

# Varying Rates of Hospital Reperfusion Therapy for Stroke: Insights From Analysis of National Stroke Audit Data

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**Background and Purpose** Disparities in stroke care exist globally. While reperfusion therapy is a standard treatment for acute ischemic stroke, variations in its implementation may exist across hospitals.

**Methods** We analyzed data from 75,870 patients admitted to 247 acute stroke care hospitals across South Korea, sourced from the Acute Stroke Quality Assessment Program (2013–2018) by the Health Insurance Review and Assessment Service. The primary metric of interest was the hospital reperfusion therapy rate (RTR)—the proportion of patients who received intravenous thrombolysis (IVT) and/or endovascular thrombectomy (EVT) among those potentially eligible for these therapies and had onset-to-arrival times ≤6 hours and initial National Institutes of Health Stroke Scale scores ≥4. We analyzed correlations between hospital RTRs, adjusted for age, sex, onset-to-arrival time, initial stroke severity, and hospital characteristics.

**Results** Of the 10,513 patients eligible for reperfusion therapy, the overall RTR was 52.9%. The average hospital RTR was 34.8% with a median (interquartile range) of 37.5% (9.8–56.2). Hospitals with a greater number of beds and higher monthly stroke volume exhibited higher hospital RTRs. Factors such as monthly stroke volume, stroke unit availability, and monthly IVT and EVT case volume independently influenced hospital RTRs. Notably, hospitals with higher RTRs demonstrated reduced 1-year mortality, irrespective of stroke volume.

**Conclusion** In a large national sample of acute stroke care hospitals, there was significant variability in hospital RTRs, with those having higher stroke volumes typically showing higher hospital RTRs. Additionally, an inverse correlation between hospital RTRs and 1-year mortality highlights the clinical importance of improving RTRs.

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## Introduction

The successful implementation of intravenous thrombolysis (IVT) and endovascular thrombectomy (EVT) has greatly reduced disability in patients with acute ischemic stroke (AIS), establishing these therapies as the usual care for re-establishing compromised brain circulation.<sup>1-3</sup> However, the implementation of these therapies varies across regions, especially areas with lower population densities and fewer stroke centers.<sup>4,5</sup> Recent reports from Europe, the United States, and Asia have addressed that such variance is common in these regions and may cause disparities in stroke-related morbidity and mortality.<sup>6-8</sup> Consequently, an urgent imperative has arisen to optimize delivery of reperfusion therapy to AIS patients and elevate regional treatment rates. In fact, reducing disparities in the utilization of reperfusion therapies may be a national goal in some regions.<sup>1,2</sup> In this context, the reperfusion therapy rate (RTR) may be of important clinical significance in AIS patients but is sometimes overlooked.<sup>3,9</sup>

Variation in the delivery of reperfusion therapy in AIS may be dependent on hospital characteristics as provision of such therapy requires specialized equipment, coordinated care pathways, and dedicated personnel.<sup>10-13</sup> Furthermore, prior research highlights regional disparities in the quality of stroke care,<sup>14</sup> racial differences in door-to-needle time for thrombolysis,<sup>15</sup> variation in imaging-to-needle time among hospitals,<sup>16</sup> and the impact of these disparities on short-term mortality after AIS.<sup>17</sup> However, the subject of variation in RTR across systems or regional hospitals remains insufficiently explored. Identification of factors responsible for low RTRs can lead to quality initiatives to improve the rates.<sup>18,19</sup>

By utilizing data from a comprehensive national stroke audit in South Korea, this study seeks to delineate the overall RTR among stroke patients eligible for reperfusion therapy, examine RTR variations across hospitals, and identify factors influencing hospital RTR at a national level.

## Methods

The study utilized data from the Acute Stroke Quality Assessment Program (ASQAP), a national audit initiated by the Health Insurance Review and Assessment Service (HIRA) in 2005 pursuant to the National Health Insurance Act and the Medical Aid Act.<sup>20</sup> South Korean hospitals were eligible for each assessment if they treated over 10 acute stroke patients within either a 3-month (2013–2014) or 6-month (2016–2018) timeframe.

ASQAP aims to: (1) improve the care quality for hospitalized acute stroke patients, (2) identify and evaluate variation in stroke care services across acute care hospitals, and (3) determine ways

to reduce costs related to stroke care.

Every resident in South Korea is a member of the National Health Insurance program.<sup>21</sup> Consequently, all reimbursement claims for medical services, made by healthcare institutions in South Korea, are consolidated and archived by HIRA. Through linkage to the ASQAP database with this claims database, we were able to extract supplementary information pertinent to our study.

The study was approved by the Institutional Review Board of Seoul National University Bundang Hospital (No. X-1704-393-906). With HIRA's assistance, we accessed hospital- and patient-level data, ensuring all protected health information remained confidential, adhering to the Act on the Protection of Personal Information Maintained by Public Institutions.

## Study participants and data collection

Our analysis included data from the 5th (2013), 6th (2014), 7th (2016), and 8th (2018) phases of the ASQAP. Data collection periods varied, spanning 3 months in 2013 and 2014, and extending to 6 months in 2016 and 2018. Either tertiary care hospitals or general hospitals were eligible for inclusion in the ASQAP if they admitted at least 10 acute stroke patients during each survey period. Patients admitted to the emergency room (ER) within 7 days of symptoms were included in the survey.

In our analysis, the criteria for determining potential eligibility for reperfusion therapy included: (1) arrival at the ER within 6 hours post the last-known-normal time, and (2) an initial National Institutes of Health Stroke Scale (NIHSS) score of 4 or higher. The RTR for each hospital was calculated based on the proportion of those receiving either IVT or EVT among these eligible patients.

Patient-level data collected from the ASQAP database included age, sex, last-known-normal time, ambulance usage, onset-to-arrival time, door-to-imaging time, IVT administration, door-to-needle time, initial NIHSS scores, and modified Rankin Scale (mRS) scores at discharge. Information on EVT, not directly collected by the ASQAP, was identified by corresponding claim information for reimbursement made within 72 hours of ER arrival. This was accomplished by linking the ASQAP database with the claims database. However, this linkage provided only the claim's date for EVT without further related details.

Hospital-level data collected included availability of a stroke unit, total number of hospital beds, the number of hospitalized stroke patients, and counts of IVT and EVT cases.

## Statistical analysis

Baseline characteristics of patients and hospitals are presented as follows: categorical variables are reported using frequency

(percentage), while continuous variables are described using mean±standard deviation, median with interquartile range (IQR), and range, as appropriate.

For hospital comparisons, we utilized an adjusted hospital RTR, derived using a model-based risk-adjustment method. This method is crucial for mitigating variations attributable to patient-level demographic and clinic factors, which is essential when comparing clinical outcomes or performance metrics across different hospitals.<sup>22</sup> The adjusted hospital RTR was defined as the indirectly standardized rate: adjusted hospital RTR = (predicted rate/expected rate) × crude overall RTR. The expected rate for each hospital was estimated using a hierarchical logistic regression model incorporating patient-level factors such as age, sex, onset-to-arrival time, and initial NIHSS scores, and the average of hospital-specific random intercepts.<sup>23-25</sup> The predicted rate for each hospital was computed by substituting the hospital-specific intercept for the average of these intercepts.

Adjusted 1-year mortality for each hospital was calculated as follows: adjusted 1-year mortality = (observed mortality/expected mortality) × crude overall 1-year mortality. Expected mortality was derived from a multivariable Cox proportional hazards model, while observed mortality was determined using the Kaplan-Meier method for each hospital.

We compared the adjusted hospital RTR according to various hospital characteristics, such as total number of hospital beds, monthly stroke volume, stroke unit availability, the number of stroke neurologists, monthly IVT and EVT case volume, using the Kruskal-Wallis test or Wilcoxon rank sum test. Spearman's rank correlation was used to analyze correlations between hospital RTRs and various hospital-level factors. Multiple linear regression analysis was performed to identify determinants of adjusted hospital RTR, including variables with *P*-values <0.1 in bivariate comparisons. The absence of multicollinearity among these determinants was confirmed with a variance inflation factor (VIF) <10.

Correlations between hospital RTRs and 1-year mortality were assessed using Spearman's rank correlation. Additionally, a stroke volume-adjusted partial Spearman's correlation was also performed.

Statistical analyses were performed using SAS version 9.4 (SAS Institute Inc., Cary, NC, USA). A *P*-value <0.05 was considered statistically significant.

## Data availability

The database for the study was provided by HIRA and stored on a dedicated server under HIRA management. Access to the data was strictly limited to researchers who had obtained prior authorization and was limited to a pre-specified period. Upon the completion of the designated study period, the data are removed

from the server. Consequently, access to the data after the conclusion of the study, even upon reasonable request, cannot be guaranteed.

## Results

Across the 5th to 8th ASQAP assessments, a total of 75,870 patients were admitted to 251 acute care hospitals via the ER for acute stroke. Median hospital NIHSS score documentation rate was 97.5% for all AIS patients. Among them, 56,939 (75.0%) patients had AIS, with 21,804 arriving at the ER within 6 hours from the last-known-normal time. Ultimately, 10,513 patients with an initial NIHSS score of 4 or higher, treated in 247 acute care hospitals, were identified as potentially eligible for reperfusion therapy and included in the study. Four hospitals were excluded due to having no patients eligible for reperfusion therapy.

The average age of the 10,513 patients was 71 years, with 45% being women (Table 1). The median NIHSS score at admission was 9, with a median time of 105 minutes from stroke onset to ER arrival. Approximately one-third of 247 hospitals had a stroke unit and performed at least one IVT and/or EVT monthly. The

**Table 1.** Characteristics of the enrolled patients and participating hospitals

| Patient-level data           | Value (n=10,513)           |
|------------------------------|----------------------------|
| Age (yr)                     | 71.2±12.9 [18, 103]        |
| Male sex                     | 5,806 (55.2)               |
| Atrial fibrillation          | 3,193 (33.0)               |
| History of smoking           | 2,194 (33.9)               |
| NIHSS score                  | 9 (6–15) [4, 42]           |
| Arrival by ambulance         | 8,240 (78.4)               |
| OTA time (min)               | 105 (49–206) [0, 359]      |
| DTI time (min)               | 16 (10–23) [0, 1,505]      |
| DTN time (min)               | 46 (34–56) [1, 5,583]      |
| Discharge mRS score          | 3 (1–4) [0, 6]             |
| Hospital-level data          | Value (n=247)              |
| Beds                         | 392 (286–634) [138, 2,583] |
| Monthly stroke volume        | 7 (3–27) [1, 98]           |
| Monthly IVT case volume      | 1 (0–2) [0, 10]            |
| Monthly EVT case volume      | 0 (0–1) [0, 8]             |
| Stroke unit availability     | 86 (34.8)                  |
| Number of stroke specialists |                            |
| Neurology                    | 2 (1–5) [0, 35]            |
| Neurosurgery                 | 3 (2–6) [0, 32]            |
| Rehabilitation               | 1 (1–3) [0, 15]            |

Values are number of patients (%), mean±standard deviation [range], or median (interquartile range) [range].

NIHSS, National Institutes of Health Stroke Scale; OTA, onset-to-arrival; DTI, door-to-imaging; DTN, door-to-needle; IVT, intravenous thrombolysis; EVT, endovascular thrombectomy; mRS, modified Rankin Scale.

number of patients eligible for reperfusion therapy in each hospital during the 18-month study period varied widely, ranging from 1 to 341, with a median (IQR) of 20 (4.5–61.5), showing a right-skewed distribution. Notably, around one-third of the hospitals (91 out of 247) had fewer than 10 patients eligible for reperfusion therapy over this period (Supplementary Figure 1).

Reperfusion therapy was administered to 52.9% of the study population, comprising IVT (30.2%), EVT (10.9%), and IVT+EVT (11.8%). The average unadjusted hospital RTR was 34.8% (median [IQR], 37.5% [9.8–56.2]), with a range from 0% to 100%. Approximately 23% of the hospitals (56 out of 247) reported an unadjusted RTR of 0% (Figure 1A and Supplementary Figure 2). Hospitals with lower unadjusted RTRs tended to use EVT less frequently compared with IVT (Figure 1B and C). Additionally, Hospitals with a lower unadjusted hospital RTR typically had smaller stroke volumes (Figure 1D). Hospitals with a 0% unadjusted RTR had an average of 3.1 patients that were eligible for reperfusion therapy over the 18-month study period, compared to an average of 54.1 patients in other hospitals.

For exploring potential determinants of RTR, we performed bivariate analysis to elucidate a dose-dependent association between all hospital characteristics (total number of beds, monthly stroke volume, stroke unit availability, the number of stroke neu-

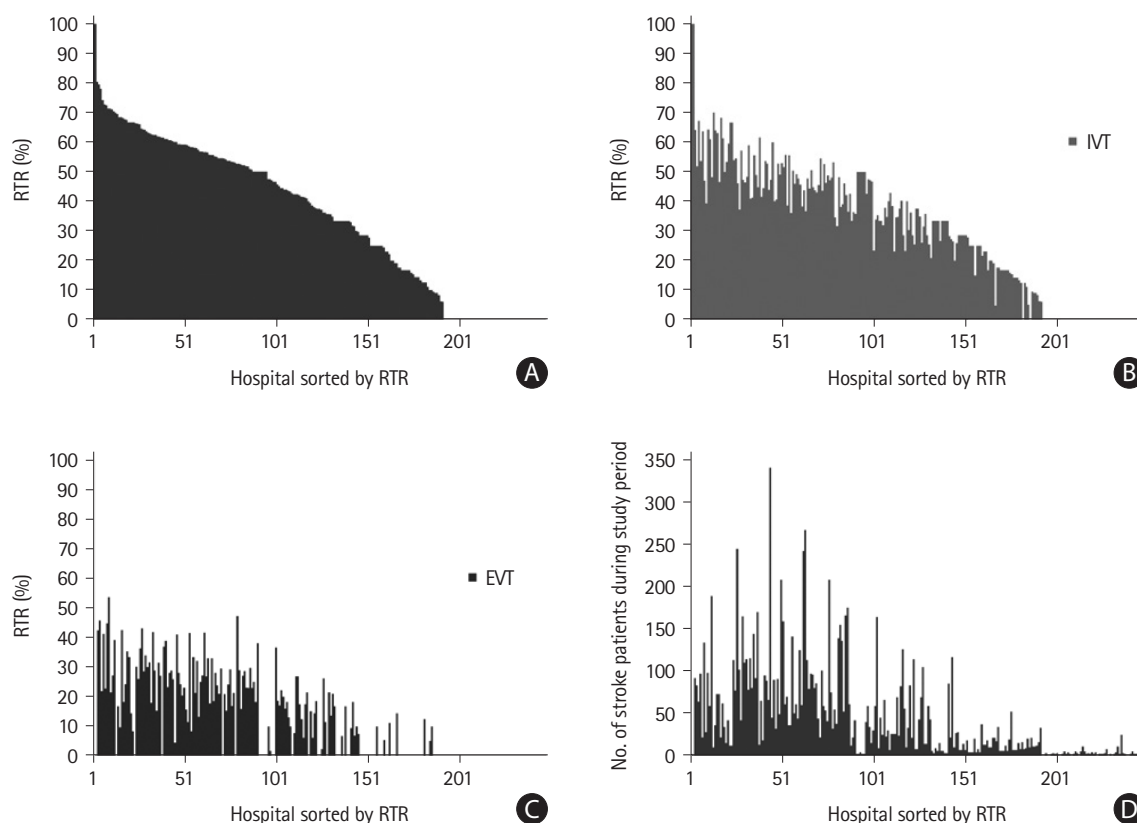
rologists, and monthly IVT/EVT case volume) and higher adjusted hospital RTRs (Table 2). Notably, larger hospital size and higher monthly stroke volume strongly correlated with higher adjusted hospital RTRs (Spearman correlation coefficient=0.61 and 0.64, respectively, both  $P<0.0001$ ) (Figure 2).

Multiple linear regression analysis was conducted to explore the determinants of adjusted hospital RTR. Due to multicollinearity between monthly stroke volume and monthly IVT case volume, two separate models (Model A and Model B) were analyzed, including these variables individually. The analysis identified that stroke unit availability and monthly stroke volume or monthly IVT/EVT case volume were independent determinants of adjusted hospital RTR (Table 3).

An inverse correlation was observed between hospital RTR and 1-year mortality post-stroke, even after adjusting for monthly stroke volume (Figure 3). The adjusted 1-year mortality was 43.5% in hospitals in the lowest quartile of adjusted hospital RTR, in contrast to 37.9% in the highest quartile (Supplementary Table 1).

## Discussion

The main findings of our nationwide study include: (1) a 52.9%



**Figure 1.** Distribution of (A) unadjusted hospital RTR, (B) hospital IVT rate, (C) hospital EVT rate, and (D) total stroke volume. RTR, reperfusion therapy rate; IVT, intravenous thrombolysis; EVT, endovascular thrombectomy.

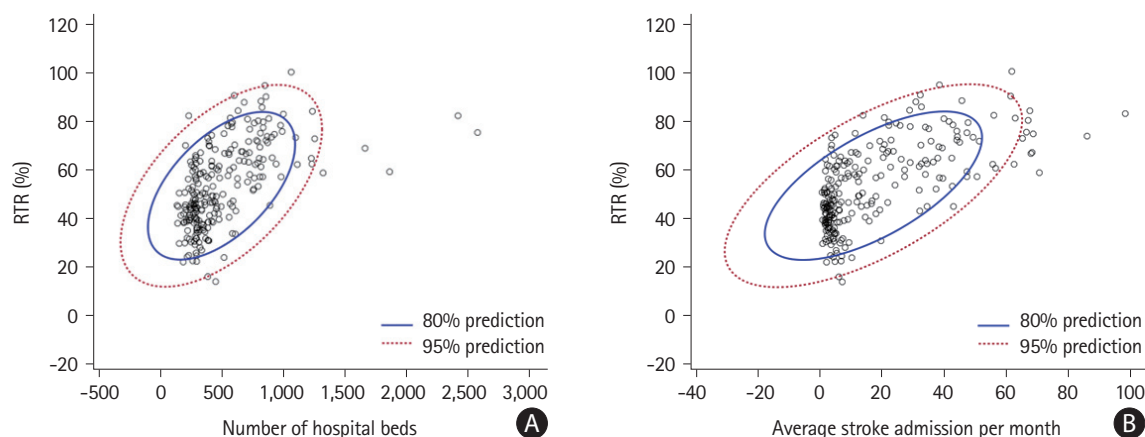
**Table 2.** Adjusted hospital RTRs according to hospital characteristics

|                                  | Adjusted hospital RTR (%) <sup>*</sup> |           |                      | <i>P</i> |
|----------------------------------|----------------------------------------|-----------|----------------------|----------|
|                                  | N                                      | Mean±SD   | Median (IQR) [range] |          |
| All hospitals (adjusted)         | 247                                    | 52.9±16.8 | 50 (40–65) [14, 100] |          |
| Beds                             |                                        |           |                      | <0.0001  |
| 100–299                          | 87                                     | 43.4±11.7 | 43 (38–50) [22, 82]  |          |
| 300–499                          | 71                                     | 47.1±13.3 | 46 (37–58) [14, 74]  |          |
| ≥500                             | 89                                     | 67.0±14.1 | 67 (58–77) [24, 100] |          |
| Monthly stroke volume (quartile) |                                        |           |                      | <0.0001  |
| <3                               | 51                                     | 42.7±8.4  | 43 (38–49) [22, 64]  |          |
| 3–7                              | 70                                     | 43.5±13.0 | 42 (34–50) [16, 74]  |          |
| 7–29                             | 65                                     | 55.2±15.3 | 57 (46–67) [14, 82]  |          |
| ≥29                              | 61                                     | 70.0±12.6 | 71 (62–79) [43, 100] |          |
| Stroke unit availability         |                                        |           |                      | <0.0001  |
| No                               | 161                                    | 46.6±14.0 | 45 (38–57) [14, 100] |          |
| Yes                              | 86                                     | 64.8±15.2 | 67 (55–76) [22, 94]  |          |
| No. of neurologists (tertile)    |                                        |           |                      | <0.0001  |
| 0–1                              | 85                                     | 42.5±11.6 | 41 (35–46) [22, 77]  |          |
| 2–4                              | 84                                     | 49.0±13.5 | 49 (40–58) [14, 82]  |          |
| 5–35                             | 78                                     | 68.6±13.2 | 70 (61–78) [32, 100] |          |
| Monthly IVT case volume          |                                        |           |                      | <0.0001  |
| 0                                | 47                                     | 40.8±7.0  | 42 (38–45) [22, 52]  |          |
| <1                               | 106                                    | 45.3±13.8 | 45 (36–56) [14, 82]  |          |
| 1–2                              | 40                                     | 59.8±8.7  | 62 (55–66) [43, 79]  |          |
| >2                               | 54                                     | 73.5±11.0 | 75 (64–81) [45, 100] |          |
| Monthly EVT case volume          |                                        |           |                      | <0.0001  |
| 0                                | 108                                    | 43.1±11.7 | 42 (35–50) [14, 75]  |          |
| <1                               | 63                                     | 49.9±13.8 | 49 (40–61) [22, 81]  |          |
| ≥1                               | 76                                     | 69.5±12.2 | 70 (61–78) [39, 100] |          |

*P*-value determined by Kruskal-Wallis test or Wilcoxon rank sum test.

RTR, reperfusion therapy rate; SD, standard deviation; IQR, interquartile range; IVT, intravenous thrombolysis; EVT, endovascular thrombectomy; NIHSS, National Institutes of Health Stroke Scale; OTA, onset-to-arrival.

<sup>\*</sup>Adjusted for age, sex, initial NIHSS scores, and OTA time.



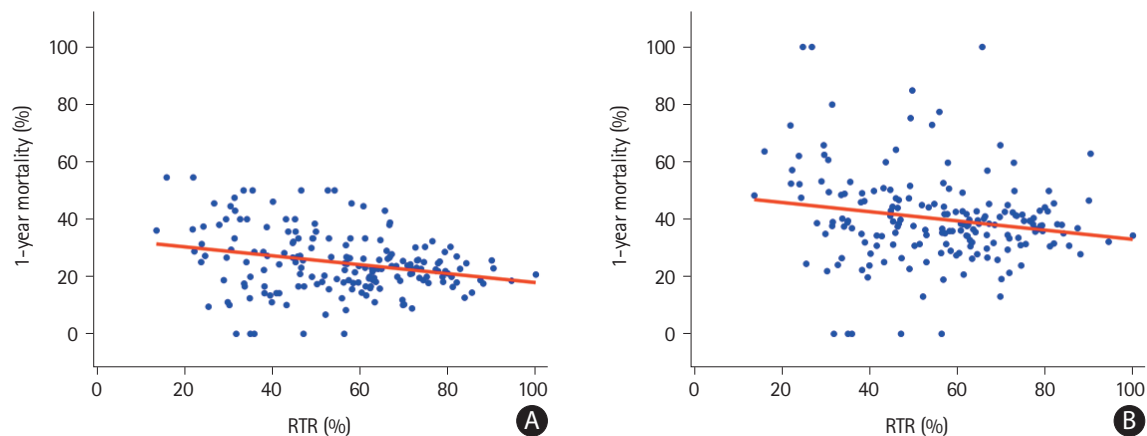
**Figure 2.** Hospital RTR in relation to hospital size and stroke volume. (A) Number of hospital beds (Spearman correlation coefficient=0.61,  $P<0.0001$ ). (B) Average monthly stroke volume (Spearman correlation coefficient=0.64,  $P<0.0001$ ). RTR, reperfusion therapy rate.

**Table 3.** The determinants of hospital RTRs: multivariable analyses

| Model A                  | $\beta$ (SE) | 95% CI        | P     | VIF  | Standardized $\beta$ |
|--------------------------|--------------|---------------|-------|------|----------------------|
| Arrival by ambulance (%) | 0.07 (0.04)  | -0.02 to 0.15 | 0.12  | 1.06 | 0.08                 |
| No. of beds              | 0.49 (0.62)  | -0.73 to 1.71 | 0.43  | 6.46 | 0.10                 |
| Monthly stroke volume    | 0.39 (0.07)  | 0.24 to 0.53  | <0.01 | 3.12 | 0.44                 |
| Stroke unit availability | 5.28 (2.25)  | 0.84 to 9.72  | 0.02  | 1.79 | 0.15                 |
| No. of neurologists      | 0.09 (0.41)  | -0.71 to 0.89 | 0.83  | 5.29 | 0.02                 |
| Model B                  | $\beta$ (SE) | 95% CI        | P     | VIF  | Standardized $\beta$ |
| Arrival by ambulance (%) | 0.06 (0.04)  | -0.02 to 0.14 | 0.14  | 1.06 | 0.07                 |
| No. of beds              | 0.48 (0.55)  | -0.59 to 1.55 | 0.38  | 5.82 | 0.09                 |
| Stroke unit availability | 4.34 (2.05)  | 0.31 to 8.37  | 0.04  | 1.71 | 0.12                 |
| No. of neurologists      | 0.04 (0.38)  | -0.71 to 0.79 | 0.91  | 5.33 | 0.01                 |
| Monthly IVT case volume  | 3.10 (1.15)  | 0.84 to 5.37  | 0.01  | 6.04 | 0.30                 |
| Monthly EVT case volume  | 3.20 (1.26)  | 0.71 to 5.69  | 0.01  | 5.57 | 0.27                 |

P-value by multiple linear regression.

RTR, reperfusion therapy rate; SE, standard error; CI, confidence interval; VIF, variance inflation factor; IVT, intravenous thrombolysis; EVT, endovascular thrombectomy.



**Figure 3.** Hospital RTR and 1-year mortality. (A) Unadjusted and (B) adjusted analysis. Hospital RTR was inversely correlated with 1-year mortality after stroke. (A) Pearson's correlation coefficient=-0.26205 ( $P=0.0003$ ), Spearman's correlation coefficient=-0.23127 ( $P=0.0015$ ), stroke volume-adjusted partial Pearson's correlation coefficient=-0.21140 ( $P=0.0040$ ), stroke volume-adjusted partial Spearman's correlation coefficient=-0.21749 ( $P=0.0030$ ). (B) Pearson's correlation coefficient=-0.18319 ( $P=0.0126$ ), Spearman's correlation coefficient=-0.18151 ( $P=0.0134$ ), stroke volume-adjusted partial Pearson's correlation coefficient=-0.15391 ( $P=0.0370$ ), stroke volume-adjusted partial Spearman's correlation coefficient=-0.15376 ( $P=0.0372$ ). RTR, reperfusion therapy rate.

overall rate of reperfusion therapy in AIS patients potentially eligible for such treatment; (2) significant variation in unadjusted hospital RTRs, with an average rate of 34.8%; (3) identification of monthly stroke volume, stroke unit availability, and monthly IVT/EVT case volumes as key determinants of RTR; and (4) an inverse correlation between hospital RTR and 1-year post-stroke mortality, independent of stroke volume.

It is noteworthy that approximately 23% of acute care hospitals in our study reported a 0% hospital RTR. These hospitals, on average, treated only 3.1 patients eligible for reperfusion therapy over an 18-month period, compared to 54.1 patients in hospitals with higher RTRs. Accordingly, it may be assumed that poor performance is related to low stroke volume. In the United States, there are 2,446 hospitals, including various kinds of stroke cen-

ters such as comprehensive, thrombectomy-capable, or primary stroke centers, and acute stroke ready hospitals, actively involved in acute stroke care.<sup>26</sup> However, there is a paucity of data regarding the distribution of hospital stroke volumes, especially the volume of patients eligible for reperfusion therapy and the corresponding therapy rates. This lack of detailed hospital-level or organizational data on acute stroke care is a common issue in most countries.<sup>27</sup> A recent analysis of ASQAP data on contributing factors for high performance among low-volume suggested a metropolitan location, a greater number of physicians, and the presence of neurologists.<sup>28</sup> The presence of neurologists was also associated with a higher defect-free care rate in these hospitals. Centers with low RTRs may lack the infrastructure or personnel necessary to deliver appropriate reperfusion therapy.

Monthly stroke volume emerged as a key determinant of hospital RTR, showing the highest standardized beta among five potential determinants. When monthly IVT/EVT case volumes were substituted for monthly stroke volume, these two factors—both indicative of patient volume—were identified as influential in determining hospital RTR. Previous studies have indicated that stroke patients treated in low-volume centers tend to experience higher mortality rates compared to those in high-volume centers.<sup>29–31</sup> This disparity may be attributed to the limited resources of low-volume centers, impacting their ability to establish and sustain experienced interdisciplinary stroke teams crucial for delivering high-quality care.<sup>32</sup>

Interestingly, a significant inverse correlation between adjusted hospital RTR and 1-year mortality persisted even after adjusting for hospital stroke volume. While this association does not imply causality, it suggests that hospital RTR could serve as a potential quality indicator at the hospital level, irrespective of hospital stroke volume or hospital size.

Our study uniquely focused on RTRs among patients potentially eligible for such treatments, diverging from previous research that included the entire stroke population. The latter studies highlighted patient-level predictors of failure to receive thrombolytic therapy, such as ineligibility due to late arrival time to the ER, mild symptoms, and history of prior stroke.<sup>33,34</sup> Assessing the performance of reperfusion therapy specifically within the target group of persons potentially eligible for thrombolytic therapies may offer more precise insights of each hospital's quality of care relative to AIS. However, accurately defining this group necessitates prerequisites like confirmation of AIS by a stroke specialist, NIHSS score assessment, and calculation of onset-to-arrival time. In the Get With The Guidelines (GWTG)–Stroke program, only 56.1% of patients had documented NIHSS scores.<sup>35</sup> Despite an increase in the average hospital-level documentation rates of NIHSS scores from 27% in 2003 to 70% in 2012, this relatively low NIHSS documentation may hinder precise identification of patients eligible for reperfusion therapy.

In contrast, our study showed a median hospital-level NIHSS documentation rate of 97.5% for all AIS patients, providing a robust basis for studying the potentially eligible group for thrombolytic therapy. Accordingly, we observed a wide variation in hospital RTRs, ranging from 0% to 100%, a phenomenon yet to be explored at a national level. However, it should be noted that there are important determinants of EVT eligibility besides NIHSS, including the occlusion status of major cerebral arteries and the degree of ischemic brain injury on brain imaging. Although NIHSS data provide potential advantages in defining the target group for EVT, NIHSS data alone cannot accurately identify all EVT-eligible patients.

To mitigate disparities in hospital RTRs, several strategies may be considered. One approach involves monitoring, providing feedback, and motivating hospitals with lower performance to improve their metrics. Alternatively, a regionalized approach to stroke systems of care could be considered, whereby AIS patients are directed to higher-volume stroke centers, either by bypassing low-volume centers or facilitating a rapid transfer. However, such strategies might face challenges in rural areas characterized by vast geographic expanses, low population densities, and sparsely located smaller hospitals. While our findings indicate that centralizing stroke systems of care—by strengthening regional stroke networks and supporting low-stroke volume centers through education—may help reduce disparities in hospital RTR and improve stroke outcomes, further research is needed to confirm these observations and guide implementation.

Our study is subject to limitations. First, determining eligibility for reperfusion therapy using national stroke audit data presents challenges. The operational definition used—arrival within 6 hours after the last-known-normal time and an initial NIHSS score of 4 or higher—was intended to be inclusive. However, we may have misclassified participants and inadvertently included patients who should not be considered for reperfusion therapy in clinical practice. For instance, a patient with a lacunar infarction, without major vessel occlusion, arriving 5 hours after stroke onset and with an NIHSS score of 5, would not usually be selected for reperfusion therapy, yet under our criteria, they could be classified as potentially eligible. Moreover, our study could not account for contraindications to reperfusion therapy, possibly leading to underestimation of the true hospital RTR.

However, due to the nature of ASQAP, an external stroke audit program administered by the governmental agency, and the lack of data on EVT eligibility in the ASQAP dataset, we decided not to use IVT exclusion causes of the ASQAP dataset but to adopt an operational definition of IVT/EVT eligibility based solely on NIHSS. The NIHSS cut-off of 4 was determined based on the facts that (1) NIHSS scores of 0–3 have been regarded as minor stroke in pivotal stroke trials such as Clopidogrel with Aspirin in Acute Minor Stroke or Transient Ischemic Attack (CHANCE)<sup>36</sup> and Clopidogrel and Aspirin in Acute Ischemic Stroke and High-Risk TIA (POINT),<sup>37</sup> and (2) NIHSS scores 6 or more are accepted as potential EVT eligibility criteria when analyzing large observational data without angiographic information.<sup>1</sup>

Second, our study lacks data on outcomes that are commonly used for evaluating the efficacy of reperfusion therapy, such as immediate NIHSS score improvement, mRS scores at 3 months, and follow-up data on infarct size or cerebral angiographic outcomes. Such detailed clinical information is often unavailable in nationwide datasets, which typically stem from administrative

or national stroke audit data, as is the case in our study. Although a meaningful association between the 3-month mRS and 1-year mortality in patients receiving reperfusion therapy has also been reported,<sup>38,39</sup> the association between RTR and 1-year mortality should be interpreted cautiously. The relationship between RTR and 1-year mortality might be mediated, at least partly, by environmental or social factors, which are commonly found among typical patients treated in low-volume centers.<sup>28</sup>

## Conclusions

In conclusion, our nationwide study showed that hospital RTRs for AIS were notably low and exhibited considerable variability, with a clear association observed between hospital RTRs and clinical outcomes post-AIS. These findings imply that hospital RTRs could serve as a valuable metric for assessing the quality of acute stroke care. Furthermore, they highlight the potential of hospital RTR as an important component of a continuous quality improvement initiative in acute stroke care. Future research is warranted to validate the utility of hospital RTR as a metric and to explore its relationship with a broader range of clinical outcomes beyond mortality. Finally, refining the operational definition of potential eligibility for reperfusion therapy may lead to more precise estimates of RTR.

## Supplementary materials

Supplementary materials related to this article can be found online at <https://doi.org/10.5853/jos.2025.00360>.

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## Conflicts of interest

Philip B. Gorelick reports serving on the Steering Committee for a sphenopalatine ganglion stimulation trial and has received honoraria from Brainsgate, outside the submitted work. Hee-Joon Bae reports grants from Astrazeneca, Bayer Korea, Bristol Myers Squibb Korea, Chong Gun Dang Pharmaceutical Corp., Dong-A ST, Jeil Pharmaceutical Co., Ltd., Korean Drug Co., Ltd.,

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## Author contribution

Conceptualization: JMP, HJB. Study design: JMP, HJB, JL. Methodology: JMP, HJB, JL, SEK. Data collection: JMP, HKP, YJC, JYK, BJK, KYP, KBL, SJL, JK, BCL, HJB. Investigation: JMP, HJB, HO, JK, BCL, IOB, GOK, SEK, JL. Statistical analysis: JL. Writing—original draft: JMP, HJB, JL. Writing—review & editing: JMP, HJB, JL, PBG, HKP, YJC, JYK, BJK, KYP, KBL, SJL, JK, BCL. Funding acquisition: JMP, HJB. Approval of final manuscript: all authors.

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## References

1. Smith EE, Saver JL, Cox M, Liang L, Matsouaka R, Xian Y, et al. Increase in endovascular therapy in Get With The Guidelines-Stroke after the publication of pivotal trials. *Circulation* 2017;136:2303-2310.
2. Menon BK, Saver JL, Goyal M, Nogueira R, Prabhakaran S, Liang L, et al. Trends in endovascular therapy and clinical outcomes within the nationwide Get With The Guidelines-Stroke registry. *Stroke* 2015;46:989-995.
3. Ye Q, Zhai F, Chao B, Cao L, Xu Y, Zhang P, et al. Rates of intravenous thrombolysis and endovascular therapy for acute ischaemic stroke in China between 2019 and 2020. *Lancet Reg Health West Pac* 2022;21:100406.
4. Maeda M, Fukuda H, Matsuo R, Ago T, Kitazono T, Kamouchi M. Regional disparity of reperfusion therapy for acute ischemic stroke in Japan: a retrospective analysis of nationwide claims data from 2010 to 2015. *J Am Heart Assoc* 2021;10:e021853.
5. Skolarus LE, Meurer WJ, Shanmugasundaram K, Adelman EE, Scott PA, Burke JF. Marked regional variation in acute stroke treatment among Medicare beneficiaries. *Stroke* 2015;46:1890-1896.
6. Denny MC, Rosendale N, Gonzales NR, Leslie-Mazwi TM,

- Middleton S. Addressing disparities in acute stroke management and prognosis. *J Am Heart Assoc* 2024;13:e031313.
7. Aguiar de Sousa D, von Martial R, Abilleira S, Gattringer T, Kobayashi A, Gallofré M, et al. Access to and delivery of acute ischaemic stroke treatments: a survey of national scientific societies and stroke experts in 44 European countries. *Eur Stroke J* 2019;4:13–28.
  8. Toyoda K, Koga M, Hayakawa M, Yamagami H. Acute reperfusion therapy and stroke care in Asia after successful endovascular trials. *Stroke* 2015;46:1474–1481.
  9. Wafa HA, Wolfe CDA, Bhalla A, Wang Y. Long-term trends in death and dependence after ischaemic strokes: a retrospective cohort study using the South London Stroke Register (SLSR). *PLoS Med* 2020;17:e1003048.
  10. Morgenstern LB, Kissela BM. Stroke disparities: large global problem that must be addressed. *Stroke* 2015;46:3560–3563.
  11. Li X, Murugiah K, Li J, Masoudi FA, Chan PS, Hu S, et al. Urban-rural comparisons in hospital admission, treatments, and outcomes for ST-segment-elevation myocardial infarction in China from 2001 to 2011: a retrospective analysis from the China PEACE study (Patient-Centered Evaluative Assessment of Cardiac Events). *Circ Cardiovasc Qual Outcomes* 2017;10:e003905.
  12. Alberts MJ, Latchaw RE, Selman WR, Shephard T, Hadley MN, Brass LM, et al. Recommendations for comprehensive stroke centers: a consensus statement from the Brain Attack Coalition. *Stroke* 2005;36:1597–1616.
  13. Alberts MJ, Latchaw RE, Jagoda A, Wechsler LR, Crocco T, George MG, et al. Revised and updated recommendations for the establishment of primary stroke centers: a summary statement from the Brain Attack Coalition. *Stroke* 2011;42:2651–2665.
  14. Seabury S, Bogner K, Xu Y, Huber C, Commerford SR, Tayama D. Regional disparities in the quality of stroke care. *Am J Emerg Med* 2017;35:1234–1239.
  15. Oluwole SA, Wang K, Dong C, Ciliberti-Vargas MA, Gutierrez CM, Yi L, et al. Disparities and trends in door-to-needle time: the FL-PR CReSD study (Florida-Puerto Rico Collaboration to Reduce Stroke Disparities). *Stroke* 2017;48:2192–2197.
  16. Sauser K, Levine DA, Nickles AV, Reeves MJ. Hospital variation in thrombolysis times among patients with acute ischemic stroke: the contributions of door-to-imaging time and imaging-to-needle time. *JAMA Neurol* 2014;71:1155–1161.
  17. Tung YC, Jeng JS, Chang GM, Chung KP. Processes and outcomes of ischemic stroke care: the influence of hospital level of care. *Int J Qual Health Care* 2015;27:260–266.
  18. Rinaldo L, Rabinstein AA, Cloft H, Knudsen JM, Castilla LR, Brinjikji W. Racial and ethnic disparities in the utilization of thrombectomy for acute stroke. *Stroke* 2019;50:2428–2432.
  19. Cruz-Flores S. Racial and ethnic disparities in stroke care. *Stroke* 2019;50:2288–2289.
  20. Yang JH, Kim SM, Han SJ, Knaak M, Yang GH, Lee KD, et al. The impact of Value Incentive Program (VIP) on the quality of hospital care for acute stroke in Korea. *Int J Qual Health Care* 2016;28:580–585.
  21. Song YJ. The South Korean health care system. *JMAJ* 2009;52:206–209.
  22. Iezzoni LI. Risk Adjustment for Measuring Health Care Outcomes. 4th ed. Chicago: Health Administration Press, 2013.
  23. Austin PC, Alter DA, Tu JV. The use of fixed- and random-effects models for classifying hospitals as mortality outliers: a Monte Carlo assessment. *Med Decis Making* 2003;23:526–539.
  24. Shahian DM, Torchiana DF, Shemin RJ, Rawn JD, Normand SL. Massachusetts cardiac surgery report card: implications of statistical methodology. *Ann Thorac Surg* 2005;80:2106–2113.
  25. Krumholz HM, Merrill AR, Schone EM, Schreiner GC, Chen J, Bradley EH, et al. Patterns of hospital performance in acute myocardial infarction and heart failure 30-day mortality and readmission. *Circ Cardiovasc Qual Outcomes* 2009;2:407–413.
  26. Boggs KM, Vogel BT, Zachrison KS, Espinola JA, Faridi MK, Cash RE, et al. An inventory of stroke centers in the United States. *J Am Coll Emerg Physicians Open* 2022;3:e12673.
  27. Purvis T, Cadilhac DA, Hill K, Gibbs AK, Ghuliani J, Middleton S, et al. Benefit of linking hospital resource information and patient-level stroke registry data. *Int J Qual Health Care* 2023;35:mzad003.
  28. Jeong HY, Kim SE, Lee K, Park JM, Park HK, Cho YJ, et al. Characteristics of high-performance low-volume hospitals in acute stroke care. *J Am Heart Assoc* 2025;14:e038348.
  29. Saposnik G, Baibergenova A, O'Donnell M, Hill MD, Kapral MK, Hachinski V. Hospital volume and stroke outcome: does it matter? *Neurology* 2007;69:1142–1151.
  30. Ogbu UC, Slobbe LC, Arah OA, de Bruin A, Stronks K, Westert GP. Hospital stroke volume and case-fatality revisited. *Med Care* 2010;48:149–156.
  31. Tung YC, Chang GM, Chen YH. Associations of physician volume and weekend admissions with ischemic stroke outcome in Taiwan: a nationwide population-based study. *Med Care* 2009;47:1018–1025.
  32. Ross JS, Normand SL, Wang Y, Ko DT, Chen J, Drye EE, et al. Hospital volume and 30-day mortality for three common medical conditions. *N Engl J Med* 2010;362:1110–1118.
  33. Asdaghi N, Wang K, Ciliberti-Vargas MA, Gutierrez CM, Koch S, Gardener H, et al. Predictors of thrombolysis administration

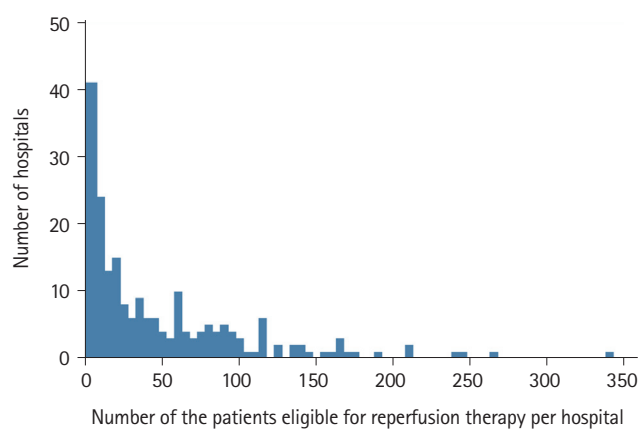
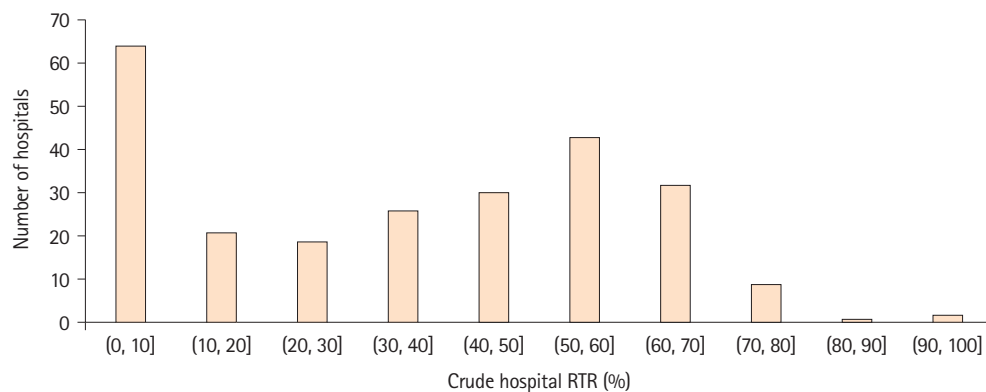
- in mild stroke: Florida–Puerto Rico Collaboration to Reduce Stroke Disparities. *Stroke* 2018;49:638–645.
34. Bergh E, Jahr SH, Rønning OM, Askim T, Thommessen B, Kristoffersen ES. Reasons and predictors of non-thrombolysis in patients with acute ischemic stroke admitted within 4.5 h. *Acta Neurol Scand* 2022;146:61–69.
  35. Reeves MJ, Smith EE, Fonarow GC, Zhao X, Thompson M, Peterson ED, et al. Variation and trends in the documentation of National Institutes of Health Stroke Scale in GWTG–Stroke hospitals. *Circ Cardiovasc Qual Outcomes* 2015;8(6 Suppl 3): S90–S98.
  36. Wang Y, Wang Y, Zhao X, Liu L, Wang D, Wang C, et al. Clopidogrel with aspirin in acute minor stroke or transient ischemic attack. *N Engl J Med* 2013;369:11–19.
  37. Johnston SC, Easton JD, Farrant M, Barsan W, Conwit RA, Elm JJ, et al. Clopidogrel and aspirin in acute ischemic stroke and high-risk TIA. *N Engl J Med* 2018;379:215–225.
  38. Yang BSK, Jang M, Lee KJ, Kim BJ, Han MK, Kim JT, et al. Comparison of hospital performance in acute ischemic stroke based on mortality and functional outcome in South Korea. *Circ Cardiovasc Qual Outcomes* 2023;16:554–565.
  39. Zeng M, Smith L, Bird A, Trinh VQ, Bacchi S, Harvey J, et al. Predictions for functional outcome and mortality in acute ischaemic stroke following successful endovascular thrombectomy. *BMJ Neurol Open* 2024;6:e000707.

**Supplementary Table 1.** Quartiles of hospital RTR and 1-year mortality after stroke

| Adjusted RTR (quartile) | Adjusted RTR (range) (%) | N   | Adjusted 1 year mortality (%) |                      | $P^*$  | $P^\dagger$ | Crude 1 year mortality (%) |                      | $P^*$  | $P^\dagger$ |
|-------------------------|--------------------------|-----|-------------------------------|----------------------|--------|-------------|----------------------------|----------------------|--------|-------------|
|                         |                          |     | Mean $\pm$ SD                 | Median (IQR) [range] |        |             | Mean $\pm$ SD              | Median (IQR) [range] |        |             |
| 1st                     | <41.52                   | 46  | 43.5 $\pm$ 21.4               | 43 (31–53) [0, 100]  | 0.2977 | 0.0703      | 27.7 $\pm$ 14.9            | 28 (14–40) [0, 55]   | 0.0417 | 0.0043      |
| 2nd                     | 41.52–56.9               | 46  | 40.5 $\pm$ 17.2               | 39 (31–47) [0, 85]   |        |             | 25.8 $\pm$ 11.6            | 26 (18–33) [0, 50]   |        |             |
| 3rd                     | 57.0–69.6                | 47  | 38.1 $\pm$ 12.0               | 36 (32–41) [21, 100] |        |             | 23.8 $\pm$ 8.2             | 23 (18–27) [11, 45]  |        |             |
| 4th                     | 69.7–100.0               | 46  | 37.9 $\pm$ 10.0               | 38 (32–43) [13, 66]  |        |             | 21.6 $\pm$ 5.2             | 22 (19–25) [9, 32]   |        |             |
| Overall                 |                          | 185 | 40.0 $\pm$ 15.8               | 38 (32–46) [0, 100]  |        |             | 24.7 $\pm$ 10.7            | 23 (18–30) [0, 55]   |        |             |

RTR, reperfusion therapy rates; SD, standard deviation; IQR, interquartile range; ANOVA, analysis of variance.

\* $P$ -value by ANOVA;  $^\dagger P$ -value by linear contrast test in ANOVA.

**Supplementary Figure 1.** Distribution of hospitals based on patient volume eligible for reperfusion therapy.**Supplementary Figure 2.** Histogram of the crude reperfusion therapy rates (RTR) of hospitals.