Stroke

ORIGINAL CONTRIBUTION

Effect of Rurality on Global Access to Mechanical Thrombectomy: A Subanalysis of the MT-GLASS Study

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BACKGROUND: Mechanical thrombectomy access (MTA) for large vessel occlusion stroke varies and is limited globally. While regional studies have suggested rurality as a barrier to MTA, the magnitude and variability of this effect across countries remain unknown. This study evaluates the association of country-level rural population proportion with mechanical thrombectomy (MT) access.

METHODS: We conducted an online survey of 75 countries through the Mission Thrombectomy (previously MT2020+) global professional peer network between November 22, 2020, and February 28, 2021. Surveys were distributed by regional committee chairs and completed by stroke-focused neurologists and neurointerventional physicians within the regional committees. Questions covered country-level availability of MT centers, operators, procedures, reimbursement, emergency medical services, cultural barriers, and other factors affecting stroke systems of care. MTA was defined as the estimated proportion of patients with thrombectomy-eligible large vessel occlusions receiving MT in each region annually. We used World Bank data to obtain each country's income class based on per capita gross national income and the proportion of rural population expressed as a percentage of the total population of each country. In the final analysis, 60 countries were included. We used multivariable generalized linear models with a logit link to evaluate the association of rural population proportion with MTA.

RESULTS: The median country-level rural population proportion among 60 countries was 30.7% (interquartile range, 16.3%–45.9%). In univariate generalized linear models, each 5% increase in country-level rural population proportion was associated with 22% lower odds of MTA (odds ratio, 0.78 [95% CI, 0.70–0.86]; $P<0.001$). After adjusting for differences in country-level health care gross domestic product, reimbursement for MT, country income class, availability of prehospital emergency medical services, training, and triage systems, each 5% increase in rural population proportion was associated with 13% lower odds of MTA (odds ratio, 0.87 [95% CI, 0.78–0.96]; $P=0.006$).

CONCLUSIONS: Country-level rural population proportion is an independent negative predictor of access to MT. The unique challenges that rural populations experience within countries should be carefully studied to strategize and align global efforts to bridge thrombectomy access gaps and address rural-urban disparities.

GRAPHIC ABSTRACT: A graphic abstract is available for this article.

Key Words: delivery of health care ■ health inequities ■ ischemic stroke ■ rural health ■ thrombectomy

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Nonstandard Abbreviations and Acronyms

EMS	emergency medical services
HIC	high-income country
LMIC	lower-middle-income country
LVO	large vessel occlusion
MT	mechanical thrombectomy
MTA	mechanical thrombectomy access
RC	regional committee

Stroke is the second-leading cause of death and a leading cause of long-term disability worldwide.[1,2] Large vessel occlusion (LVO) ischemic strokes are associated with a nearly 4-fold increase in the odds of mortality and long-term disability.[3] Despite extremely high efficacy and proven cost-effectiveness, mechanical thrombectomy (MT) access is limited globally.[4] This is particularly pronounced in rural settings where acute stroke care delivery varies considerably across regions due to disparities in the resources and capabilities of health care facilities.

Several studies have highlighted the restricted access to MT for rural-dwelling patients in high-income countries (HICs),[5–7] as well as low-middle-income countries.[8] Due to many systemic and structural constraints, rural patients present to hospitals that are ill-equipped to provide time-sensitive acute stroke treatment. This results from lower utilization of emergency medical services (EMS) by rural patients, lack of prehospital EMS bypass protocols, and disparities in the geographic distribution of stroke centers relative to the population, leading to insufficient care and worse outcomes.[9] Mitigating these inequities first requires an investigation of the country- and region-specific factors affecting rural access to MT to devise customized, cost-effective strategies that improve care and reduce variability across broad, diverse geographic regions.

Mission Thrombectomy (previously MT 2020+) is a global initiative of the Society of Vascular and Interventional Neurology comprising an international peer network of multidisciplinary stroke experts across >100 countries. It aims to accelerate access to MT for LVO stroke. To define the global disparities in access to MT, we conducted the MT-GLASS study,[4] which surveyed an international cohort of countries to study MT access (MTA), its components, and its determinants. While regional studies have suggested rurality as a barrier to MTA,[6] the magnitude and variability of this effect across countries are unknown. This study aims to evaluate the association between country-level rural population proportion and access to MT.

METHODS

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Survey Design and Data Collection

The methodology of the survey administration has been published previously.[4] The survey was designed on Qualtrics and created by the Mission Thrombectomy (MT2020+) core executive committee composed of vascular and interventional neurologists, and further reviewed by 8 global co-chairs who are prominent stroke and neurointerventional experts in different regions of the world.

The survey was designed on Qualtrics and globally distributed to the MT2020+ regional committee (RC) chairpersons between November 22, 2020, and February 28, 2021. Each RC has at least 2 chairpersons with at least 1 stroke-focused neurologist and 1 neurointerventionist. The distribution of RCs varies depending on the size of the country and other demographic and sociocultural factors. The survey was sent to 75 RC chairpersons who were responsible for distributing the survey to stroke-focused neurologists and neurointerventional physicians practicing in the RC (Figure 1).

The survey included 17 questions, which assessed the following components for each country: MT procedures, MT centers, MT operators, EMS availability and training, prehospital stroke protocols, MT procedure reimbursement, presence of nationwide thrombectomy center designation, and cultural barriers to stroke care. The details of the survey and its respondents have been previously described and are available in the Supplemental Material associated with the initial study.[4] Our institutional review board waived the need for patient consent. Ethics approval was not needed for our study.

As a part of the Mission Thrombectomy (MT2020+) initiative, over 100 RCs have been established worldwide. Each RC comprises a cohort of neurologists, neurointerventionalists, emergency physicians, stroke nurses, stroke coordinators, administrative personnel, health policy officials, and EMS. Each RC was assigned at least 2 Mission Thrombectomy chairpersons who were responsible for distributing surveys to neurointerventionalists and stroke neurologists in the region. Exceptions were made for the following countries for which the RC co-chair was assigned to respond to the study: Australia, the Caribbean islands, Cameroon, Kenya, Ghana, Tanzania, and South Africa.

Outcomes

MTA was the primary outcome explored and was defined as the percentage of patients with MT-eligible LVOs who received MT in each country. The total number of patients with LVOs annually per country was extracted using data on ischemic stroke incidence from the Global Burden of Disease database[10]: the number of patients with MT-eligible LVOs was then estimated as 20% of total ischemic stroke incidence per country. This percentage is an estimate based on publications that have estimated MT-eligible LVOs as anywhere between 10% and 30%.[11–13]

MTA is defined in the equation in Table 1. The secondary outcomes explored were the number and availability of MT centers and operators. The MT operator and center availability were defined by the equations in Table 1.

These equations function under the assumption that each operator would ideally perform 50 thrombectomies per year, and each MT center would have 3 operators, therefore producing 150 thrombectomies per center per year. These numbers are estimates that were chosen to represent an ideal number

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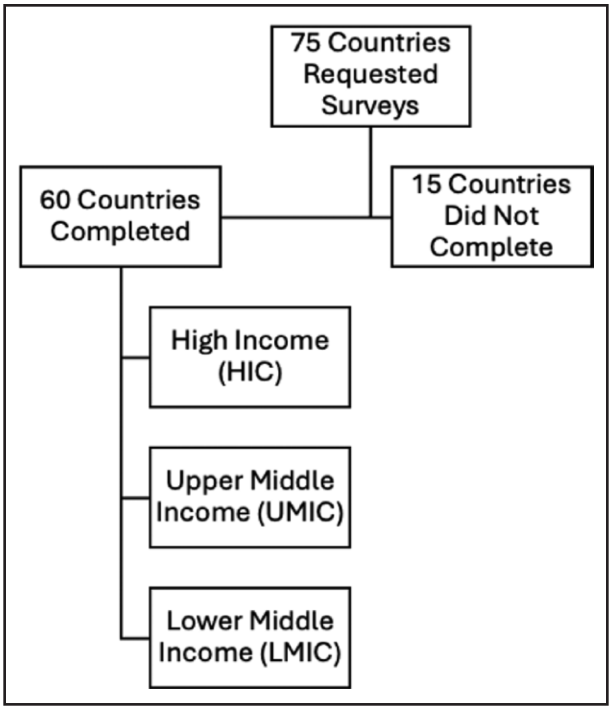

Figure 1. Flow of country participation and final inclusion by income level.

of thrombectomies per center and operator based on research within the field, which has demonstrated improved outcomes and decreased complications at certain volumes per operator/center. Prior studies have reported varying benchmarks: a Korean study identified 24 MTs per year per center as a minimal threshold, United States-based studies observed improved outcomes at >35 to 53 MTs per year per center, and a registry demonstrated higher odds of successful recanalization when operators performed ≥40 MTs annually.[14–16]

Country Income Level and Rurality Classification

Each participating country was assigned an income level based on the gross national income as defined by the World Bank. Countries are categorized into either lower-middle-income countries (LMICs), upper-middle-income countries, or HICs. We used the World Bank data from 2021 to obtain the proportion of the rural population expressed as % of the total population of each country.

It is important to note that there are potential variations in rural classification in the World Bank data, which stem from how each country defines urban areas. Some countries base the urban-rural distinction on settlement size or administrative criteria, while others consider the availability of infrastructure and services. Because the rural population is calculated as the difference between the total population and the urban population, the rurality percentage is inherently shaped by this variable definition of urban areas. For example, the Economic Co-Operation and Development defines rurality based on population density and access to urban centers as the driving time needed for at least half of the population to reach a populated center of 50000 or more inhabitants. Ideally, this better captures the economic distance from markets and services.[17] Similarly, the US census bases rurality on housing density and population density requirements. Consequently, rurality is better understood as a spectrum rather than a strict binary, with population density and proximity to urban centers serving as key gradients that contribute to cross-country variation in classification.

Table 1. Equations for Measured Outcomes

Outcome	Equation
MT access rate, %	Number of annual MT procedures (total number of annual estimated LVOs×100)
MT operator availability, %	Current number of MT operators (estimated thrombectomy-eligible LVOs annually/[50×100])
MT center availability, %	Current number of MT centers (estimated thrombectomy-eligible LVOs annually/[150×100])

LVO indicates large vessel occlusion; and MT, mechanical thrombectomy.

Statistical Analysis

We collated numerical survey responses and calculated the median for numerical responses and dichotomous yes/no responses, as well as the mode (the choice picked by≥50% of responders). We used univariate generalized linear models with logit links, as outlined in the study by Chen et al,[18] to study the association of rural population proportion evaluated as a continuous variable with MTA. Similar generalized linear models with multivariable-adjustment for World Bank income level (HIC and upper-middle-income country versus LMIC), percent of health care gross domestic product, reimbursement for MT, presence of prehospital medical services, presence of EMS education on acute stroke, and EMS training on LVO strokes were used to evaluate the association of rurality with MTA. We assessed for possible effect modification of the association of rural population proportion by country-level income class by constructing additional regression models containing interaction terms for rurality and income. Where positive interactions were identified suggesting effect modification, we stratified estimates by the income categories of countries. All primary analyses were performed using STATA 16.1 (College Station, TX). A 2-tailed α of <0.05 was required for statistical significance.

Sensitivity Analysis

Because of wide variability in the estimated percentage of strokes that may be LVO, we conducted sensitivity analysis with MTA in which the LVO strokes were estimated as 10% and 30% of all ischemic strokes and qualitatively compared the results from multivariable models conducted using these estimates to those obtained from MTA calculated as 20% of all ischemic strokes.

Missing Data

Analysis was restricted to countries with nonmissing data with respect to all variables of interest. Countries with incomplete responses (n=15) were excluded from analyses (Figure 1).

RESULTS

Of the 75 countries surveyed, 60 countries with complete survey responses and available data on rurality were included in this analysis. The distribution of rurality by countries along with MTA[4] is illustrated in Table 2 and Figure 2A. The median country-level rurality was 30.7% (interquartile range, 16.3%–45.9%; P<0.001). The distribution of rurality by countries is illustrated in Figure 2B.

To assess how rurality affected the odds of MTA, we used univariate and multivariate generalized linear models (Table 3). Model 1 is a univariate model. Model 2 builds on model 1 with additional adjustments for the percentage of gross domestic product spent on health care, reimbursement for MT, prehospital emergency services (EMS) system availability, EMS training on stroke recognition, and EMS training on LVO strokes. Model 3 extends model 2 by including an interaction term between the percentage of the rural population and income status. Model 4 is based on model 2 but is restricted to high-income and upper-middle-income countries. Model 5 is also based on model 2 but is restricted to low-income and lower-middle-income countries.

In univariate generalized linear models, each 5% increase in country-level % of the rural population was associated with 22% lower odds of MTA (odds ratio, 0.78 [95% CI, 0.70–0.86]). After adjustment for differences in country-level % of gross domestic product spent on health care, reimbursement for MT, country income class, prehospital EMS availability, EMS training on LVO strokes, and triage systems, each 5% increase in % rurality was associated with 13% lower odds of MTA (odds ratio, 0.87 [95% CI, 0.78–0.96]). In these models, HICs had 300% greater odds of MTA (odds ratio, 3.20 [95% CI, 1.34–7.73]) compared with LMICs.

In additional models that include interaction terms between the country's income category and rurality (Table 2, model 3), there was a significant rurality-by-income category interaction ($P_{interaction}$=0.01), with 20% lower odds of MTA by rurality in HMICs compared with LMICs (odds ratio, 0.80 [95% CI, 0.68–0.95]). In these models, the proportion of rurality alone (representing baseline rurality in LMICs) was not associated with MTA, suggesting that most of the association of rurality with income is present in HMICs and not LMICs.

Sensitivity Analysis

The MTA of countries with LVOs estimated as 10% and 30% of all strokes is depicted in Table S1. The results of multivariable models with MTA calculated using LVO as 10% and 30% were similar to those calculated using MTA as 20% of all ischemic strokes (Table S2).

DISCUSSION

In this first worldwide survey studying access to MT, an increase in the proportion of a country's population that was rural was directly associated with lower odds of MTA, even after correcting for variables such as access to prehospital emergency services, stroke and LVO knowledge, cultural barriers, and per capita gross domestic product. Notably, the association of rurality with lower odds of thrombectomy was not seen in LMICs compared with HICs. This may reflect more uniformly reduced MTA across urban and rural regions in LMICs than HICs.

These findings align with global evidence demonstrating the challenges rural populations face in accessing acute stroke care. In the United States, rural populations have limited access, particularly to time-sensitive treatments, and experience worse functional outcomes than their urban counterparts.[17] A study across acute stroke care hospitals in 11 US states showed that compared with urban patients, rural patients are less likely to arrive at thrombectomy-capable hospitals.[6] Similarly, in Canada, only 32% of rural Ontario residents live within a 60-minute driving distance of a thrombectomy-capable center.[5] In Australia, data from 50 acute care hospitals (25 urban and 25 rural) participating in the Australian Stroke Clinical Registry between 2010 and 2015 revealed that rural hospitals offered comparatively poorer access to recommended acute stroke care components.[19] In addition, analysis from the Austrian Stroke Unit Registry demonstrated that while national onset-to-door and onset-to-treatment times have gradually improved, they remain significantly higher for rural patients.[20]

Our study found that rurality was associated with lower MTA only in HICs and upper-middle-income countries, whereas this association was absent in LMIC. The lack of association between the proportion of rurality and MTA in LMICs is likely a result of very low baseline MTA. The limited public knowledge of stroke symptoms, delayed presentations, unavailability of MT centers and MT-trained operators, and EMS systems in LMICs likely exert a stronger influence than rurality. MTA in LMICS is 48%, significantly lower than in upper-middle countries and HICs.[4] A recent survey of 17 African countries demonstrated that stroke units and centers are present in only 5 countries, with the majority of treatment overtaken by general hospitals.[19] Similarly, a recent study from Tanzania demonstrated that even in a large urban referral hospital, of 566 patients with stroke, only 6% presented within the 4.5-hour thrombolysis window; none of these received thrombolytics.[20] Health care professionals in many LMICs understand that public sensitization to the signs and symptoms of stroke, in addition to increased access to acute treatments, is essential. In East Africa, a public campaign translating and disseminating the common stroke acronym FAST into Swahili is underway.[21] In contrast to our findings, other regional studies from LMICs suggest that rurality poses a significant barrier to stroke care overall. A study in Colombia found that rural patients, despite similar risk factors, were more likely to arrive outside the therapeutic window for thrombolysis, present with severe strokes, and have worse outcomes

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Table 2. The Distribution of Rurality, World Income Level, and MT Access by Countries in This Study

Country	Rurality, %	World income level	MT access, %
Argentina	7.8	UMIC	4.25
Australia	13.6	HIC	46.09
Bahrain	10.4	HIC	45.33
Bangladesh	61.1	LMIC	0.05
Bolivia	29.5	LMIC	1.06
Brazil	12.7	UMIC	1.36
Bulgaria	24.0	UMIC	1.03
Cameroon	41.9	LMIC	0.00
Canada	18.3	HIC	21.56
Caribbean	49.0	UMIC	2.05
Chile	12.2	HIC	6.98
China	37.5	UMIC	7.27
Colombia	18.3	UMIC	6.24
Czech Republic	25.8	HIC	26.53
Ecuador	35.6	UMIC	1.37
Egypt	57.1	LMIC	2.79
El Salvador	25.9	LMIC	0.00
Georgia	40.1	UMIC	8.25
Ghana	42.0	LMIC	0.40
Greece	20.0	HIC	2.25
Honduras	41.0	LMIC	0.00
India	64.6	LMIC	1.83
Indonesia	42.7	LMIC	0.24
Iraq	28.9	UMIC	0.00
Japan	8.1	HIC	32.65
Jordan	8.4	UMIC	8.61
Kazakhstan	42.2	UMIC	6.05
Kenya	71.5	LMIC	0.35
Lebanon	10.9	UMIC	1.90
Malaysia	22.3	UMIC	4.70
Mexico	19.0	UMIC	0.70
Mongolia	31.2	LMIC	5.00
Myanmar	68.6	LMIC	0.00
New Zealand	40.7	HIC	32.28
Nicaragua	13.2	LMIC	0.57
Nigeria	47.3	LMIC	0.00
Pakistan	62.6	LMIC	0.66
Paraguay	37.5	UMIC	3.78
Peru	21.5	UMIC	0.81
Philippines	52.3	LMIC	0.44
Poland	39.9	HIC	14.70
Puerto Rico	6.4	HIC	15.11
Qatar	0.7	HIC	42.06
Romania	45.7	HIC	1.76
Saudi Arabia	15.5	HIC	10.04
Singapore	0.0	HIC	40.07
Slovakia	46.2	HIC	27.30
Slovenia	44.6	HIC	24.45
South Africa	32.2	UMIC	2.49
Sri Lanka	81.1	LMIC	0.52
Sudan	64.4	LMIC	3.15
Tanzania	64.0	LMIC	0.00
Thailand	47.8	UMIC	2.76
Tunisia	30.1	LMIC	1.13
Turkey	23.4	UMIC	18.88
United Arab Emirates	12.7	HIC	11.74
Ukraine	17.1	LMIC	0.92
Uruguay	30.2	HIC	16.02
United States	4.4	HIC	37.86
Vietnam	61.9	LMIC	6.56

HIC indicates high-income country; LMIC, lower-middle-income country (N=60 countries); MT, mechanical thrombectomy; and UMIC, upper-middle-income country.

at hospital discharge and 3-month follow-up.[22] In South Asia and Southeast Asia, the concentration of health care facilities in urban areas further exacerbates disparities in stroke care for remote rural populations.[21–23] Therefore, understanding and addressing the specific challenges faced by LMICs in the rural context are essential.

Disparities in access to MT between rural and urban populations are complex and multifactorial. Studies across many countries indicate that patients living in rural communities have lower odds of using EMS for stroke.[24–26] Lower population density contributes to an uneven distribution of certified stroke centers[25] with rural areas often served by less-resourced hospitals.[27–29] The location of rural primary stroke centers is often inadequate for optimal population coverage.[30] Urban centers in the United States have a 13-fold greater odds of becoming primary stroke centers versus rural hospitals,[31] limiting the development of regional networks essential to transfer eligible patients with LVO to MT-capable centers. Many rural hospitals lack the necessary resources and adequate staffing and may not initiate transfers either due to a lack of recognition or the absence of formal transfer networks.[6] In addition, rural hospitals are less likely to be equipped with stroke units, having fewer resources, and less robust staffing. In LMICs, where MT-capable centers are predominantly in large major cities, the presence of regional networks is even more critical yet is often lacking.[22]

Customized regional strategies are essential to expand MTA in rural and remote areas, complementing broader national interventions. Public awareness campaigns boost EMS utilization, while sustaining improvements remains challenging.[32] Targeted awareness programs tailored to the sociocultural context, language, and existing knowledge can be strategically implemented. EMS

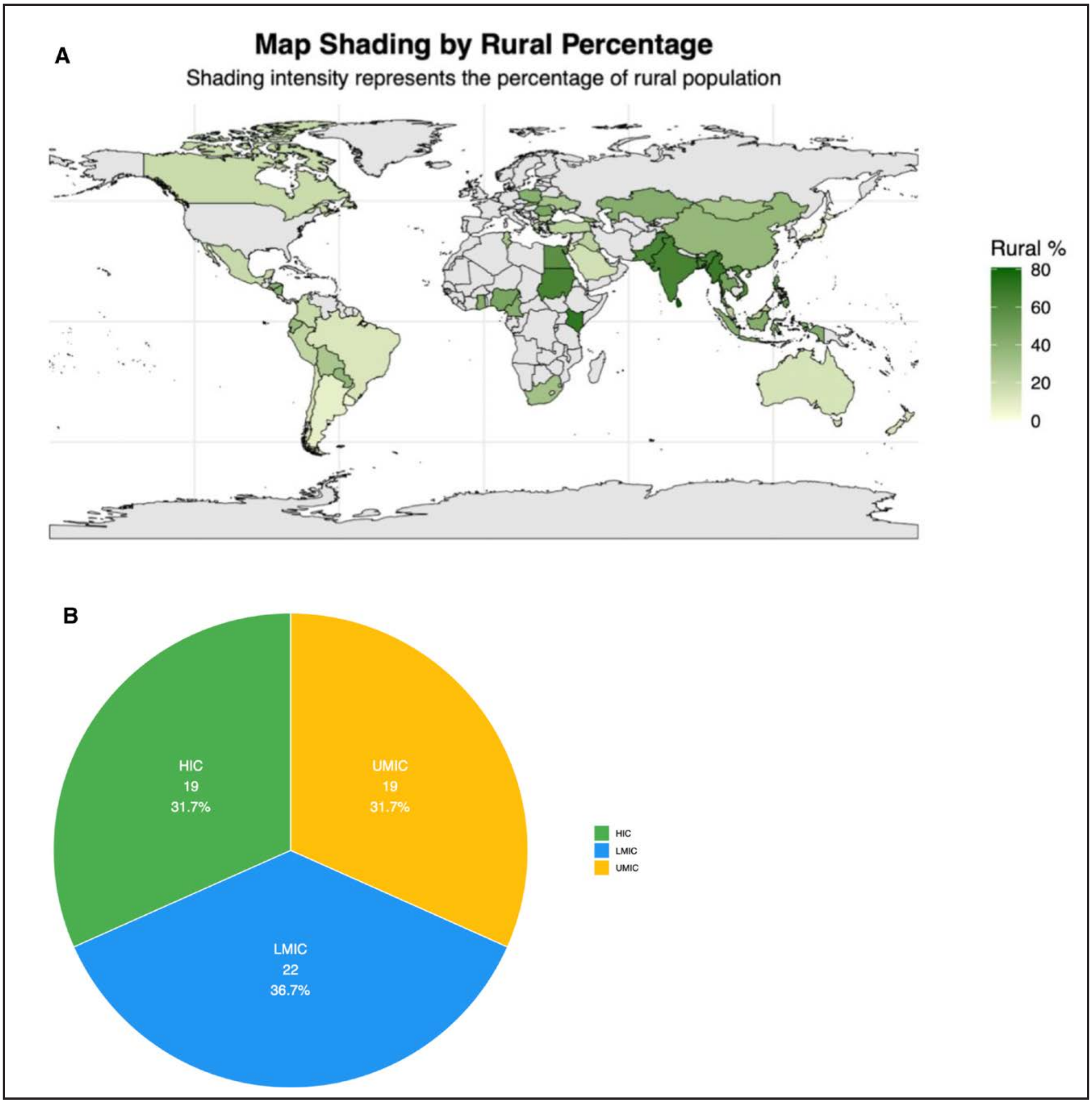

Figure 2. XXX.
A, Map shading of countries by rurality (n=60). **B**, Distribution of countries by world income level (n=60). HIC indicates high-income country; LMIC, lower-middle-income country (n=60); and UMIC, upper-middle-income country.

stroke education aids in stroke recognition, hospital prenotification, and faster thrombolysis delivery,[33] while LVO-focused EMS training can facilitate regional triage protocols and improve workflows though standardized, high-quality EMS training is lacking.[34] Collaborative efforts between stroke and neurointerventional societies, EMS organizations, and policymakers could bridge this gap. Prehospital telemedicine, artificial intelligence–based smartphone applications, and mobile stroke units should be considered based on resource availability to promote health equity.[35] For example, China implemented MSUs based at rural emergency stations to deliver prehospital thrombolysis and improve access in remote areas,[36] while Germany and several European countries have successfully expanded their telestroke programs to facilitate thrombectomy access to rural areas.[37] Kazakhstan implemented an artificial intelligence–assisted system for CT diagnostics and direct referral to angiography in rural settings to expedite stroke triage and intervention.[38]

Given unique spatial challenges, a live map for EMS that depicts proximity to the nearest stroke and

Table 3. Association of Percentage Rural Population of Countries With Odds of Mechanical Thrombectomy Access

Variables	Odds ratio	95% CI	*P* value
Model 1 (N=60 countries)			
Rural % population (5-unit increase)	0.78	0.70–0.86	<0.001
Model 2			
Upper-middle- and high-income countries (N=42) Ref: low-middle- and lower-income countries (N=18)	3.21	1.34–7.73	0.009
Rural % population (5-unit increase)	0.87	0.78–0.96	0.004
Model 3			
Upper-middle- and high-income countries (N=42) Ref: low-middle- and lower-income countries (N=18)	18.69	5.02–69.62	<0.001
Rural % population (5-unit increase)	1.05	0.93–1.19	0.420
Interaction term for upper-income and high-income vs low-income and lower-middle-income countries	0.80	0.68–0.95	0.009
Model 4: model 2 but restricted to high-income and upper-middle-income countries (N=42)			
Rural % population (5-unit increase)	0.84	0.76–0.94	0.001
Model 5: model 2 but restricted to low-income and lower-middle-income countries (N=18)			
Rural % population (5-unit increase)	0.97	0.80–1.18	0.784

Model 1: univariable model. Model 2: model 1 plus further adjustment for % of GDP spent on health care, reimbursement for mechanical thrombectomy, prehospital emergency services (EMS) system availability, EMS training on stroke recognition, and EMS training on LVO strokes. Model 3: model 2 but with an interaction term between rural % population and income status. Model 4: model 2 but restricted to high-income and upper-middle-income countries. Model 5: model 2 but restricted to low-income and lower-middle-income countries. EMS indicates emergency medical services; GDP, gross domestic product; and LVO, large vessel occlusion.

thrombectomy-capable center, factoring in traffic and operator availability, could be valuable. Strategic resources to establish stroke and thrombectomy-capable centers in underserved areas with formal stroke center certification can help bridge gaps and ensure quality.[39] Rapid in-hospital LVO detection with simultaneous CTA and centralized image-sharing minimizes delays.[40] Regional stroke transfer networks tailored to specific needs with formal agreements among hospitals and ambulances, including air transport, can ensure smoother and more efficient transfers.[41] Mobile interventional stroke teams may also be viable when feasible.[42,43] While there remains limited systematic data on regional implementation models, the above examples and recommendations provide actionable strategies for enhancing stroke care in low-resource or remote settings.[44] This includes clinical and administrative representatives from hospitals across varied geographic areas and facility types, as well as policymakers, legislative and regulatory advocates at local, regional, and state levels, and patient advocacy groups. Ongoing monitoring of the rural-urban gap in stroke care access is essential to guide continuous improvement efforts and sustain progress, especially as demographics shift and economies change over time.

Limitations

A major limitation of the study is the reliance on self-reported data via surveys to ascertain MTA and other country-level stroke metrics. This self-reported method of survey distribution did not allow estimation of the exact number of individual recipients, so response rates were reported at the country rather than the individual level. We also assumed that 20% of patients with ischemic stroke were eligible for thrombectomy, acknowledging that this may not be accurate for all regions, as LVO incidence estimates range from 13% to 52%.

Second, this study is prone to the limitations of an ecological analysis. There is potential for confounding due to unexamined geographic and regional factors, which may restrict the generalizability of the findings. For example, estimation of LVO strokes using Global Burden of Disease ischemic stroke data is exploratory; although Global Burden of Disease provides the most reliable global ischemic stroke estimates, it does not classify LVO specifically.

Third, while our analysis demonstrates the impact of rurality on access to MT, it also highlights the complex and multidimensional nature of this issue, which varies significantly by region and economic status, as well as other social and structural determinants of health.

Fourth, our assumptions on optimal operator and center volumes do not account for heterogeneity in population, part-time/full-time operator status, or case distribution within countries. We report on the absolute number of MT operators in these countries but have no information on which of these operators may work on a part-time basis in the corresponding country. Fifth, despite adjusting for multiple variables, residual confounding by geographic and regional factors remains possible. Finally, although we aimed for broad global participation, regions such as Russia, Western Europe, and Africa were not represented; hence, the findings in this study may not be generalizable to these regions. Our results should also be viewed with caution as there may be underlying selection bias in the surveyed countries. Further studies could explore a more nuanced, region-specific approach that accounts for these varied factors and develops actionable solutions to overcome barriers to MTA in rural and underserved areas.

Conclusions

The proportion of the rural population within countries is an independent negative predictor of access to MT. The unique challenges that rural populations experience should be carefully studied. Efforts to bridge thrombectomy access gaps and the development of policies and strategies must address rural-urban disparities.

ARTICLE INFORMATION

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Disclosures

Dr Asif reports compensation from the Society of Vascular and Interventional Neurology for other services. Dr Otite reports employment by Rutgers New Jersey Medical School and employment by State University of New York Upstate Medical University. Dr Crowe reports compensation from Emergency Call for Heart Attack and Stroke, LLC, for consultant services. N. Krothapalli reports compensation from the American Heart Association for other services. Dr Jadhav reports stock options in Gravity Medical Technology, compensation from Neurotrauma Sciences and Basking Biosciences for consultant services; a patent issued for Novel Stent Retriever device licensed to Basking Biosciences, employment by Barrow Brain and Spine, and travel support from Johnson and Johnson. Dr Zachrison reports grants from the American College of Emergency Physicians, the Society for Academic Emergency Medicine, and the National Institute on Aging. Dr Ortega-Gutierrez has stock holdings in Eureka Therapeutics and stock options in Active Motif and BrainFlow, and receives grants from the Patient-Centered Outcomes Research Institute. Dr Saver reports stock options in Neuronics Medical, MindRhythm, and Rapid Medical; compensation from CSL Behring, Roche, Stream Medical, Boehringer Ingelheim (prevention only), Biogen, BrainsGate, Johnson & Johnson Health Care Systems, Inc, Bayer, Aeromics, Abbott Laboratories, Medtronic USA, Inc, and BrainQ for consultant services; and compensation from Occlutech and MIVI Neuroscience for data and safety monitoring services. Dr Yavagal reports stock options in Poseydon, Gravity Medical Technology, and Rapid Medical; compensation from Poseydon, Johnson & Johnson Health Care Systems, Inc, Gravity Medical Technology, Athersys, Medtronic USA, Inc, Vascular Dynamics, and Stryker Corporation for consultant services; and stock holdings in Synchron, Galaxy Therapy, and Athersys. The other authors report no conflicts.

REFERENCES

1. Krishnamurthi RV, Ikeda T, Feigin VL. Global, regional and country-specific burden of ischaemic stroke, intracerebral haemorrhage and subarachnoid haemorrhage: a systematic analysis of the Global Burden of Disease Study 2017. *Neuroepidemiology*. 2020;54:171–179. doi: 10.1159/000506396
2. Feigin VL, Brainin M, Norrving B, Martins S, Sacco RL, Hacke W, Fisher M, Pandian J, Lindsay P. World Stroke Organization (WSO): global stroke fact sheet 2022. *Int J Stroke*. 2022;17:18–29. doi: 10.1177/17474930211065917
3. Malhotra K, Gornbein J, Saver JL. Ischemic strokes due to large-vessel occlusions contribute disproportionately to stroke-related dependence and death: a review. *Front Neurol*. 2017;8:651. doi: 10.3389/fneur.2017.00651
4. Asif KS, Otite FO, Desai SM, Herial N, Inoa V, Al-Mufti F, Jadhav AP, Dmytriw AA, Castonguay A, Khandelwal P, et al; Global Executive Committee of the MT-GLASS Study. Mechanical Thrombectomy Global Access for Stroke (MT-GLASS): a mission thrombectomy (MT-2020 plus) study. *Circulation*. 2023;147:1208–1220. doi: 10.1161/CIRCULATIONAHA.122.063366
5. Kapral MK, Hall R, Gozdyra P, Yu AYX, Jin AY, Martin C, Silver FL, Swartz RH, Manuel DG, Fang J, et al. Geographic access to stroke care services in rural communities in Ontario, Canada. *Can J Neurol Sci*. 2020;47:301–308. doi: 10.1017/cjn.2020.9
6. Kamel H, Parikh NS, Chatterjee A, Kim LK, Saver JL, Schwamm LH, Zachrison KS, Nogueira RG, Adeoye O, Díaz I, et al. Access to mechanical thrombectomy for ischemic stroke in the United States. *Stroke*. 2021;52:2554–2561. doi: 10.1161/STROKEAHA.120.033485
7. Yan Y, Hu K, Alcock S, Ghrooda E, Trivedi A, McEachern J, Kaderali Z, Shankar J. Access to endovascular thrombectomy for stroke in rural versus urban regions. *Can J Neurol Sci*. 2022;49:70–75. doi: 10.1017/cjn.2021.35
8. Pandian NG, Kim JK, Arias-Godinez JA, Marx GR, Michelena HI, Chander Mohan J, Ogunyankin KO, Ronderos RE, Sade LE, Sadeghpour A, et al. Recommendations for the use of echocardiography in the evaluation of rheumatic heart disease: a report from the American Society of Echocardiography. *J Am Soc Echocardiogr*. 2023;36:3–28. doi: 10.1016/j.echo.2022.10.009
9. Aroor SR, Asif KS, Potter-Vig J, Sharma A, Menon BK, Inoa V, Zevallos CB, Romano JG, Ortega-Gutierrez S, Goldstein LB, et al. Mechanical thrombectomy access for all? challenges in increasing endovascular treatment for acute ischemic stroke in the United States. *J Stroke*. 2022;24:41–48. doi: 10.5853/jos.2021.03909
10. Global Burden of Disease Collaborative Network. *Global Burden of Disease Study 2021 (GBD 2021)*. Seattle, United States: Institute for Health Metrics and Evaluation (IHME). 2024. https://ghdx.healthdata.org/gbd-2021
11. Chia NH, Leyden JM, Newbury J, Jannes J, Kleinig TJ. Determining the number of ischemic strokes potentially eligible for endovascular thrombectomy: a population-based study. *Stroke*. 2016;47:1377–1380. doi: 10.1161/STROKEAHA.116.013165
12. Vanacker P, Lambrou D, Eskandari A, Mosimann PJ, Maghraoui A, Michel P. Eligibility and predictors for acute revascularization procedures in a stroke center. *Stroke*. 2016;47:1844–1849. doi: 10.1161/STROKEAHA.115.012577
13. Waqas M, Mokin M, Primiani CT, Gong AD, Rai HH, Chin F, Rai AT, Levy EI, Siddiqui AH. Large vessel occlusion in acute ischemic stroke patients: a dual-center estimate based on a broad definition of occlusion site. *J Stroke Cerebrovasc Dis*. 2020;29:104504. doi: 10.1016/j.jstrokecerebrovasdis.2019.104504
14. Rinaldo L, Brinjikji W, Rabinstein AA. Transfer to high-volume centers associated with reduced mortality after endovascular treatment of acute stroke. *Stroke*. 2017;48:1316–1321. doi: 10.1161/STROKEAHA.116.016360
15. Shim D-H, Kim Y, Roh J, Kang J, Park K-P, Cha J-K, Baik SK, Kim Y. Hospital volume threshold associated with higher survival after endovascular recanalization therapy for acute ischemic stroke. *J Stroke*. 2020;22:141–149. doi: 10.5853/jos.2019.00955
16. Gupta R, Horev A, Nguyen T, Gandhi D, Wisco D, Glenn BA, Tayal AH, Ludwig B, Terry JB, Gershon RY, et al. Higher volume endovascular stroke centers have faster times to treatment, higher reperfusion rates and higher rates of good clinical outcomes. *J Neurointerv Surg*. 2013;5:294–297. doi: 10.1136/neurintsurg-2011-010245
17. Brezzi M, Dijkstra L, Ruiz V. OECD extended regional typology: the economic performance of remote rural regions. *OECD Reg Dev Work Pap*. 2011. doi: 10.1787/5kg6z83tw7f4-en
18. Chen K, Cheng Y, Berkout O, Lindhiem O. Analyzing proportion scores as outcomes for prevention trials: a statistical primer. *Prev Sci*. 2017;18:312–321. doi: 10.1007/s11121-016-0643-6
19. Dwyer M, Francis K, Peterson GM, Ford K, Gall S, Phan H, Castley H, Wong L, White R, Ryan F, et al; AuSCR Consortium. Regional differences in the care and outcomes of acute stroke patients in Australia: an observational study using evidence from the Australian Stroke Clinical Registry (AuSCR). *BMJ Open*. 2021;11:e040418. doi: 10.1136/bmjopen-2020-040418
20. Javor A, Ferrari J, Posekany A, Asenbaum-Nan S. Stroke risk factors and treatment variables in rural and urban Austria: an analysis of the Austrian Stroke Unit Registry. *PLoS One*. 2019;14:e0214980. doi: 10.1371/journal.pone.0214980
21. Waweru PK, Yulu E, Matuja SS, Gatimu SM. UPESI: Swahili translation of the FAST acronym for stroke awareness campaigns in East Africa. *Afr J Emerg Med*. 2024;14:141–144. doi: 10.1016/j.afjem.2024.05.003
22. Llanos-Leyton N, Pardo C, Pinilla-Monsalve GD, Arango A, Valderrama J, Pugliese I, Amaya P. Disparities influencing functional outcomes between

rural and urban patients with acute stroke. *Front Neurol*. 2022;13:869772. doi: 10.3389/fneur.2022.869772

23. Sebastian IA, Gandhi DBC, Sylaja PN, Paudel R, Kalkonde YV, Yangchen Y, Gunasekara H, Injety RJ, Vijayanand PJ, Chawla NS, et al. Stroke systems of care in South-East Asia Region (SEAR): commonalities and diversities. *Lancet Reg Health Southeast Asia*. 2023;17:100289. doi: 10.1016/j.lansea.2023.100289
24. Ding K, Chen H, Wang Y, Liu H, Ceceke B, Zhang W, Geng L, Deng G, Sun T, Zhang W, et al. Emergency medical service utilization among acute ischemic stroke patients in Beijing: an observational study. *Front Neurol*. 2022;13:969947. doi: 10.3389/fneur.2022.969947
25. Moreira E, Correia M, Magalhães R, Silva MC. Stroke awareness in urban and rural populations from northern Portugal: knowledge and action are independent. *Neuroepidemiology*. 2011;36:265–273. doi: 10.1159/000328867
26. Ekundayo OJ, Saver JL, Fonarow GC, Schwamm LH, Xian Y, Zhao X, Hernandez AF, Peterson ED, Cheng EM. Patterns of emergency medical services use and its association with timely stroke treatment: findings from Get With The Guidelines-Stroke. *Circ Cardiovasc Qual Outcomes*. 2013;6:262–269. doi: 10.1161/CIRCOUTCOMES.113.000089
27. Hammond G, Luke AA, Elson L, Towfighi A, Joynt Maddox KE. Urban-rural inequities in acute stroke care and in-hospital mortality. *Stroke*. 2020;51:2131–2138. doi: 10.1161/STROKEAHA.120.029318
28. Yu CY, Blaine T, Panagos PD, Kansagra AP. Demographic disparities in proximity to certified stroke care in the United States. *Stroke*. 2021; 52:2571–2579. doi: 10.1161/STROKEAHA.121.034493
29. Prior SJ, Mather CA, Campbell SJ. Redesigning rural acute stroke care: a person-centered approach. *Int J Environ Res Public Health*. 2023;20: 1581. doi: 10.3390/ijerph20021581
30. Leira EC, Fairchild G, Segre AM, Rushton G, Froehler MT, Polgreen PM. Primary stroke centers should be located using maximal coverage models for optimal access. *Stroke*. 2012;43:2417–2422. doi: 10.1161/STROKEAHA.112.653394
31. Shen Y-C, Chen G, Hsia RY. Community and hospital factors associated with stroke center certification in the United States, 2009 to 2017. *JAMA Netw Open*. 2019;2:e197855. doi: 10.1001/jamanetworkopen.2019.7855
32. Hickey A, Mellon L, Williams D, Shelley E, Conroy RM. Does stroke health promotion increase awareness of appropriate behavioural response? Impact of the face, arm, speech and time (FAST) campaign on population knowledge of stroke risk factors, warning signs and emergency response. *Eur. Stroke J*. 2018;3:117–125. doi: 10.1177/2396987317753453
33. Oostema JA, Nasiri M, Chassee T, Reeves MJ. The quality of prehospital ischemic stroke care: compliance with guidelines and impact on in-hospital stroke response. *J Stroke Cerebrovasc Dis*. 2014;23:2773–2779. doi: 10.1016/j.jstrokecerebrovasdis.2014.06.030
34. Asif KS, Novakovic R, Nguyen TN, Ortega-Gutierrez S, Kim Y, Jagolino-Cole A, Aroor S, Castonguay A, Kumar P, Jhadav AP, et al; SVIN Education and SPEED Committees. Large-vessel occlusion stroke knowledge and training for stroke severity assessment among emergency medical services personnel in the United States. *Stroke Vasc Interv Neurol*. 2018;27:803. doi: 10.1161/svin.123.001038
35. Richards CT, Oostema JA, Chapman SN, Mamer LE, Brandler ES, Alexandrov AW, Czap AL, Martinez-Gutierrez JC, Martin-Gill C, Panchal AR, et al. Prehospital stroke care part 2: on-scene evaluation and management by emergency medical services practitioners. *Stroke*. 2023;54: 1416–1425. doi: 10.1161/STROKEAHA.123.039792
36. Liu B, Zhang P, Wang H, Miao Q, Wang S, Zhang W. Mobile stroke units based on rural emergency medical stations for pre-hospital intravenous thrombolysis of stroke in remote areas. *Neurol Res*. 2024;46:1160–1166. doi: 10.1080/01616412.2024.2423588
37. Barlinn J, Winzer S, Worthmann H, Urbanek C, Häusler KG, Günther A, Erdur H, Görtler M, Busetto L, Wojciechowski C, et al. Telemedicine in stroke-pertinent to stroke care in Germany. *Nervenarzt*. 2021;92:593–601. doi: 10.1007/s00115-021-01137-6
38. Makhanbetkhan S, Turdaliyeva B, Sarshayev M, Adilbekov Y, Medukhanova S, Davletov D, Maidan A, Berdikhojayev M. Improving acute ischemic stroke care in Kazakhstan: cross-sectional survey. *J Clin Med*. 2025;14:2336. doi: 10.3390/jcm14072336
39. Man S, Schold JD, Uchino K. Impact of stroke center certification on mortality after ischemic stroke: the medicare cohort from 2009 to 2013. *Stroke*. 2017;48:2527–2533. doi: 10.1161/STROKEAHA.116.016473
40. Ver Hage A, Teleb M, Smith E. An emergent large vessel occlusion screening protocol for acute stroke: a quality improvement initiative. *J Neurosci Nurs*. 2018;50:68–73. doi: 10.1097/JNN.0000000000000346
41. Kunte SA, Anderson D, Brown-Espaillat K, Froehler MT. Total transfer time for ground vs. air transport for interhospital and scene transfers of acute stroke patients. *J Stroke Cerebrovasc Dis*. 2021;30:105704. doi: 10.1016/j.jstrokecerebrovasdis.2021.105704
42. Hubert GJ, Hubert ND, Maegerlein C, Kraus F, Wiestler H, Müller-Barna P, Gerdsmeier-Petz W, Degenhart C, Hohenbichler K, Dietrich D, et al. Association between use of a flying intervention team vs patient interhospital transfer and time to endovascular thrombectomy among patients with acute ischemic stroke in Nonurban Germany. *JAMA*. 2022;327:1795–1805. doi: 10.1001/jama.2022.5948
43. Morey JR, Oxley TJ, Wei D, Kellner CP, Dangayach NS, Stein L, Hom D, Wheelwright D, Rubenstein L, Skliut M, et al; Mount Sinai Stroke Investigators. Mobile interventional stroke team model improves early outcomes in large vessel occlusion stroke: the NYC MIST trial. *Stroke*. 2020;51:3495–3503. doi: 10.1161/STROKEAHA.120.030248
44. Zachrison KS, Asif KS, Chapman S, Joynt Maddox KE, Leira EC, Maynard S, Nobleza COS, Wira CR; on behalf of the American Heart Association Emergency Neurovascular Care and Telestroke Committee of the Stroke Council; Council on Cardiovascular and Stroke Nursing; and Council on Cardiovascular Radiology and Intervention. Identifying best practices for improving the evaluation and management of stroke in rural lower-resourced settings: a scientific statement from the American Heart Association. *Stroke*. 2025;56:e62. doi: 10.1161/str.0000000000000478