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# Composite Arterial and Venous Collateral Score on Single-Phase CTA Predicts 90-Day Outcomes in Anterior Circulation Large-Vessel Occlusion Stroke

Hamza A. Salim MD[1,2], Dhairya A. Lakhani MD[3,2], Janet Mei MD[2], Manisha Koneru MD[2], Aneri Balar MD[2,3], Meisam Hoseinyazdi MD[2], Shyam Majmundar MD[4], Dylan Wolman MD[5], Risheng Xu MD[6], Victor Urrutia MD[7], Elisabeth Breese Marsh MD[7], Thanh N. Nguyen MD[8], Judy Huang MD[2], David S. Liebeskind MD[9], Achala Vagal MD[10], Adam A. Dmytriw MD MPH MSc[11,12], Adrien Guenego MD[13], Gregory W Albers MD[14], Hanzhang Lu MD PhD[2], Kambiz Nael MD[15], Argye E. Hillis MD[7], Rafael Llinas MD[7], Max Wintermark MD[1], Tobias D. Faizy MD[16], Jeremy J. Heit MD PhD[14], Vivek Yedavalli MD[2]

1 Department of Neuroradiology, MD Anderson Medical Center, Houston, TX 77030, USA
2 Department of Radiology, Division of Neuroradiology, Johns Hopkins Medical Center, Baltimore, Maryland, USA
3 Department of Neuroradiology, Rockefeller Neuroscience Institute, West Virginia University, Morgantown, WV
4 Department of Neurology, University of Maryland Medical Center, Baltimore, Maryland, United States
5 Department of Radiology, Brown University, Providence, RI, USA
6 Department of Neurosurgery, Division of Neuroradiology, Johns Hopkins Medical Center, Baltimore, Maryland, USA
7 Department of Neurology, Division of Neuroradiology, Johns Hopkins Medical Center, Baltimore, Maryland, USA
8 Departments of Radiology & Neurology, Boston Medical Center, Boston, MA, USA
9 UCLA Stroke Center and Department of Neurology Department, UCLA, Los Angeles, California, USA
10 Departments of Radiology, University of Cincinnati Medical Center, OH;
11 Neuroendovascular Program, Massachusetts General Hospital & Brigham and Women's Hospital, Harvard Medical School, Boston, MA, USA
12 Department of Neuroradiology, Oxford University Hospitals NHS Foundation Trust, Nuffield Departments of Clinical Neurosciences and Surgical Sciences, University of Oxford, UK
13 Department of Diagnostic and Interventional Neuroradiology, Erasme University Hospital, Brussels, Belgium
14 Department of Interventional Neuroradiology, Stanford Medical Center, Palo Alto, California, USA
15 Department of Radiology & Biomedical Imaging, University of California, San Francisco, California, USA.
16 Department of Radiology, Neuroendovascular Program, University Medical Center Münster, Germany

***Corresponding author:**

Hamza A. Salim

The University of Texas MD Anderson Cancer Center

1515 Holcombe Blvd, Houston, TX 77030, USA

Email: HASalim@mdanderson.org

## ABSTRACT

*Background:* Collateral circulation influences clinical outcomes in patients with acute ischemic stroke due to anterior circulation large-vessel occlusion (LVO). While both arterial and venous collateral assessments on single-phase CTA have prognostic value, they have traditionally been evaluated independently.

*Purpose:* We developed the CTA Collateral Impairment Score (CCIS), a composite measure incorporating arterial (Tan) and venous (COVES) scores, and investigated its association with 90-day functional outcomes.

*Materials and Methods:* We conducted a retrospective cohort study including 1,080 patients with anterior circulation LVO stroke across four comprehensive stroke centers. Patients were assigned a CCIS of 0 (preserved), 1 (moderate impairment), or 2 (severe impairment) based on predefined thresholds for Tan and COVES scores.

*Results:* Favorable outcomes (mRS 0–2) occurred in 66% of patients with CCIS 0, 32% with CCIS 1, and 17% with CCIS 2 ($p<0.001$). Mortality increased with higher CCIS (11%, 25%, and 36% for CCIS 0, 1, and 2 respectively; $p<0.001$). In multivariable models, CCIS 0 and 1 were independently associated with greater odds of favorable outcomes compared with CCIS 2 (adjusted OR 5.77 [95% CI, 3.78–8.82] and 1.72 [95% CI, 1.14–2.60], respectively). CCIS also predicted mortality (adjusted OR for CCIS 0 vs. 2: 0.39 [95% CI, 0.25–0.61]; $p<0.001$). The predictive performance of CCIS (AUC 0.73) exceeded that of ASPECTS and occlusion site and approximated NIHSS; inclusion of CCIS improved multivariable model discrimination (AUC 0.84).

*Conclusions:* CCIS, a composite arterial and venous collateral score derived from single-phase CTA, was strongly and independently associated with 90-day outcomes in anterior circulation LVO stroke. Its integration into acute stroke imaging assessment may improve risk stratification and guide therapeutic decisions.

*What is already known on this topic*

Collateral circulation is a critical determinant of outcomes in acute ischemic stroke due to large-vessel occlusion (LVO). Arterial collateral assessment (Tan score) and venous collateral assessment (COVES) on single-phase CTA each have independent prognostic value, but they have traditionally been evaluated separately, and no single simple composite score is widely implemented.

*What this study adds*

We developed the CTA Collateral Impairment Score (CCIS), which combines arterial and venous collateral information into a simplified three-tier system derived entirely from single-phase CTA. In a large multicenter cohort of 1,080 patients with anterior circulation LVO, CCIS independently predicted 90-day functional outcomes and mortality, with stronger prognostic performance than either arterial or venous scores alone.

*How this study might affect research, practice or policy*

CCIS can be rapidly applied to routine single-phase CTA without requiring additional imaging or postprocessing, enabling fast collateral assessment at both comprehensive and primary stroke centers. Its integration into clinical workflows may improve risk stratification, guide therapeutic decisions, and serve as a simple reference standard for validating emerging automated collateral assessment tools.

## INTRODUCTION

The extent and status of collateral circulation are critical determinants of clinical outcomes in patients with acute ischemic stroke due to large-vessel occlusion (LVO) of the anterior circulation.[1,2] Robust pial collaterals can sustain cerebral perfusion in the setting of arterial occlusion, limit infarct growth, and increase the likelihood of favorable recovery.[3,4] Computed tomography angiography (CTA) is the most widely used modality to assess collateral status in the acute setting with a variety grading systems such as the Tan,[5] Maas,[6] or Miteff[7]. Among the available grading systems, the Tan score provides a semiquantitative assessment of arterial collateral filling and has been consistently associated with infarct size and clinical outcome.[1,8,9] Tan scores correlate with better functional outcomes, and has been incorporated into patient selection for endovascular therapy.[10,11]

More recently, the prognostic relevance of venous-phase imaging has been recognized. The Cortical Vein Opacification Score (COVES) was developed to assess the degree of venous contrast opacification in key cortical veins on CTA.[10,12,13] In one study, two-thirds of patients who developed malignant cerebral edema had no venous opacification on CTA, compared to only 5% among those without edema.[12] Conversely, higher COVES values have been linked to favorable 90-day outcomes. Hoffman *et al.* reported that an "unfavorable" venous score was independently associated with a three-fold higher odds of poor functional outcome at 90 days.[14,15]

In this study, we introduce the CTA Collateral Impairment Score (CCIS), a composite measure derived from the Tan and COVES scores, and evaluate its association with 90-day clinical outcomes in a large, multicenter cohort of patients with anterior circulation LVO. We hypothesized that higher CCIS values, indicating more severely impaired collateral circulation, would be independently associated with worse functional outcomes and increased mortality.

## METHODS

This retrospective multicenter cohort study included data from four comprehensive stroke centers. Institutional review boards at all centers approved the study, with a waiver of informed consent.[16–34] The study adhered to the Declaration of Helsinki and complied with HIPAA regulations. Reporting followed the STROBE guidelines.

*Study Population*

Patients were identified from prospectively maintained acute ischemic stroke (AIS) registries at four comprehensive stroke centers. Data were collected from September 1, 2017 to September 22, 2022.

Inclusion criteria were: (1) AIS due to CT angiography (CTA)-confirmed anterior circulation large vessel occlusion (LVO; internal carotid artery, M1, or M2 segment); (2) available Tan score and COVES assessment; (3) availability of 90-day modified Rankin Scale (mRS).

*Data Collection*

The data were obtained from electronic health records and stroke center databases. The gathered data encompassed patient characteristics such as age, sex, and medical history, including risk factors for acute ischemic stroke (diabetes mellitus, hypertension, coronary artery disease, atrial fibrillation). Additionally, the data included admission National Institutes of Health Stroke Scale (NIHSS) score, Alberta Stroke Program Early CT Score (ASPECTS), occlusion site, and administration or performance of IVT or MT. Modified Rankin Scale scores at discharge and 90 days (90-day mRS) were determined by a stroke neurologist or certified nurse practitioner.

The administration of intravenous thrombolysis (IVT) and the performance of mechanical thrombectomy (MT) were determined on a case-by-case basis, following a consensus appraisal by the stroke team according to our institution's protocols.

*Imaging Analysis and parameters*

The evaluation of all images was performed by experienced board-certified neuroradiologists. (>8 years of experience in stroke imaging)

*Non-Contrast CT (NCCT)*

NCCT scans in our study were conducted using helical scanning technique. The scans were performed with each slice having a thickness of 5 mm and a reconstruction resolution of 0.75 mm. The kilovoltage peak (kVp) was set at 120, and the milliampere-seconds (mAs) were set at 365. The rotation time of the CT scanner was maintained at 1 second, and the total acquisition time for each scan ranged between 6 to 8 seconds. The collimation of the scans was 128 x 0.6 mm, and a pitch value of 0.55 was used. All scans were performed in a craniocaudal direction.

*Pretreatment CTA*

The CTA of the head and neck in our study was carried out with administration of non-ionic iodinated contrast material in the volume range of 50-70 ml, injected at a flow rate of 5-6 ml per second. The contrast was introduced from the aortic arch through to the vertex of the head, employing a bolus-triggered technique. The scanning process was conducted with a slice thickness of 3 mm and further refined with 0.75 mm reconstructions. The CTA scanning parameters were the kVp was adjusted to a range of 90/150 with the utilization of an Sn filter. The Quality Reference mAs was set to 180. The rotation time was 0.25 seconds, with an average acquisition time ranging from 3 to 5 seconds for efficient imaging. The collimation was set at 128 x 0.6 mm, and a pitch value of 0.7 was used. The scans were conducted in a craniocaudal direction.

The Cortical Vein Opacification Score (COVES) grading[35] was independently assessed by board certified neuroradiologists. COVES scores ranged from 0 to 6, COVES score of 0-2 is considered as poor collateral filling, and COVES score of 3 to 6 is considered as good collateral filling. This score was obtained by assessing venous opacification as absent (0), partial (1), or full (2) for the vein of Labbé, sphenoparietal sinus, and superficial middle cerebral vein for the cerebral hemisphere ipsilateral to the occlusion[35]

The Tan score was calculated using a 4-point grading system, ranging from 0 to 3, to evaluate arterial filling in the affected territory, where a score of 1 indicates arterial contrast filling of ≤50% of the occluded MCA territory, a score of 2 indicates filling in >50% but <100%, and a score of 3 indicates filling in 100% of the occluded territory.[36]

The CCIS was calculated using a composite of Tan and COVES scores to reflect the severity of collateral impairment. Patients received a CCIS of 2 if they had both a Tan score of 0-1 and a COVES score of 0-2 (severely impaired collaterals). A CCIS of 1 was assigned if either the Tan score was 0-1 or the COVES score was 0-2 (moderately impaired collaterals). A CCIS of 0 was given when neither criterion was met (preserved collaterals). The CCIS are demonstrated through case examples in Figures 1-2.

*Statistical Analysis*

Continuous data are reported as medians and interquartile ranges (IQR), and categorical variables as frequencies and percentages. Baseline characteristics and clinical outcomes were compared across CTA collateral impairment score (CCIS) categories (0-2) using the Kruskal-Wallis rank sum test for continuous variables and Pearson's chi-squared or Fisher's exact test for categorical variables.

Univariate and multivariate logistic regression analyses were conducted to assess the association between elevated CCIS and 90-day modified Rankin Scale (mRS) outcomes, including favorable outcomes (mRS 0-1, 0-2, and 0-3), mortality and HT. Multivariate models were adjusted for age, sex, smoking, occlusion location ,occlusion laterality, admission NIHSS, MT administration, IV thrombolysis (IVT) administration, and ASPECTS scores. R statistical software (version 4.3.0, R Project for Statistical Computing) and Rstudio statistical software (version 2023.03.0+386, Rstudio) were used for statistical analyses and data visualization.

**RESULTS**

*Baseline Characteristics*

A total of 1,080 patients met the inclusion criteria and were categorized by CCIS of 0 (n=379), 1 (n=388), and 2 (n=313). Baseline demographic and clinical characteristics, including age, admission NIHSS scores, smoking status, and occlusion segments significantly differed among groups (**Table 1**).Procedural and imaging characteristics varied across CCIS categories (**Table 2**).

*Outcomes*

Clinical outcomes at 90 days differed significantly among CCIS groups (**Table 3**). Favorable outcomes (mRS 0-2) occurred in 66% of patients with CCIS 0, 32% with CCIS 1, and 17% with CCIS 2 ($p<0.001$). Mortality rates were significantly higher in patients with higher CCIS scores (CCIS 0: 11%, CCIS 1: 25%, CCIS 2: 36%; $p<0.001$). (**Figure 3**) The incidence of HT and parenchymal hematoma (PH) increased significantly with higher CCIS ($p=0.001$ and $p=0.002$, respectively).

*Multivariate Logistic Regression Analyses*

In multivariate logistic regression analyses (Table 4), elevated CCIS was independently associated with decreased odds of achieving favorable 90-day outcomes (mRS 0-2; CCIS 1 vs. 2: adjusted OR 1.72; 95% CI 1.14 to 2.60; $p=0.009$, CCIS 0 vs. 2: adjusted OR 5.77; 95% CI 3.78 to 8.82; $p<0.001$). Similar associations were observed for 90-day mRS 0-1 and mRS 0-3 outcomes. Elevated CCIS also independently associated with increased odds of mortality (CCIS 0 vs. 2: adjusted OR 0.39; 95% CI 0.25 to 0.61; $p<0.001$). However, there were no significant independent associations between CCIS categories and HT, PH, or hemorrhagic infarction (HI).

*CCIS Predictive Performance*

In ROC analyses, CCIS demonstrated higher predictive accuracy for 90-day poor functional outcomes (mRS 3-6) compared to the Tan score (AUC 0.73 vs. 0.62) and COVES (AUC 0.73 vs. 0.7). Moreover, CCIS showed predictive power for 90-day mRS 3–6 (AUC 0.73), outperforming age, ASPECTS, and

occlusion segment, and closely matching NIHSS (AUC 0.75). The multivariable model including CCIS yielded the highest AUC (0.84) (**Figure 4**).

*Association Between CCIS and Poor Outcomes*

Higher CCIS was associated with increased probability of mRS 3–6: 37% for CCIS 0, 67% for CCIS 1, and 84% for CCIS 2 (**Figure 5**)

## DISCUSSION

In this multicenter retrospective cohort study of 1,080 patients with anterior circulation LVO stroke, we found that the CCIS was strongly and independently associated with 90-day clinical outcomes. Patients with lower CCIS values had significantly higher odds of achieving favorable functional outcomes (mRS 0-2) and lower mortality rates, even after adjusting for known confounders including age, baseline NIHSS, ASPECTS, and treatment with thrombolysis or thrombectomy.

Although both the Tan and COVES scores can be derived from single-phase CTA, they have traditionally been evaluated separately despite their physiologic interdependence. Single-phase CTA is widely available and rapidly acquired, whereas multiphase CTA provides improved temporal resolution but is not universally accessible and adds workflow complexity.[9,10,14] Maximizing the prognostic utility of single-phase CTA therefore remains a priority. The Tan score uses a four-tier scale to assess arterial collateral filling[36], while the COVES score grades venous outflow using a three-tier system for each of three cortical veins (score range, 0-6).[15] CCIS integrates these established metrics into a simplified three-category framework that captures both arterial inflow and venous outflow, enabling rapid interpretation in routine workflows, including settings without advanced imaging or multiphase CTA.

CCIS captured the combined impact of impaired arterial inflow and inadequate venous outflow on tissue perfusion more comprehensively than either measure alone. This enhanced prognostic capability was evidenced by the graded relationship between CCIS values and outcomes: favorable 90-day functional outcomes occurred in 66% of patients with preserved collaterals (CCIS=0) versus only 17% in those with

severely impaired collaterals (CCIS=2). Similarly, mortality significantly increased with collateral impairment, ranging from 11% in patients with CCIS=0 to 36% with CCIS=2. Importantly, outcomes differed significantly not only across the extremes of CCIS but also between intermediate (CCIS = 1) and severely impaired (CCIS = 2) groups, highlighting that the combined score captures clinically relevant information, that may be overlooked when either score is used alone.

Our results align with and extend previous smaller-scale studies. Parthasarathy et al. introduced a similar combined collateral assessment (the CRISP score) and demonstrated its prognostic superiority compared to separate arterial or venous scores.[37]

A key advantage of CCIS is its ability to overcome known limitations of single-phase CTA, which provides a static snapshot and may misrepresent collateral status in cases of delayed contrast filling. A combined arterial and venous assessment mitigates this limitation by capturing perfusion both upstream and downstream of the occlusion. In particular, discordant findings, such as good arterial collaterals with poor venous opacification, may arise due to persistent forward flow through an occlusion or the no-reflow phenomenon, resulting in deceptively favorable arterial grades but inadequate microvascular perfusion.[37–39] CCIS captures this mismatch and may therefore provide a more reliable indicator of true collateral function.

From a clinical perspective, CCIS offers several practical advantages. Because it is derived from standard single-phase CTA, it requires no additional image acquisition or postprocessing, enabling rapid application without workflow disruption. Importantly, even among patients with severely impaired collaterals (CCIS = 2), 17% achieved functional independence at 90 days. This highlights that poor collateral status does not preclude recovery when reperfusion is achieved, consistent with outcomes seen in recent large-core thrombectomy trials, demonstrating that even patients with extensive baseline injury and severe strokes can benefit from timely reperfusion therapy.[40] CCIS is therefore intended as an adjunct for risk stratification and counseling, not as a determinant for treatment exclusion. Its use should complement,

not replace, evidence-based reperfusion strategies that confer benefit even in patients with impaired collaterals.

Another important consideration is that collateral assessment continues to evolve, with emerging quantitative and machine-learning approaches offering increasingly standardized and reproducible adjuncts to visual grading.[41,42] The CCIS framework could serve as a simple reference standard for validating such automated techniques, potentially enabling fast, scalable collateral evaluation across diverse clinical settings.

Several limitations should be acknowledged. First, the retrospective design introduces potential for selection and information bias, though we mitigated this by including a large, multicenter cohort and applying standardized image interpretation by board-certified neuroradiologists. Second, although Tan and COVES are well-validated scoring systems, single-phase CTA may underestimate collateral filling in cases of delayed flow, potentially affecting the accuracy of CCIS in select patients. In particular, the moderate-impairment category (CCIS = 1) combines patients with discordant collateral patterns (good arterial but poor venous collaterals, or vice versa), which may lead to over- or underestimation of collateral impairment in some cases. Third, we did not compare CCIS with perfusion-based indices or time-resolved collateral scores, which remain reference standards in some institutions. Fourth, this study focused exclusively on anterior circulation LVO, and the generalizability of CCIS to posterior circulation strokes warrants further evaluation. Finally, although interrater agreement for this study was not directly measured, both Tan and COVES have demonstrated good reproducibility in prior studies (Tan $\kappa = 0.76$; COVES $\kappa = 0.73$)[43,44].

## CONCLUSION

In patients with acute ischemic stroke due to anterior circulation large-vessel occlusion, CCIS was strongly and independently associated with 90-day functional outcomes and mortality. As CCIS can be derived efficiently from single-phase CTA without additional imaging requirements, it represents a practical and

reliable prognostic tool that could facilitate rapid clinical decision-making and patient selection for endovascular therapy. Further prospective validation, particularly in comparison to multiphase CTA and perfusion imaging, is warranted to confirm these findings and clarify its broader applicability.

## Disclosure Statements

*Funding*: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

*Ethics Approval*: This study was approved by the Institutional Review Boards of all participating centers with a waiver of informed consent due to its retrospective nature.

*Conflicts of Interest*: The authors declare no conflicts of interest relevant to this study.

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Table 1: Baseline Demographic and Clinical Characteristics Stratified by CTA collateral impairment score (CCIS)

| Variable | 0 | 1 | 2 | P[1] |
|---|---|---|---|---|
| | N = 379 | N = 388 | N = 313 | |
| **Age, Median (Q1, Q3)** | 71 (62, 80) | 74 (62, 83) | 75 (64, 83) | 0.021 |
| **Sex, n (%)** | | | | 0.48 |
| **Female** | 206 (79) | 193 (82) | 151 (78) | |
| **Male** | 56 (21) | 42 (18) | 43 (22) | |
| **Race, n (%)** | | | | 0.59 |
| **Black** | 48 (40) | 43 (41) | 49 (47) | |
| **White** | 60 (50) | 54 (51) | 51 (49) | |
| **Asian** | 7 (5.8) | 4 (3.8) | 1 (1.0) | |
| **Other/UTD** | 5 (4.2) | 5 (4.7) | 4 (3.8) | |
| **Occlusion Segment, n (%)** | | | | <0.001 |
| **ICA** | 49 (13) | 74 (19) | 81 (26) | |
| **M1** | 209 (55) | 250 (64) | 200 (64) | |
| **M2** | 121 (32) | 64 (16) | 32 (10) | |
| **Smoking Status, n (%)** | 142 (39) | 117 (31) | 95 (32) | 0.048 |
| **Hypertension, n (%)** | 268 (71) | 275 (71) | 232 (75) | 0.47 |
| **Dyslipidemia, n (%)** | 150 (42) | 134 (36) | 107 (38) | 0.26 |
| **Diabetes, n (%)** | 90 (24) | 88 (23) | 79 (25) | 0.7 |
| **Admission NIHSS Score, Median (Q1, Q3)** | 11 (7, 17) | 15 (10, 20) | 18 (13, 22) | <0.001 |
| **Occlusion Laterality, n (%)** | | | | 0.67 |
| **left** | 208 (79) | 194 (77) | 160 (76) | |
| **right** | 52 (20) | 57 (23) | 50 (24) | |
| **bilateral** | 2 (0.8) | 1 (0.4) | 0 (0) | |

[1] **Kruskal-Wallis rank sum test; Pearson's Chi-squared test; Fisher's exact test**

Table 2: Procedural and Imaging Characteristics Stratified by CTA collateral impairment score (CCIS)

| Variable | 0 | 1 | 2 | P[1] |
|---|---|---|---|---|
| | N = 379 | N = 388 | N = 313 | |
| **ASPECTS, Median (Q1, Q3)** | 9.00 (8.00, 10.00) | 8.00 (7.00, 10.00) | 7.00 (6.00, 9.00) | <0.001 |
| **rCBF <20% volume (mL), Median (Q1, Q3)** | 0 (0, 0) | 0 (0, 6) | 5 (0, 24) | <0.001 |
| **rCBF <30% volume (mL), Median (Q1, Q3)** | 0 (0, 10) | 10 (0, 30) | 30 (8, 64) | <0.001 |
| **rCBF <34% volume (mL), Median (Q1, Q3)** | 0 (0, 14) | 10 (0, 33) | 33 (6, 73) | <0.001 |
| **rCBF <38% volume (mL), Median (Q1, Q3)** | 6 (0, 21) | 15 (0, 43) | 40 (10, 85) | <0.001 |
| **Tmax >4s volume (mL), Median (Q1, Q3)** | 157 (68, 239) | 198 (125, 311) | 222 (143, 326) | <0.001 |
| **Tmax >6s volume (mL), Median (Q1, Q3)** | 84 (48, 131) | 123 (70, 171) | 145 (99, 196) | <0.001 |
| **Tmax >8s volume (mL), Median (Q1, Q3)** | 37 (5, 76) | 71 (27, 119) | 104 (51, 147) | <0.001 |
| **Tmax >10s volume (mL), Median (Q1, Q3)** | 21 (8, 50) | 48 (21, 91) | 81 (42, 117) | <0.001 |
| **Mismatch Volume (mL), Median (Q1, Q3)** | 60 (17, 113) | 94 (45, 145) | 95 (54, 145) | <0.001 |
| **Mismatch Ratio, Median (Q1, Q3)** | 4 (0, 10) | 4 (2, 10) | 3 (2, 6) | 0.053 |
| **Hypoperfusion Intensity Ratio (HIR), Median (Q1, Q3)** | 0.30 (0.14, 0.40) | 0.50 (0.30, 0.60) | 0.60 (0.40, 0.70) | <0.001 |
| **CBV <34%, Median (Q1, Q3)** | 0 (0, 7) | 3 (0, 21) | 15 (0, 56) | <0.001 |
| **CBV <38%, Median (Q1, Q3)** | 0 (0, 8) | 5 (0, 25) | 19 (0, 63) | <0.001 |
| **CBV <42%, Median (Q1, Q3)** | 0 (0, 11) | 6 (0, 28) | 22 (4, 68) | <0.001 |
| **CBV Index, Median (Q1, Q3)** | 0.80 (0.70, 0.90) | 0.80 (0.70, 0.90) | 0.70 (0.60, 0.80) | 0.005 |
| **Tan score, n (%)** | | | | <0.001 |
| **0-1** | 0 (0) | 67 (17) | 313 (100) | |
| **2-3** | 379 (100) | 321 (83) | 0 (0) | |
| **COVES, n (%)** | | | | <0.001 |
| **0-2** | 0 (0) | 321 (83) | 313 (100) | |
| **3-6** | 379 (100) | 67 (17) | 0 (0) | |
| **IVT Administered, n (%)** | 198 (52) | 160 (42) | 128 (42) | 0.003 |
| **MT Attempted, n (%)** | 305 (80) | 333 (86) | 259 (83) | 0.14 |
| **Type of Thrombectomy, n (%)** | | | | 0.87 |
| **Direct Aspiration** | 38 (53) | 40 (56) | 39 (54) | |
| **Stent Retriever** | 10 (14) | 7 (9.7) | 7 (9.7) | |
| **Combined** | 22 (31) | 25 (35) | 25 (35) | |
| **Number of Passes, Median (Q1, Q3)** | 1.00 (1.00, 2.00) | 1.00 (1.00, 2.00) | 1.00 (1.00, 2.50) | 0.059 |
| **Type of Anesthesia Used, n (%)** | | | | 0.87 |
| **General** | 71 (92) | 70 (91) | 69 (93) | |
| **MAC** | 6 (7.8) | 7 (9.1) | 5 (6.8) | |
| **Symptom Onset to Door Time (mins), Median (Q1, Q3)** | 68 (46, 286) | 60 (49, 158) | 70 (37, 138) | 0.72 |
| **Door to CT Time (minutes), Median (Q1, Q3)** | 29 (19, 45) | 23 (13, 39) | 30 (16, 45) | 0.075 |
| **Door to Needle Time (minutes), Median (Q1, Q3)** | 87 (62, 150) | 85 (63, 120) | 84 (55, 124) | 0.29 |
| **Groin Puncture to First Pass Time (minutes), Median (Q1, Q3)** | 23 (18, 32) | 24 (16, 35) | 21 (15, 30) | 0.48 |
| **Door to Recanalization Time (mins), Median (Q1, Q3)** | 413 (253, 864) | 334 (210, 744) | 326 (191, 645) | 0.18 |
| **Groin Puncture to Recanalization Time (minutes), Median (Q1, Q3)** | 31 (23, 50) | 37 (22, 57) | 33 (22, 73) | 0.52 |

[1] **Kruskal-Wallis rank sum test; Pearson's Chi-squared test; Fisher's exact test**

Table 3: 90-Day Clinical Outcomes and Infarct Volumes by CTA collateral impairment score (CCIS)

| Variable | 0 | 1 | 2 | P[1] |
|---|---|---|---|---|
| | N = 379 | N = 388 | N = 313 | |
| **Hemorrhagic Transformation (HT), n (%)** | 102 (29) | 148 (41) | 114 (41) | 0.001 |
| **Parenchymal Hematoma (PH), n (%)** | 34 (9.7) | 64 (18) | 52 (19) | 0.002 |
| **Hemorrhagic Infarction (HI), n (%)** | 65 (19) | 81 (23) | 60 (22) | 0.41 |
| **Discharge NIHSS, Median (Q1, Q3)** | 2 (1, 5) | 7 (2, 15) | 13 (5, 19) | <0.001 |
| **90-days mRS 0-2, n (%)** | 250 (66) | 124 (32) | 54 (17) | <0.001 |
| **90-days mRS 0-1, n (%)** | 183 (48) | 91 (23) | 33 (11) | <0.001 |
| **90-days mRS 0-3, n (%)** | 287 (76) | 166 (43) | 80 (26) | <0.001 |
| **90-days mRS 5-6, n (%)** | 56 (15) | 145 (37) | 166 (53) | <0.001 |
| **90-days mRS 6 (Mortality), n (%)** | 43 (11) | 97 (25) | 112 (36) | <0.001 |

[1] **Kruskal-Wallis rank sum test; Pearson's Chi-squared test; Fisher's exact test**

Table 4: Association of Elevated CTA collateral impairment score (CCIS) with Clinical Outcomes: Univariable and Multivariable Logistic Regression Analyses

| Outcome | CCIS | Unadjusted | | Adjusted* | |
|---|---|---|---|---|---|
| | | OR (95% CI) | p-value | OR (95% CI) | p-value |
| **90-days mRS 0-2** | 2 | *Reference* | | *Reference* | |
| | 1 | 2.25 (1.57 to 3.24) | <0.001 | 1.72 (1.14 to 2.60) | 0.009 |
| | 0 | 9.30 (6.47 to 13.4) | <0.001 | 5.77 (3.78 to 8.82) | <0.001 |
| **90-days mRS 0-3** | 2 | *Reference* | | *Reference* | |
| | 1 | 2.18 (1.57 to 3.01) | <0.001 | 1.76 (1.22 to 2.53) | 0.002 |
| | 0 | 9.09 (6.43 to 12.8) | <0.001 | 5.97 (4.00 to 8.91) | <0.001 |
| **90-days mRS 0-1** | 2 | *Reference* | | *Reference* | |
| | 1 | ing | <0.001 | 1.94 (1.21 to 3.10) | 0.006 |
| | 0 | 7.92 (5.24 to 12.0) | <0.001 | 4.42 (2.76 to 7.06) | <0.001 |
| **90-days mRS 5-6** | 2 | *Reference* | | *Reference* | |
| | 1 | 0.53 (0.39 to 0.72) | <0.001 | 0.67 (0.48 to 0.94) | 0.021 |
| | 0 | 0.15 (0.11 to 0.22) | <0.001 | 0.26 (0.17 to 0.40) | <0.001 |
| **90-days mRS 6 (Mortality)** | 2 | *Reference* | | *Reference* | |
| | 1 | 0.60 (0.43 to 0.83) | 0.002 | 0.76 (0.53 to 1.09) | 0.13 |
| | 0 | 0.23 (0.16 to 0.34) | <0.001 | 0.39 (0.25 to 0.61) | <0.001 |
| **Hemorrhagic Transformation (HT)** | 2 | *Reference* | | *Reference* | |
| | 1 | 1.01 (0.73 to 1.39) | 0.95 | 1.20 (0.86 to 1.69) | 0.28 |
| | 0 | 0.60 (0.43 to 0.83) | 0.002 | 0.82 (0.56 to 1.20) | 0.31 |
| **Parenchymal Hematoma (PH)** | 2 | *Reference* | | *Reference* | |
| | 1 | 0.94 (0.63 to 1.42) | 0.78 | 1.17 (0.76 to 1.79) | 0.47 |
| | 0 | 0.47 (0.29 to 0.75) | 0.001 | 0.72 (0.43 to 1.21) | 0.21 |
| **Hemorrhagic Infarction (HI)** | 2 | *Reference* | | *Reference* | |
| | 1 | 1.06 (0.73 to 1.55) | 0.76 | 1.12 (0.76 to 1.66) | 0.57 |
| | 0 | 0.83 (0.56 to 1.23) | 0.36 | 0.91 (0.58 to 1.41) | 0.67 |

**Abbreviations: CI = Confidence Interval, OR = Odds Ratio**

***Adjusted for age, sex, smoking, occlusion location ,occlusion laterality, admission NIHSS, MT, IVT Administration, ASPECTS**

**Figures**

*Figure 1:* Axial single-phase CTA source images from a patient in their sixties with acute right M1 occlusion demonstrate absent arterial and venous collaterals (Tan score = 0; COVES = 0). (A) Markedly reduced arterial filling in the right MCA territory, consistent with Tan score 0. (B) Absent opacification of the vein of Labbé (orange arrow). (C) No visualization of the superficial middle cerebral vein (blue arrow). (D) Absent sphenoparietal sinus opacification. This patient was classified as having severely impaired collaterals (CCIS 2) and died during follow-up (mRS 6 at 90 days).

*Figure 2:* Axial single-phase CTA images from a patient in their eighties with acute left M1 occlusion show preserved arterial and venous collateralization (Tan score = 2; COVES = 5). (A) Partial opacification of the vein of Labbé (blue arrow) and proximal arterial occlusion at the left M1 segment (orange arrow). (B) Full opacification of the superficial middle cerebral vein (green arrow). (C) Full opacification of the sphenoparietal sinus (yellow arrow). (D) Adequate arterial collateral filling involving >50% but <100% of the MCA territory, consistent with Tan score 2. This patient was classified as having CCIS of 0.

*Figure 3:* Distribution of 90-Day Modified Rankin Scale Outcomes Stratified by CCIS

*Figure 4:* Comparison of Predictive Accuracy (ROC Curves) of CCIS and Other Clinical and Imaging Predictors for 90-day Poor Outcomes (mRS 3–6)

*Figure 5:* Predictive Performance and Probability of Poor Outcomes (mRS 3–6) Based on CCIS Categories