Journal of the American Heart Association

ORIGINAL RESEARCH

Patients With Acute Ischemic Stroke Who Receive Brain Magnetic Resonance Imaging Demonstrate Favorable In-Hospital Outcomes

Hwan Lee, MD*; Yifeng Yang, MD*; Baoqiong Liu, MD, PhD; Simon A. Castro, MD; Tiantian Shi, MD

BACKGROUND: Use of inpatient brain magnetic resonance imaging (MRI) in patients with acute ischemic stroke is highly institution dependent and has been associated with increased length and cost of hospital stay. We examined whether inpatient brain MRI in patients with acute ischemic stroke is associated with improved clinical outcomes to justify its resource requirements.

METHODS AND RESULTS: The National Inpatient Sample database was queried retrospectively to find 94 003 patients who were admitted for acute ischemic stroke and then received inpatient brain MRI between 2012 and 2014. Multivariable regression analysis was performed with respect to a control group to assess for differences in the rates of inpatient mortality and complications, as well as the length and cost of hospital stay based on brain MRI use. Inpatient brain MRI was independently associated with lower rates of inpatient mortality (1.67% versus 3.09%; adjusted odds ratio [OR], 0.60; 95% CI, 0.53–0.68; $P<0.001$), gastrostomy (2.28% versus 2.89%; adjusted OR, 0.82; 95% CI, 0.73–0.93; $P<0.001$), and mechanical ventilation (1.97% versus 2.82%; adjusted OR, 0.68; 95% CI, 0.60–0.77; $P<0.001$). Brain MRI was independently associated with ≈0.32 days (8%) and $1131 (11%) increase in the total length ($P<0.001$) and cost ($P<0.001$) of hospital stay, respectively.

CONCLUSIONS: Inpatient brain MRI in patients with acute ischemic stroke is associated with substantial decrease in the rates of inpatient mortality and complications, at the expense of marginally increased length and cost of hospitalization.

Key Words: ischemic stroke ■ magnetic resonance imaging ■ outcomes research

Acute ischemic stroke (AIS) comprises 87% of ≈800 000 stroke cases in the United States every year,[1] and neuroimaging is an essential component in evaluation of AIS. Although computed tomography (CT) is currently the primary imaging modality for AIS, magnetic resonance imaging (MRI) is an alternative with strong performance profile. MRI is more sensitive than CT for initial diagnosis of AIS,[2,3] and MRI can fulfill the indications for CT in AIS, including screening patients for mechanical thrombectomy.[4,5] However, MRI's lack of availability, higher cost, longer scan time, potential hardware incompatibility, and more complicated workflow make it a less used option in the hyperacute setting.[6,7] In the absence of a unique indication for MRI, use of MRI in initial assessment and management of AIS remains limited at present.

Following the emergency setting, brain MRI can provide more detailed diagnostic information to optimize further management. It may not only allow confirmation of AIS with high sensitivity and specificity, but also identify the cause and estimate the full extent of stroke.[8,9] In addition, identification of stroke mimics on MRI may lead to alternative management pathways, as up to 38% of patients admitted with

Correspondence to: Hwan Lee, MD, Department of Radiology, University of Pennsylvania Perelman School of Medicine, 3400 Spruce St, Philadelphia, PA 19104. E-mail: hwan.lee@pennmedicine.upenn.edu

*Dr Lee and Dr Yang are co–first authors.

For Sources of Funding and Disclosures, see page 6.

JAHA is available at: www.ahajournals.org/journal/jaha

CLINICAL PERSPECTIVE

What Is New?

- A significant association exists between inpatient brain magnetic resonance imaging and decreased rates of inpatient mortality and complications in patients with acute ischemic stroke.
- Inpatient brain magnetic resonance imaging was also associated with marginally increased length and cost of hospitalization.

What Are the Clinical Implications?

- Physicians should consider obtaining brain magnetic resonance imaging for all patients admitted with acute ischemic stroke.
- Further studies are needed to establish causality and to characterize the change in stroke management following inpatient brain magnetic resonance imaging to explain the improved outcomes.

Nonstandard Abbreviations and Acronyms

AIS acute ischemic stroke
NIS National Inpatient Sample

suspected acute stroke may have alternative diagnoses on brain MRI.[10]

There is a paucity of literature, let alone a clear guideline, about use of inpatient brain MRI following the early management of AIS. Although use of inpatient brain MRI in patients with stroke is increasing, there is a high degree of geographical and institutional variability, which has stronger influence than patients' clinical factors on brain MRI use.[11,12] Inpatient brain MRI is most commonly performed in addition to initial CT-based workup, and it has been associated with increased length and cost of hospital stay.[12,13]

Therefore, an outcome study is warranted to examine whether inpatient brain MRI in patients with AIS will lead to clinical benefit that can justify its resource requirements. Given the institutional heterogeneity in use of inpatient brain MRI for AIS and the multifactorial nature of potential changes in patient management following brain MRI, the effect of inpatient brain MRI on patient outcomes needs to be examined across a large number of institutions. For the present study, we used the clinical data from the National Inpatient Sample (NIS) to test the hypothesis that use of brain MRI in patients admitted with AIS is associated with improved clinical outcomes.

METHODS

Patient Database

Anonymized data and materials have been made publicly available at the NIS and can be accessed at http://www.hcup-us.ahrq.gov/nisoverview.jsp. The present study was performed retrospectively using the NIS, a public inpatient database in the United States. Maintained by the Agency for Healthcare Research and Quality, the NIS depicts an ≈20% stratified sample of inpatient admissions at nonfederal hospitals, representing the US population regardless of payer type.[14] The database contains information on diagnoses and procedures based on *International Classification of Diseases, Ninth Revision, Clinical Modification* (*ICD-9-CM*) codes. Three years of data (2012–2014) were used, comprising >21 million discharges from >4000 hospitals in 45 states. The study was conducted in accordance with the US Health Insurance Portability and Accountability Act and did not require local Institutional Review Board approval because of the use of a public database.

Study Population

We queried the NIS database to search for patients aged ≥18 years with the principal diagnosis of AIS. The study population was then stratified into 2 groups based on use of inpatient brain MRI. The baseline characteristics of the control and MRI groups were organized with respect to sex, age, income, and insurance type, as well as hospital characteristics, including location, size, and teaching status. Major comorbidities were also included for characterization, as outlined in Table 1.

Study Outcomes

The primary outcome of the study was in-hospital mortality. The secondary outcomes were resource use (length and cost of hospital stay) and in-hospital complications: intracranial hemorrhage, gastrostomy, mechanical ventilation, and nonhome discharge.

The *ICD-9-CM* codes used to identify the study population, comorbidities, and outcomes have been outlined in Table 1.

Statistical Analysis

As stated by the developers, the NIS is a self-weighted, stratified, systematic, random sample of discharges from all hospitals in the sampling frame after sorting discharges by diagnosis-related group, hospital, and admission month.[15] The NIS sample is stratified on the basis of hospital characteristics, and within each stratum, hospitals (clusters) were selected from the sampling frame at the rate of 100% and discharges from hospitals were sampled at a rate of ≥20% (starting year 2012). Therefore, in our

Table 1. *ICD-9-CM* Codes Used to Identify Study Population, Comorbidities, and In-Hospital Complications

Variable	*ICD-9-CM* Codes
Study population	
Acute ischemic stroke	433–437.1
Brain MRI	88.91 (Procedure code)
Comorbidities	
Dementia	290, 294, 331
History of myocardial infarction	412
Chronic liver disease	571.2, 571.4, 571.5, 571.6, 572.2, 572.3, 572.4, 572.8
Thrombocytopenia	287.5, 287.30, 287.31, 287.33, 287.39, 287.49
Hypertension	Hypertension, uncomplicated: 401.1, 401.9, 642.00–642.04 Hypertension, complicated: 401.0, 402.00–405.99, 437.2, 642.10–642.24, 642.70–642.94
Diabetes mellitus	Diabetes mellitus without chronic complications: 249.00–249.31, 250.00–250.33, 648.00–648.04 Diabetes mellitus with chronic complications: 249.40–249.91 250.40–250.93, 775.1
Chronic kidney disease	403, 404, 582, 583, 585, 586, 588
Atrial fibrillation/atrial flutter	427.3
Peripheral artery disease	440–440.9, 441.00–441.9, 442.0–442.9, 443.1–443.9, 444.21–444.22, 447.1, 449, 557.1, 557.9, V43.5
Metastatic malignancy	37, 38, 39, 40, 41, 42 (Clinical Classifications Software code)
Obesity	278, V77.8
Chronic obstructive pulmonary disease	491, 492, 496
HIV	042, 043, 044
Congestive heart failure	398.91, 402.01, 402.11, 402.91, 404.01, 404.03, 404.11, 404.13, 404.91, 404.93, 425, 428
In-hospital complications	
Mechanical ventilation	96.70, 96.71, 96.72 (Procedure codes)
Intracranial hemorrhage	430–432.9
Gastrostomy	43.11, 43.19 (Procedure codes)

ICD-9-CM indicates *International Classification of Diseases, Ninth Revision, Clinical Modification*; and MRI, magnetic resonance imaging.

model, we used statements "egen STA=group (YEAR NIS_STRATUM)" and "svyset [pweight=DISCWT], strata (STA) psu (HOSP_NIS)." The stratum statement specifies NIS_STRATUM as the stratum identifier, and the cluster statement specifies HOSP_NIS as the cluster identifier. We used a survey-specific method, with the commands svyset and svy with pweight using the discharge-level weight from 2012 to 2014 to generate nationwide estimates.[16]

We used descriptive statistics to compare demographic characteristics and outcomes between patients with AIS with and without MRI of the brain. The baseline characteristics were compared between the MRI and control groups using the χ^2 test for categorical variables and the Student *t* test for continuous variables. In our multivariable regression model, we assessed differences in binary outcomes by using logistic regression and in continuous outcomes by using ordinary least squares linear regression.

Analyses were performed using Stata version 14 (StataCorp, College Station, TX). All statistical tests were performed with weighted samples using the survey data analysis tools on Stata.[16] All statistical tests were 2 sided, and $P<0.05$ was considered statistically significant.

RESULTS

Baseline Characteristics

A total of 94 003 patients who received inpatient brain MRI were identified for the study, the baseline characteristics of whom have been summarized in Table 2 along with the control group. Patients who underwent brain MRI were more likely to be younger (mean age, 69.0±14.2 versus 71.0±14.0 years), be Black, have higher income, and hold private insurance. Patients in the MRI group were more likely to be admitted to large urban teaching hospitals in the northeast region. The patients in the MRI group showed overall decreased prevalence of significant comorbidities, as shown in Table 2. No significant difference in sex was found between the 2 groups.

Clinical Outcomes

Unadjusted mortality rate was lower in the MRI group at 1.67% compared with 3.09% in the control group. On multivariable regression analysis, undergoing inpatient brain MRI was independently associated with lower mortality (adjusted odds ratio [OR], 0.60; 95% CI, 0.53–0.68; $P<0.001$) (Table 3).

Table 2. Baseline Characteristics of the Control and MRI Groups

Characteristic	Control Group (n=1 583 768), %	MRI Group (n=94 003), %	*P* Value
Sex			
Women	53.3	52.7	0.098
Race			<0.001
White	70.9	60.6	
Black	15.8	22.4	
Hispanic	8.0	8.4	
Asian or Pacific Islander	2.4	4.0	
Native American	0.4	0.2	
Other	2.5	4.4	
Age, mean±SD, y	71.0±14.0	69.0±14.2	<0.001
Median annual income in patient's zip code, US$			<0.001
1–38 999	29.7	27.4	
39 000–47 999	26.6	22.3	
48 000–62 999	23.8	22.6	
≥63 000	19.9	27.7	
Insurance type			<0.001
Medicaid	69.9	64.0	
Medicare	7.3	9.7	
Private	18.1	21.7	
Uninsured	4.8	4.7	
Hospital characteristics			
Hospital region			<0.001
Northeast	17.5	46.1	
Midwest	21.6	11.2	
South	42.4	30.0	
West	18.5	12.8	
Hospital bed size			<0.001
Small	14.0	9.2	
Medium	28.0	28.8	
Large	58.0	62.0	
Location of hospital			<0.001
Rural hospital	10.1	5.8	
Urban hospital	89.9	94.2	
Teaching status of hospital			<0.001
Nonteaching hospital	48.3	31.6	
Teaching hospital	51.7	68.4	
Comorbidities			
Dementia	14.1	11.6	<0.001
History of myocardial infarction	7.2	6.3	<0.001
Metastatic malignancy	2.1	2.2	0.393
Thrombocytopenia	2.9	2.5	0.001
Chronic liver disease	10.9	10.7	0.546
HIV	0.2	0.2	0.001
Hypertension	82.6	82.7	0.717
Diabetes mellitus	36.1	37.1	0.030
Chronic obstructive lung disease	11.2	8.6	<0.001
Chronic kidney disease	15.8	14.2	<0.001
Atrial fibrillation/flutter	22.7	18.2	<0.001
Coronary artery disease	28.2	24.0	<0.001
Peripheral artery disease	9.4	8.4	<0.001
Obesity	10.3	10.2	0.728
Congestive heart failure	15.1	11.8	<0.001

MRI indicates magnetic resonance imaging.

Major in-hospital complications were also significantly less likely to occur in the brain MRI group (Table 3). On multivariable regression analysis, brain MRI was independently associated with a significantly lower incidence of gastrostomy (adjusted OR, 0.82; 95% CI, 0.73–0.93; *P*<0.001) and mechanical ventilation (adjusted OR, 0.68; 95% CI, 0.60–0.77; *P*<0.001). No significant difference in intracranial hemorrhage (adjusted OR, 1.04; 95% CI, 0.93–1.15; *P*=0.490) and nonhome discharge (adjusted OR, 1.04; 95% CI, 0.99–1.10; *P*=0.140) was observed between the 2 groups.

Resource Use

Unadjusted length of stay was longer in the MRI group at 4.57±5.82 days compared with 4.18±5.33 days (mean±SD) in the control group. On multivariable regression analysis, brain MRI independently accounted for increase in length of hospital stay of ≈0.32 days (95% CI, 0.19–0.45 days; *P*<0.001) (Table 3).

Similarly, the MRI group had higher unadjusted cost of hospital stay at $11 681±$12 815 compared with $10 465±$12 113 (mean±SD) in the control group. The estimated effect size of brain MRI on inpatient cost was ≈$1131 (95% CI, $744–$1527; *P*<0.001) (Table 3).

DISCUSSION

In the present study, we used a national database to examine the clinical benefit of inpatient brain MRI for patients admitted with AIS. Compared with the control group, the MRI group showed more favorable baseline characteristics with respect to age, socioeconomic status, care setting, and comorbidities. Therefore, multivariable regression analysis was the central component of the study to isolate the effects of brain MRI.

On multivariable regression analysis, we found that brain MRI was independently associated with

Table 3. Differences in In-Hospital Outcomes Based on Brain MRI Use

Outcome	Unadjusted Incidence	Adjusted Odds Ratio (95% CI)	*P* Value
Mortality, %	1.67 vs 3.09	0.60 (0.53–0.68)	<0.001
Intracranial hemorrhage, %	2.85 vs 2.46	1.04 (0.93–1.15)	0.490
Gastrostomy, %	2.28 vs 2.89	0.82 (0.73–0.93)	<0.001
Mechanical ventilation, %	1.97 vs 2.82	0.68 (0.6–0.77)	<0.001
Nonhome discharge, %	52.41 vs 53.41	1.04 (0.99–1.10)	0.140
Outcome	**Unadjusted Value (Mean±SD)**	**Regression Coefficient (95% CI)**	***P* Value**
Length of stay, d	4.57±5.82 vs 4.18±5.33	0.32 (0.19–0.45)	<0.001
Cost of hospital stay, US$	11 681±12 815 vs 10 465±12 113	1131 (744–1527)	<0.001

All values are based on MRI group vs control group. MRI indicates magnetic resonance imaging.

improved clinical outcomes. Specifically, in-hospital mortality was significantly lower in the brain MRI group, which was accompanied by corresponding reductions in incidence of in-hospital complications. Previously, equivalent or superior clinical outcomes were demonstrated with MRI-guided management compared with CT-guided management of AIS in the emergency setting.[5,17–20] Our results extend the clinical benefit of MRI-based management to the subacute period during inpatient admission.

Because MRI only provides diagnostic information, the associated change in patient management responsible for the improved outcomes remains in question. In a previous study, the single best predictor of receiving inpatient MRI for AIS was admission to a dedicated stroke unit,[21] consistent with integration of MRI into routine clinical workflow in some stroke units.[22] As dedicated stroke unit care has been shown to reduce in-hospital mortality,[23–25] the association between brain MRI and stroke unit admission offers a potential explanation for our results. However, in contrast to inpatient stroke unit care, inpatient brain MRI was not associated with improved 1-year outcomes following discharge in a single-institution study where MRI did not change the management decisions known to influence outcome.[21,26] Therefore, the treatment changes associated with brain MRI are likely multifactorial with institutional variation, and further studies are needed to explain the improved in-hospital outcomes that we observed.

The present study showed that the benefits of inpatient brain MRI for AIS come at the expense of increased length and cost of hospitalization, as previously found in resource use studies.[12,13] When we compared the clinical benefit of brain MRI against its resource requirements, we found that the relative increase in length (8%) and cost (11%) of hospitalization is marginal compared with the degree of mortality benefit (adjusted OR, 0.62), which translates to relative risk reduction of ≈38% with rare outcome assumption.[27] Overall, the improved clinical outcomes associated with brain MRI are sufficient to justify its resource use.

The limitations of the present study are as follows. Because we only examined the association between inpatient brain MRI and clinical outcomes retrospectively, the results could not be directly attributed to the effect of brain MRI. Although the downstream changes in patient management following MRI could have caused improved outcomes, obtaining MRI could have simply been a consequence of favorable baseline patient characteristics, such as a lower National Institutes of Health Stroke Scale score or environmental characteristics, such as availability of MRI. Lack of information on the clinical context of receiving MRI is an intrinsic limitation of the NIS database, and it prohibits making any conclusions on causation from our study. Similarly, the lack of information on detailed patient management in the NIS database precluded characterization of the change in management associated with brain MRI. Although imaging studies are underreported in the NIS database,[28] statistical power was maintained by enrollment of a large number of subjects through national-level analysis. Furthermore, as a limitation of the database, our study was not able to take into account the different types or timing of MRI, which were previously found to affect the diagnostic performance of MRI and cost of hospital stay.[29,30]

In summary, inpatient brain MRI in patients admitted with AIS is associated with reduced in-hospital mortality and complications, but with increased length and cost of hospitalization. The clinical benefits associated with inpatient brain MRI outweigh the resource requirements. The present study provides the first evidence for the relationship between inpatient brain MRI and in-hospital outcomes in AIS. A prospective, randomized study is needed to establish causality and to characterize the change in patient management following inpatient brain MRI.

ARTICLE INFORMATION

Received April 27, 2020; accepted August 17, 2020.

Affiliations

From the Department of Radiology, University of Pennsylvania Perelman School of Medicine, Philadelphia, PA (H.L.); Department of Medicine, St. Vincent's Medical Center, Bridgeport, CT (H.L., Y.Y., S.A.C.); Department of Medicine, Florida Hospital Medical Group, Orlando, FL (B.L.); and Department of Medicine, Bridgeport Hospital–Yale New Haven Health, Bridgeport, CT (T.S.).

Acknowledgments

The authors acknowledge Jiehui Xu, MPH, at Division of Biostatistics, New York University Grossman School of Medicine, New York, NY, for helpful discussions on statistical methods.

Sources of Funding

The authors recognize support from the Division of Neuroradiology at the University of Pennsylvania Health System to cover the article publication charge.

Disclosures

None.

REFERENCES

1. Mozaffarian D, Benjamin EJ, Go AS, Arnett DK, Blaha MJ, Cushman M, Das SR, de Ferranti S, Despres JP, Fullerton HJ, et al. Heart disease and stroke statistics—2016 update: a report from the American Heart Association. *Circulation*. 2016;133:e38–e360.
2. Chalela JA, Kidwell CS, Nentwich LM, Luby M, Butman JA, Demchuk AM, Hill MD, Patronas N, Latour L, Warach S. Magnetic resonance imaging and computed tomography in emergency assessment of patients with suspected acute stroke: a prospective comparison. *Lancet*. 2007;369:293–298.
3. Schellinger PD, Bryan RN, Caplan LR, Detre JA, Edelman RR, Jaigobin C, Kidwell CS, Mohr JP, Sloan M, Sorensen AG, et al. Evidence-based guideline: the role of diffusion and perfusion MRI for the diagnosis of acute ischemic stroke: report of the Therapeutics and Technology Assessment Subcommittee of the American Academy of Neurology. *Neurology*. 2010;75:177–185.
4. Nogueira RG, Jadhav AP, Haussen DC, Bonafe A, Budzik RF, Bhuva P, Yavagal DR, Ribo M, Cognard C, Hanel RA, et al. Thrombectomy 6 to 24 hours after stroke with a mismatch between deficit and infarct. *N Engl J Med*. 2018;378:11–21.
5. Albers GW, Marks MP, Kemp S, Christensen S, Tsai JP, Ortega-Gutierrez S, McTaggart RA, Torbey MT, Kim-Tenser M, Leslie-Mazwi T, et al. Thrombectomy for stroke at 6 to 16 hours with selection by perfusion imaging. *N Engl J Med*. 2018;378:708–718.
6. Jenson M, Libby J, Soule E, Sandhu SJ, Fiester PJ, Rao D. CT perfusion protocol for acute stroke expedites mechanical thrombectomy. *Cureus*. 2019;11:e4546.
7. Powers WJ, Rabinstein AA, Ackerson T, Adeoye OM, Bambakidis NC, Becker K, Biller J, Brown M, Demaerschalk BM, Hoh B, et al. 2018 Guidelines for the early management of patients with acute ischemic stroke: a guideline for healthcare professionals from the American Heart Association/American Stroke Association. *Stroke*. 2018;49:e46–e110.
8. Leiva-Salinas C, Wintermark M. Imaging of acute ischemic stroke. *Neuroimaging Clin N Am*. 2010;20:455–468.
9. Wessels T, Wessels C, Ellsiepen A, Reuter I, Trittmacher S, Stolz E, Jauss M. Contribution of diffusion-weighted imaging in determination of stroke etiology. *AJNR Am J Neuroradiol*. 2006;27:35–39.
10. Quenardelle V, Lauer-Ober V, Zinchenko I, Bataillard M, Rouyer O, Beaujeux R, Pop R, Meyer N, Delplancq H, Kremer S, et al. Stroke mimics in a stroke care pathway based on MRI screening. *Cerebrovasc Dis*. 2016;42:205–212.
11. Rosen MP, Oake N, Forster AJ, Goelman A, Levy F. The effect of imaging capacity on the imaging workup of patients with stroke: a preliminary case for a cross-country comparison. *J Am Coll Radiol*. 2011;8:428–435.e3.
12. Burke JF, Kerber KA, Iwashyna TJ, Morgenstern LB. Wide variation and rising utilization of stroke magnetic resonance imaging: data from 11 states. *Ann Neurol*. 2012;71:179–185.
13. Nguyen H, Afzal MR, Bandaru H, Qureshi M, Ghatali M, Vellipuram A, Piriyawat P, Khatri R, Kassar D, Maud A, et al. Impact of doing echocardiogram (ECHO) and brain magnetic resonance imaging (MRI) on length of stay and hospital charges in ischemic stroke patients in United States: analysis of Nationwide Inpatient Sample (NIS) 2006–2014. *Neurology*. 2019;92:P3.9-013.
14. Healthcare Cost and Utilization Project Databases. Agency for Healthcare Research and Quality. www.hcup-us.ahrq.gov/nisoverview.jsp. Accessed December 1, 2019.
15. Final Report on Calculating National Inpatient Sample (NIS) Variances for Data Years 2012 and Later. Agency for Healthcare Research and Quality, Rockville, MD: HCUP Methods Series Report; 2015.
16. *Stata Survey Data Reference Manual, Release 14. StataCorp*. College Station, TX: Stata Press Publication; 2015.
17. Kohrmann M, Juttler E, Fiebach JB, Huttner HB, Siebert S, Schwark C, Ringleb PA, Schellinger PD, Hacke W. MRI versus CT-based thrombolysis treatment within and beyond the 3 h time window after stroke onset: a cohort study. *Lancet Neurol*. 2006;5:661–667.
18. Gerischer LM, Fiebach JB, Scheitz JF, Audebert HJ, Endres M, Nolte CH. Magnetic resonance imaging-based versus computed tomography-based thrombolysis in acute ischemic stroke: comparison of safety and efficacy within a cohort study. *Cerebrovasc Dis*. 2013;35:250–256.
19. Menjot de Champfleur N, Saver JL, Goyal M, Jahan R, Diener HC, Bonafe A, Levy EI, Pereira VM, Cognard C, Yavagal DR, et al. Efficacy of stent-retriever thrombectomy in magnetic resonance imaging versus computed tomographic perfusion-selected patients in SWIFT PRIME trial (solitaire FR with the intention for thrombectomy as primary endovascular treatment for acute ischemic stroke). *Stroke*. 2017;48:1560–1566.
20. Kim JT, Cho BH, Choi KH, Park MS, Kim BJ, Park JM, Kang K, Lee SJ, Kim JG, Cha JK, et al. Magnetic resonance imaging versus computed tomography angiography based selection for endovascular therapy in patients with acute ischemic stroke. *Stroke*. 2019;50:365–372.
21. Hefzy H, Neil E, Penstone P, Mahan M, Mitsias P, Silver B. The addition of MRI to CT based stroke and TIA evaluation does not impact one year outcomes. *Open Neurol J*. 2013;7:17–22.
22. Langhorne P, Pollock A. What are the components of effective stroke unit care? *Age Ageing*. 2002;31:365–371.
23. Minnerup J, Wersching H, Unrath M, Berger K. Explaining the decrease of in-hospital mortality from ischemic stroke. *PLoS One*. 2015;10:e0131473.
24. Jorgensen HS, Nakayama H, Raaschou HO, Larsen K, Hubbe P, Olsen TS. The effect of a stroke unit: reductions in mortality, discharge rate to nursing home, length of hospital stay, and cost: a community-based study. *Stroke*. 1995;26:1178–1182.
25. Birbeck GL, Zingmond DS, Cui X, Vickrey BG. Multispecialty stroke services in California hospitals are associated with reduced mortality. *Neurology*. 2006;66:1527–1532.
26. Langhorne P, Ramachandra S, Stroke Unit Trialists' Collaboration. Organised inpatient (stroke unit) care for stroke: network meta-analysis. *Cochrane Database Syst Rev*. 2020;4:CD000197.
27. Cummings P. The relative merits of risk ratios and odds ratios. *Arch Pediatr Adolesc Med*. 2009;163:438–445.
28. Dismuke CE. Underreporting of computed tomography and magnetic resonance imaging procedures in inpatient claims data. *Med Care*. 2005;43:713–717.
29. Lansberg MG, Norbash AM, Marks MP, Tong DC, Moseley ME, Albers GW. Advantages of adding diffusion-weighted magnetic resonance imaging to conventional magnetic resonance imaging for evaluating acute stroke. *Arch Neurol*. 2000;57:1311–1316.
30. Manwani B, Rath S, Lee NS, Staff I, Stretz C, Modak J, Finelli PF. Early magnetic resonance imaging decreases hospital length of stay in patients with ischemic stroke. *J Stroke Cerebrovasc Dis*. 2019;28:425–429.