:

Table 1: Patient Characteristics for Internal Carotid Artery and Middle Cerebral Artery Infarction Hospitalizations and Thrombectomy

Factor	Patients with Stroke (n = 290 460)	Patients with Events after Thrombectomy (n = 30 835)	Event Rate (%)*	P Value
Age (y)				<.001
Mean†	70.5 ± 14.2	69.2 ± 14.7	…	
<50	23 735 (8.2)	3205 (10.4)	13.5 (13.0, 14.0)	
50–64	70 195 (24.2)	7430 (24.1)	10.6 (10.4, 10.8)	
65–79	105 580 (36.3)	11 190 (36.3)	10.6 (10.4, 10.8)	
80–89	66 860 (23.0)	7195 (23.3)	10.8 (10.5, 11.0)	
≥90	24 090 (8.3)	1815 (5.9)	7.5 (7.2, 7.9)	
Sex				<.001
M	141 765 (48.8)	14 690 (47.6)	10.4 (10.2, 10.5)	
F	148 620 (51.2)	16 140 (52.3)	10.9 (10.7, 11.0)	
Race				<.001
White	198 460 (68.3)	20 700 (67.1)	10.4 (10.3, 10.6)	
Black	43 365 (14.9)	4280 (13.9)	9.9 (9.6, 10.2)	
Hispanic	20 235 (7.0)	2270 (7.4)	11.2 (10.8, 11.7)	
Asian and/or Pacific Islander	8025 (2.8)	940 (3.0)	11.7 (11.0, 12.5)	
Native American	1325 (0.5)	80 (0.3)	6.0 (4.8, 7.5)	
Other	7745 (2.7)	1005 (3.3)	13.0 (12.2, 13.8)	
Household income‡				<.001
1st quartile	85 905 (29.6)	8520 (27.6)	9.9 (9.7, 10.1)	
2nd quartile	73 780 (25.4)	7680 (24.9)	10.4 (10.2, 10.6)	
3rd quartile	69 410 (23.9)	7370 (23.9)	10.6 (10.4, 10.9)	
4th quartile	56 190 (19.3)	6665 (21.6)	11.9 (11.6, 12.2)	
Health insurance				<.001
Medicare	192 140 (66.2)	19 505 (63.3)	10.2 (10.0, 10.3)	
Medicaid	27 290 (9.4)	2740 (8.9)	10.0 (9.7, 10.4)	
Private	53 710 (18.5)	6690 (21.7)	12.5 (12.2, 12.8)	
Self-pay	9930 (3.4)	1135 (3.7)	11.4 (10.8, 12.1)	
Other	6375 (2.2)	730 (2.4)	11.5 (10.6, 12.3)	
Elective admission				<.001
No	275 530 (94.9)	29 665 (96.2)	10.8 (10.6, 10.9)	
Yes	14 340 (4.9)	1115 (3.6)	7.8 (7.3, 8.2)	
APR-DRG severity				
Minor to moderate	98 070 (33.8)	405 (1.3)	0.4 (0.4, 0.5)	
Major	120 210 (41.4)	18 965 (61.5)	15.8 (15.6, 16.0)	
Extreme	72 180 (24.9)	11 465 (37.2)	15.9 (15.6, 16.2)	
APR-DRG mortality risk				<.001
Minor to moderate	143 635 (49.5)	10 445 (33.9)	7.3 (7.1, 7.4)	
Major	69 420 (23.9)	8060 (26.1)	11.6 (11.4, 11.9)	
Extreme	77 405 (26.6)	12 330 (40.0)	15.9 (15.7, 16.2)	
ECI score†	3.4 ± 1.9	3.9 ± 1.8	NA	…

Note.—Data are from the National Inpatient Sample, 2016–2017. Unless otherwise specified, data are numbers of patients, with percentages in parentheses. APR-DRG = All Patient Refined Diagnosis Related Groups, ECI = Elixhauser comorbidity index, NA = not applicable.

* Event rate is relative frequency of treatment within each category in each variable. Numbers in parentheses are 95% CIs.

† Data are means ± standard deviations.

‡ Median household income for patient's zip code, from lowest (first) to highest (fourth) quartile.

1.25; 95% CI: 1.21, 1.28; $P < .001$) or self-pay (aRR: 1.25; 95% CI: 1.18, 1.33; $P < .001$) insurance, or those admitted to a large (aRR: 3.08; 95% CI: 2.91, 3.26; $P < .001$), teaching (aRR: 2.36; 95% CI: 2.27, 2.45; $P < .001$), private investor-owned (aRR: 1.25, 95% CI: 1.21, 1.28; $P < .001$), East South Central division (aRR: 1.31; 95% CI: 1.23, 1.39, $P < 0.001$), or Pacific division (aRR: 1.30; 95% CI: 1.22, 1.37; $P < .001$) hospital had the highest likelihood of undergoing thrombectomy (Fig 3).

Inpatient Adverse Events and Clinical Outcomes at Discharge

In the 30 835 patients with AIS who underwent thrombectomy, the two most common adverse events were acute respiratory failure (7240 patients, 23.5%) and nontraumatic cerebral hem-

Table 2: Hospital Characteristics for Internal Carotid Artery and Middle Cerebral Artery Infarction Hospitalizations and Thrombectomy

Factor	Patients with Stroke (*n* = 290 460)	Patients with Events after Thrombectomy (*n* = 30 835)	Event Rate (%)*	*P* Value
Hospital bed size				<.001
Small	33 405 (11.5)	1240 (4.0)	3.7 (3.5, 3.9)	
Medium	74 500 (25.6)	5720 (18.6)	7.7 (7.5, 7.9)	
Large	182 555 (62.9)	23 875 (77.4)	13.1 (12.9, 13.3)	
Hospital ownership				<.001
Government	34 340 (11.8)	4385 (14.2)	12.8 (12.4, 13.2)	
Private, not for profit	225 130 (77.5)	23 450 (76.1)	10.4 (10.3, 10.6)	
Private, investor owned	30 990 (10.7)	3000 (9.7)	9.7 (9.4, 10.0)	
Hospital census division				<.001
New England	13 550 (4.7)	1330 (4.3)	9.8 (9.3, 10.4)	
Middle Atlantic	39 660 (13.7)	4150 (13.5)	10.5 (10.2, 10.8)	
East North Central	44 180 (15.2)	4300 (13.9)	9.7 (9.4, 10.0)	
West North Central	19 215 (6.6)	2210 (7.2)	11.5 (11.0, 12.0)	
South Atlantic	62 990 (21.7)	6995 (22.7)	11.1 (10.9, 11.4)	
East South Central	23 520 (8.1)	2760 (9.0)	11.7 (11.3, 12.2)	
West South Central	34 355 (11.8)	2695 (8.7)	7.8 (7.6, 8.1)	
Mountain	17 025 (5.9)	1765 (5.7)	10.4 (9.9, 10.9)	
Pacific	35 965 (12.4)	4630 (15.0)	12.9 (12.5, 13.3)	
Hospital teaching status				<.001
Nonteaching	65 540 (22.6)	3205 (10.4)	4.9 (4.7, 5.1)	
Teaching	224 920 (77.4)	27 630 (89.6)	12.3 (12.1, 12.4)	

Note.—Data are from the National Inpatient Sample, 2016–2017. Unless otherwise specified, data are numbers of events, with percentages in parentheses.

* Event rate is relative frequency of treatment within each category in each variable. Numbers in parentheses are 95% CIs.

orrhage (7035 patients, 22.8%) (Fig 4). Approximately 10.8% of patients (3325 of 30 835) required percutaneous endoscopic gastrostomy, whereas only 2.6% (800 of 30 835) required tracheostomy. Acute kidney failure was seen in 14.4% of patients (4445 of 30 835), but only 1.4% of patients (435 of 30 835) required hemodialysis. In-hospital mortality for thrombectomy was 12.1% (3740 of 30 835), and 19.1% of patients (5900 of 30 835) were able to be discharged to home (Fig 4).

To determine factors associated with in-hospital mortality and routine discharge, univariable regression was performed on patient and hospital characteristics (Tables E3, E4 [online]), and factors with $P < .15$ were entered into the multivariable model. In multivariable analysis, patients aged 90 years or older had the highest risk of in-hospital mortality (aRR: 1.78; 95% CI: 1.48, 2.14; $P < .001$) and the lowest risk of routine discharge (aRR: 0.12; 95% CI: 0.09, 0.16; $P < .001$) (Fig 5) but represented less than 6% of thrombectomies (Table 1). In adjusted analyses, octogenarians, representing nearly a quarter of the thrombectomy population, had the second highest risk of in-hospital mortality (aRR: 1.76; 95% CI: 1.51, 2.06; $P < .001$) and the second lowest risk of routine discharge (aRR: 0.37; 95% CI: 0.33, 0.41; $P < .001$). Female sex (aRR: 1.11; 95% CI: 1.04, 1.18; $P = .001$), Asian and/or Pacific Islander race (aRR: 1.21; 95% CI: 1.06, 1.39; $P = .005$), and lowest quartile household income (aRR: 1.10; 95% CI: 1.00, 1.20; $P = .04$) were other risk factors for in-hospital mortality. Moreover, medium-sized (aRR: 1.33; 95% CI: 1.11, 1.60; $P = .002$), large (aRR: 1.32; 95% CI: 1.11, 1.57; $P = .002$), and teaching (aRR: 1.20; 95% CI: 1.07, 1.34; $P = .001$) hospitals had higher risks of mortality after thrombectomy than other hospitals (Fig 5).

Routine discharges were most likely to be seen in patients younger than 50 years (aRR: 8.48; 95% CI: 6.31, 11.40; $P < .001$), those with the highest quartile household income (aRR: 1.12; 95% CI: 1.04, 1.19; $P = .001$), and those with self-pay insurance (aRR: 1.82; 95% CI: 1.65, 2.01; $P < .001$). Geographic variations were also noted in mortality and routine discharge after thrombectomy (Fig 3). The West South Central division hospitals had the highest inpatient mortality risk after thrombectomy (aRR: 1.35; 95% CI: 1.14, 1.60; $P < .001$), and the Mountain division hospitals had the highest likelihood of routine discharge (aRR: 1.61; 95% CI: 1.38, 1.87; $P < .001$) (Fig 5).

Rates, Reasons, and Risks for Readmission

Of a total of 29 617 patients with AIS in the NRD who underwent thrombectomy between 2016 and 2017, 25 706 were discharged alive. Following exclusion of patients with index hospitalization occurring too late in the calendar year for 30-day readmission analysis (*n* = 2872) and those with elective readmissions (*n* = 1008) or same-day readmissions or transfers (*n* = 305), 2664 of 22 834 patients (11.7%; 95% CI: 11.2%, 12.1%) were readmitted within 30 days of their initial hospitalization (Fig 1). After similar exclusions (7432, 919, and 262 patients, respectively; Fig 1), 3449 of 18 274 patients (18.9%; 95% CI: 18.3%, 19.5%) were readmitted within 90

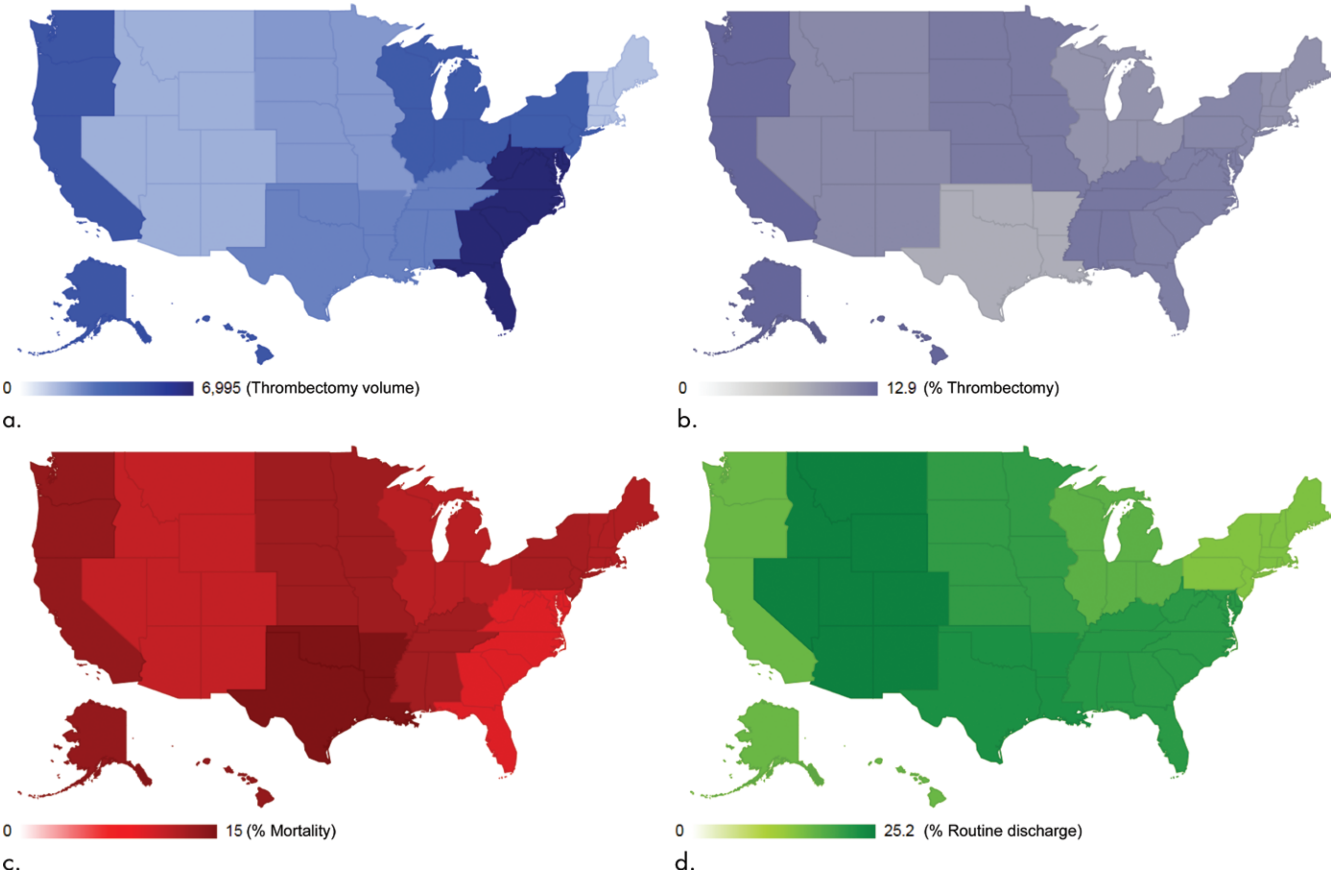

Figure 2: Diagrams show geographic distribution of anterior circulation stroke demonstrating **(a)** absolute number of thrombectomies, **(b)** proportion of stroke hospitalizations with thrombectomy, and **(c, d)** in-hospital mortality (**c**) and routine discharge (**d**) after thrombectomy (National Inpatient Sample [NIS], 2016–2017). The following states did not participate in NIS: Alabama (2016, 2017), Delaware (2016), Idaho (2016, 2017), and New Hampshire (2016, 2017).

days of their initial hospitalization. The most frequent reasons for 30- and 90-day readmissions were cardiovascular complications (576 of 2664 patients [21.6%] and 759 of 3449 patients [22.0%], respectively), followed by cerebrovascular complications (564 of 2664 patients [21.2%] and 629 of 3449 patients [18.2%]) and infections (432 of 2664 patients [16.2%] and 520 of 3449 patients [15.1%]) (Fig 6).

Cerebrovascular complications constituted a broad range of diagnoses, with recurrent ischemic stroke accounting for 17.0% (454 of 2664 patients) and 15.0% (519 of 3449 patients) of all diagnoses responsible for 30- and 90-day readmissions, respectively. Transient ischemic attacks were noted in 0.8% (21 of 2664 patients) and 0.7% (23 of 3449 patients) of these readmissions, respectively. Intracranial hemorrhage of any type was responsible for 8.2% (218 of 2664 patients) and 5.4% (186 of 3449 patients) of readmissions at 30 and 90 days, respectively, with locations including intracerebral (188 of 2664 patients [7.1%] and 156 of 3449 patients [4.5%]) and subarachnoid (40 of 2664 patients [1.5%] and 37 of 3449 patients [1.1%]) hemorrhages and subdural hematoma (13 of 2664 patients [0.5%] and 15 of 3449 patients [0.4%]). Univariable and multivariable regression analyses of individual factors affecting the risks of 30- and 90-day readmission are presented in Appendix E1 (online), Tables E5 and E6 (online), and Figure E1 (online).

Comparison of NIS Cohort to Clinical Trials

Comparison of the NIS data with data from the five thrombectomy trials showed that the NIS thrombectomy cohort was older (mean age, 69.2 years ± 14.7 vs 66.3 years ± 13.2, respectively; $P < .001$), had a higher proportion of patients aged 80 years or older (9010 of 30 835 patients [29.2%] vs 107 of 634 patients [16.9%], respectively; $P < .001$), and had a higher incidence of comorbidities than the intervention group in HERMES (Table E7 [online]). However, the NIS thrombectomy cohort had fewer ICA strokes (4903 of 30 835 [15.9%] vs 133 of 634 [21.0%], respectively; $P < .001$).

Discussion

Stroke is the fifth leading cause of death and the number one cause of permanent disability in the United States (1). After years of incremental advances (2), thrombectomy became the standard of care for anterior circulation stroke in 2015 (8) following publication of five seminal positive trials (3–7). To evaluate subsequent real-world thrombectomy rates, adverse events, outcomes, and readmissions across the United States, we examined the most recently available National Inpatient Sample Database and Nationwide Readmissions Database and found that 2.8% of all patients with acute ischemic stroke and 10.6% of patients with internal carotid artery or middle cerebral artery stroke underwent thrombectomy in

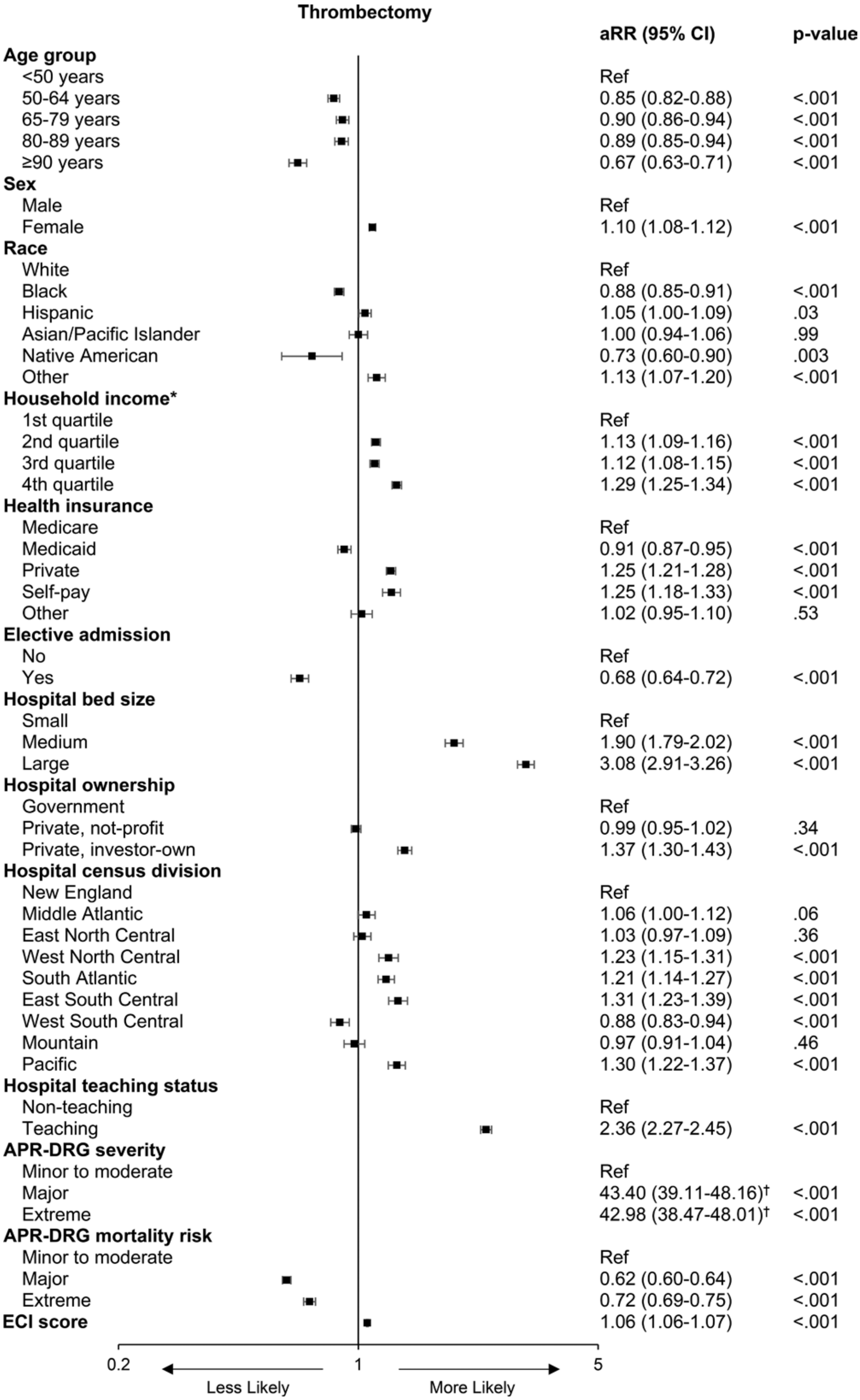

Figure 3: Plot shows factors associated with likelihood of undergoing thrombectomy in patients with stroke (National Inpatient Sample, 2016–2017). Risk ratios were adjusted for age group, sex, household income, health insurance, type of admission, hospital characteristics (size, ownership, division, and teaching status), All Patient Refined Diagnosis Related Groups (APR-DRG) severity and mortality risk, and Elixhauser comorbidity index (ECI) score. * = Median household income for patient's zip code, from lowest (first) to highest (fourth) quartile, † = value too large to represent on a graph. aRR = adjusted risk ratio, Ref = reference.

2016–2017. Thrombectomy rates were lower in patients aged 90 years or older (7.5%), Black patients (9.9%), patients with the lowest income (9.9%), patients on Medicaid (10%), and those treated in small (3.7%), nonteaching (4.9%), or West South Central division (7.8%) hospitals ($P <$ .001 for all). In-hospital adverse events were not uncommon and included acute respiratory failure (23.5%), intracranial hemorrhage (22.8%), acute kidney failure (14.4%), percutaneous endoscopic gastrostomy (10.8%), and tracheostomy (2.6%). Following thrombectomy, 12.1% of patients died in the hospital, and only 19.1% were discharged to home. Demographic, hospital-based, and geographic disparities were also noted in the likelihood of discharge to home or death after thrombectomy. Readmissions after thrombectomy were seen in 18.9% of patients within 90 days and were most commonly due to cardiovascular (22%), cerebrovascular (18.2%), or infectious (15.1%) complications.

Our results show a substantial increase in the proportion of all AIS managed with thrombectomy in the United States, from 0.1% in 2004, 0.6% in 2008, and 1.1% in 2012 (18,19) to 2.8% in 2016–2017. This increase in the use of thrombectomy did not benefit patients uniformly, suggesting that the demographic, socioeconomic, and regional disparities observed in stroke care before the thrombectomy era (20–23) remain persistent today. Similar to other investigators, we also found age to be a key factor affecting mortality, especially in patients aged 80 years and older (24,25). The rate of readmission for recurrent stroke at 90 days (2.9%) was similar to that in the Multicenter Collaboration

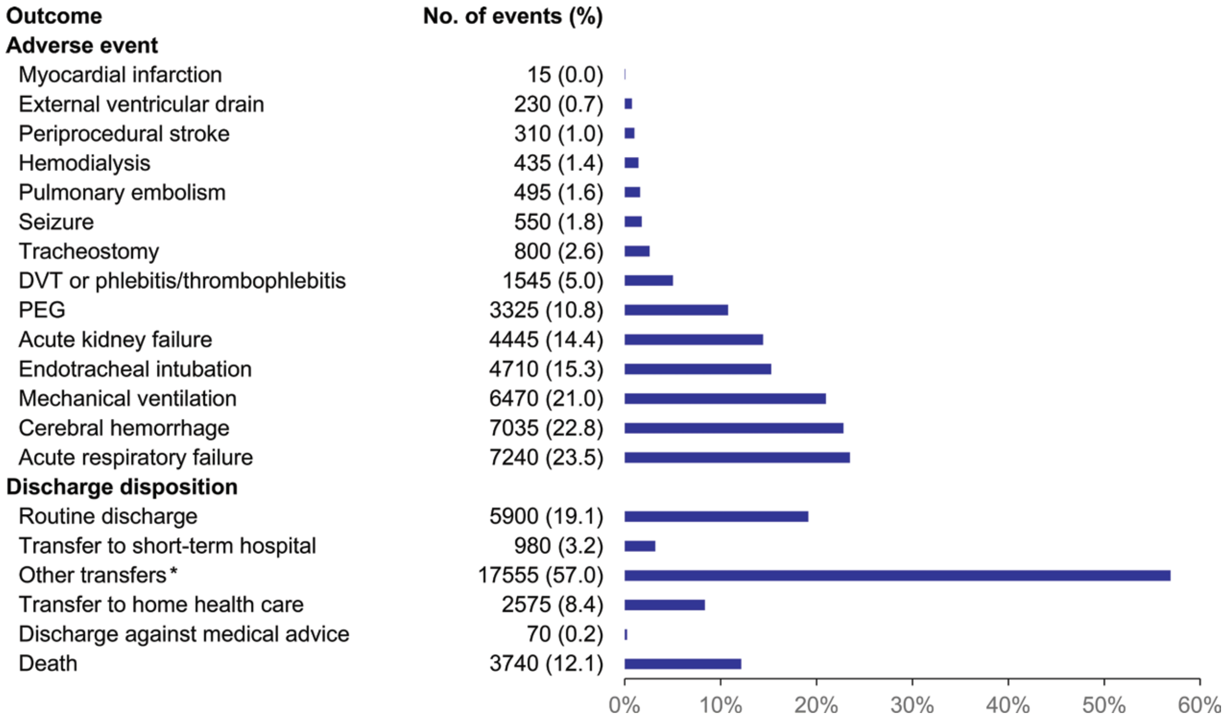

Figure 4: Chart shows adverse events and discharge dispositions in 30 835 patients with stroke who underwent thrombectomy (National Inpatient Sample, 2016–2017). * = Discharge to skilled nursing, intermediate care, and inpatient rehabilitation facility. DVT = deep vein thrombosis, PEG = percutaneous endoscopic gastrostomy.

for Endovascular Treatment of Acute Ischemic Stroke in the Netherlands, or MR CLEAN, trial (5), Endovascular Treatment for Small Core and Anterior Circulation Proximal Occlusion with Emphasis on Minimizing CT to Recanalization Times, or ESCAPE, trial (3), and Randomized Trial of Revascularization with Solitaire FR Device versus Best Medical Therapy in the Treatment of Acute Stroke Due to Anterior Circulation Large Vessel Occlusion Presenting within Eight Hours of Symptom Onset, or REVASCAT trial (6), (5.6%, 4.8%, and 3.9%, respectively), and reasons for readmission aligned with those published before thrombectomy became standard of care (26–28), including a nearly twofold increase in readmission rates in patients with stroke after percutaneous endoscopic gastrostomy placement (29).

Direct comparison of good outcome or mortality after thrombectomy in the NIS cohort with that observed in the five thrombectomy trials (3–7) or their combined meta-analysis as in the HERMES study (15) is complicated because outcomes of these trials were reported as 90-day outcomes. Nevertheless, the inpatient mortality rate in our cohort (12.1%) appears higher than the 7-day mortality rate in the REVASCAT trial (9.7%) (6) or the inpatient mortality rate in the Extending the Time for Thrombolysis in Emergency Neurological Deficits—Intra-Arterial, or EXTEND-IA, trial (5.7%) (4). Because one-third to one-half of postthrombectomy deaths at 3 months occur within the first 7 days or at discharge (6,30), the estimated 90-day mortality in our cohort (24.2%–36.3%) is higher than that in HERMES (15.3%) (15). When considering discharge disposition, 34.3% of patients discharged to rehabilitation or skilled nursing care after thrombectomy have been shown to reach a modified Rankin scale score of 0–2 at 3 months (31). Assuming a similar recovery in the NIS cohort, an estimated 38.6% of patients in the NIS would reach a modified Rankin Scale score of 0–2 at 3 months, which is lower than the 46% who achieved this outcome in the HERMES meta-analysis, albeit equivalent to or better than the 32.6% in the Multicenter Collaboration for Endovascular Treatment of Acute Ischemic Stroke in the Netherlands trial (5) (the least selective trial, with the lowest proportion of patients reaching a modified Rankin scale score of 0–2 at 3 months).

The preceding comparisons imply that real-world mortality and outcomes after thrombectomy may be less favorable than those demonstrated in the combined thrombectomy trials (15). Because neither the individual thrombectomy trials nor the HERMES meta-analysis provided data regarding patients screened but not enrolled, we could not determine if differences in outcome between NIS and HERMES can be attributed to selection bias. However, patients who underwent thrombectomy in the NIS were older, had a higher proportion aged 80 years or older, and had more comorbidities than those who underwent thrombectomy in HERMES. Previous studies have shown higher mortality and less favorable outcomes after thrombectomy in patients aged 80 years or older (24,25) and in patients with worse premorbid disability (32). However, fewer ICA strokes in the NIS thrombectomy cohort would have favored better outcomes in this group.

There were several limitations to the use of the NIS and NRD, including known caveats associated with analysis of retrospective administrative databases (28). First, a lack of 90-day functional outcomes and mortality necessitated

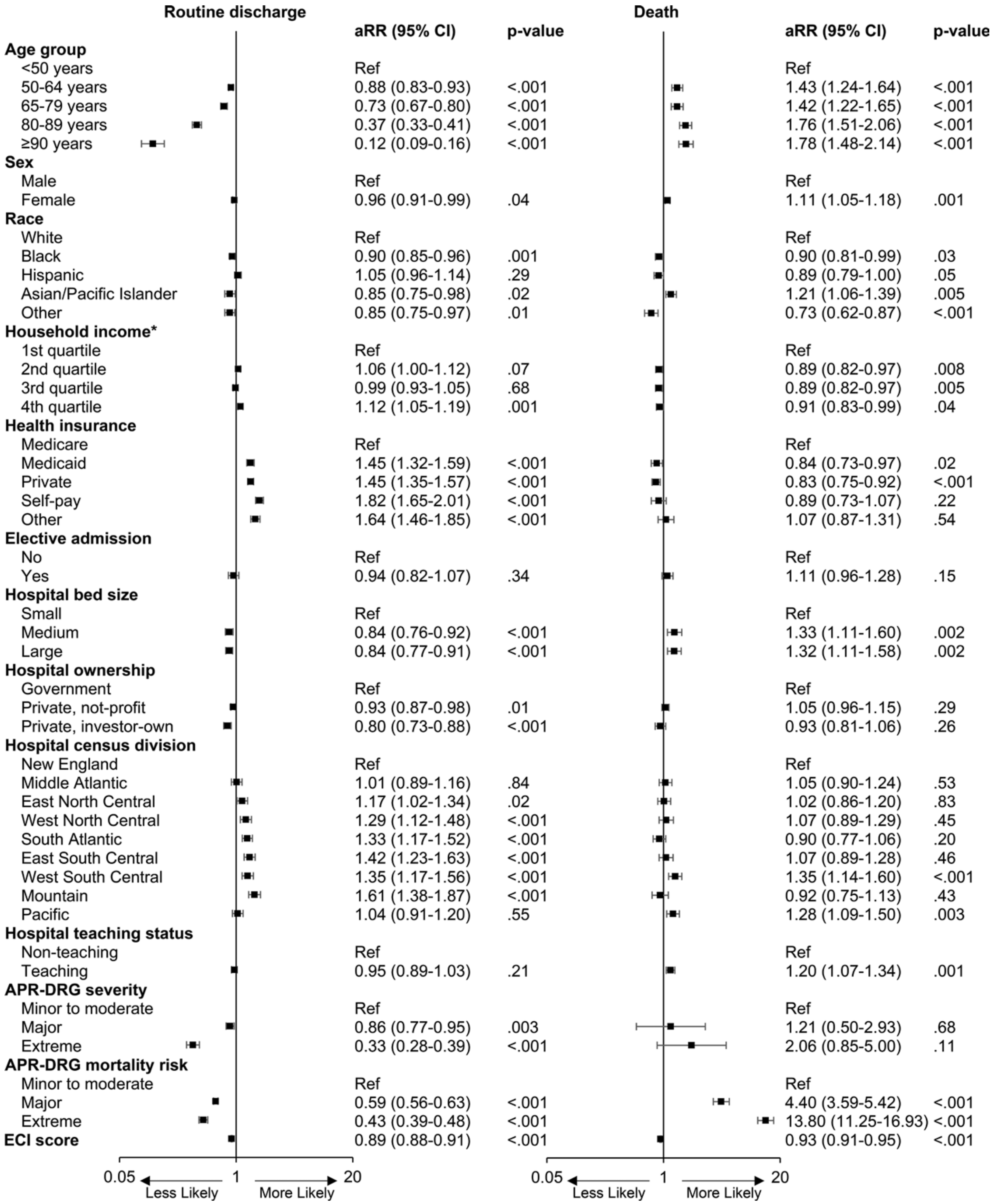

Figure 5: Plot shows factors associated with routine discharge and death in patients with stroke who underwent thrombectomy (National Inpatient Sample, 2016–2017). Risk ratios were adjusted for age group, sex, race, household income, health insurance, type of admission, hospital characteristics (size, ownership, division, and teaching status), All Patient Refined Diagnosis Related Groups (APR-DRG) severity and mortality risk, and Elixhauser comorbidity index (ECI) score. * = Median household income for patient's zip code, from lowest (first) to highest (fourth) quartile. aRR = adjusted risk ratio, Ref = reference.

estimation rather than direct comparison with the individual thrombectomy trials and HERMES meta-analysis. Second, missing National Institutes of Health Stroke Scale scores and lack of premorbid modified Rankin Scale score in the NIS did not allow us to adjust for initial stroke severity or premorbid functional status. Third, NIS definitions did not permit comparison of symptomatic intracerebral hemorrhage rates with those in prior trials or with the HERMES meta-analysis. Fourth, the NIS does not specify whether a hospital is a primary or comprehensive stroke center. Fifth, the NIS and NRD are separately maintained databases (but with potential overlap of anonymized patients); hence, analysis of factors affecting readmission after thrombectomy was independently performed and reported by using only NRD data. Finally, the NIS and NRD do not include the time at which the patient was last known to be well. However, because our data spanned only 2016–2017, prior to the extension of the thrombectomy window to 16–24 hours (33,34), our findings are likely reflective of thrombectomy within the same early time window studied in the 2015 thrombectomy trials.

In conclusion, thrombectomy for ischemic stroke increased substantially in the United States after the 2015 revision of American Heart Association–American Stroke Association guidelines. However, disparities in thrombectomy rates and outcomes exist across age, race, income, insurance, and hospital size, location, and ownership. Adverse events and readmissions are not uncommon, with fewer than one-fifth of all patients being discharged to home after thrombectomy and nearly one-fifth of all patients being readmitted within 90 days. Mortality and outcomes appear less favorable than in randomized trials, although comparison is limited by the differing populations and recording metrics. Nevertheless, as volume increases and indications for thrombectomy in acute ischemic stroke expand, careful attention to long-term outcomes and adjudicated metrics in prospective registries will be necessary to ensure that the clinical benefits seen in randomized trials are translated into real-world practice.

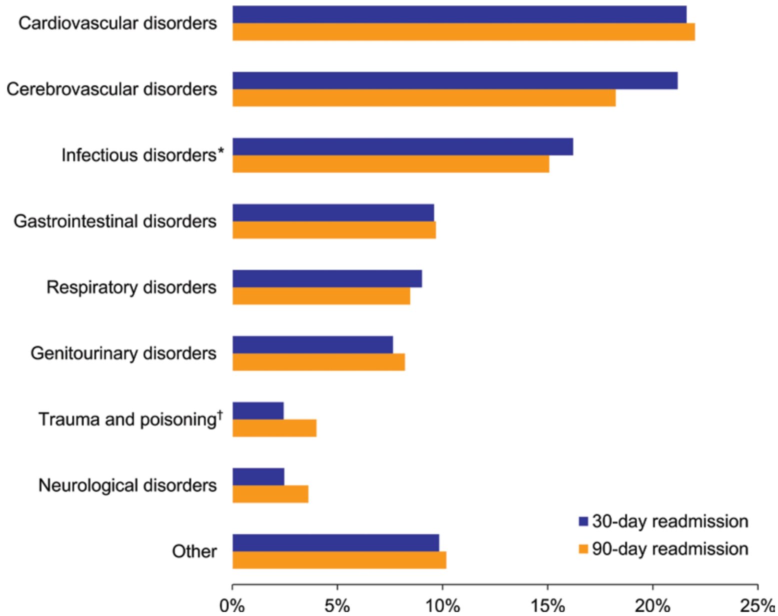

Figure 6: Chart shows grouped diagnoses of recurrent stroke in 30- and 90-day readmission of patients with stroke who underwent thrombectomy (Nationwide Readmissions Database, 2016–2017). * = Only systemic infections not otherwise categorized with other groups of disorders, † = Per Healthcare Cost and Utilization Project categorization, "poisoning" refers to accidental poisoning by unspecified narcotics, anticoagulants, and local anesthetics in this group of patients.

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