# RADIOLOGICAL METHODS AND METHODOLOGIES FOR ASSESSING COLLATERAL BLOOD CIRCULATION OF THE BRAIN

**[1]Tamaz Jaoshvili, [2]Erekle Gigiadze, [1]Nikoloz Sainishvili**

**[1]David Aghmashenebeli University of Georgia, [2]SEU**

**DOI:** https://doi.org/10.52340/spectri.2025.12.02.03

**Collateral circulation** is assigned a **decisive role** in the final outcome of ischemic stroke. Accordingly, the refinement of various methods and methodologies for assessing this system is becoming increasingly relevant. Currently, there are numerous **radiological methods** that allow us to assess not only the anatomy of collateral circulation but also to gain an understanding of its quantitative characteristics. Furthermore, the modern radiological literature publishes the latest studies comparing various methodologies for the **qualitative and quantitative assessment** of collateral circulation to determine which of them is more accurate and yielding better results.

## აბსტრაქტი

## ტვინის კოლატერალური სისხლის მიმოქცევის შეფასების რადიოლოგიური მეთოდები და მეთოდოლოგიები

[1]თამაზ ჯაოშვილი, დოქტორანტი

[2]ერეკლე გიგიაძე, პროფესორი

[1]ნიკოლოზ საინიშვილი, პროფესორი

[1]საქართველოს დავით აღმაშენებლის სახელობის უნივერსიტეტი; [2]სეუ

კოლატერალურ სისხლის მიმოქცევას ენიჭება გადამწყვეტი როლი იშემიური ინსულტის საბოლოო გამოსავალში.შესაბამისად დღითიდღე აქტუალური ხდება სისტემის შეფასების სხვადასხვა მეთოდების და მეთოდოლოგიების დახვეწა. დღესდღეობით არსებობს მრავალი რადიოლოგიური მეთოდი,რომლებიც საშუალება სგვაძლევენ შევაფასოთ არა მხოლოდ კოლატერალუი სისხლის მიმოქცევის

ანატომია,არამედ წარმოდგენა შევიქმნათ მის რაოდენობრივ მახასიათებლებზეც. ასევე, თანამედროვე რადიოლოგიური ლიტერატურაში ქვეყნდება უახლესი კვლევები,რომლის საშულებითაც ერთმანეთს დარდება კოლატერალური სისხლის მიმოქცევის თვისოვრივი და რაოდენობრივი შეფასების სხვადასხვა მეთოდოლოგიები, რათა დადგინდეს, თუ რომელი მათგანია უფრო ზუსტი და შედეგის მომცემი.

**Key words:** Cerebral infarction, Collateral circulation, Radiological methods of collateral assessment, Normal anatomy of collaterals.

Well-perfused blood flow via collaterals may **increase the benefit of endovascular treatment** in acute ischemic stroke and reduce the risk of hemorrhagic transformation. It also significantly **reduces the risk of recurrent stroke** in patients with symptomatic intracranial atherosclerotic stenosis and **decreases the volume of the infarct core** during ischemic stroke.

Accurate assessment of the **anatomy and function of cerebral collateral circulation** is an important prerequisite for the individualized management of stroke patients. Currently, the assessment and intervention of collateral circulation in ischemic stroke is a subject of **active research**. Various imaging criteria have been developed to assess collateral status and correlate with prognosis in stroke patients. There are also interventions aimed at **enhancing collateral circulation** in stroke patients.

**Abbreviations**

| **Abbreviation** | **Full Name** |
|---|---|
| **DSA** | Digital Subtraction Angiography |
| **TCD** | Transcranial Doppler |
| **TOF-MRA** | Time-of-Flight Magnetic Resonance Angiography |

| Abbreviation | Full Name |
|---|---|
| **CTA** | Computed Tomography Angiography |
| **SPECT** | Single-Photon Emission Computed Tomography |
| **PET** | Positron Emission Tomography |
| **CTP** | Computed Tomography Perfusion |
| **QMRA** | Quantitative Magnetic Resonance Angiography |
| **ASL** | Arterial Spin Labelling |
| **MCA** | Middle Cerebral Artery |
| **ACA** | Anterior Cerebral Artery |
| **PCA** | Posterior Cerebral Artery |
| **ASITN/SIR** | American Society of Interventional and Therapeutic Neuroradiology / Society of Interventional Radiology |

---

**Overview of Assessment Methods**

Currently, many radiological methods exist for assessing collateral circulation (Table 1).

The **gold standard** for assessment is **Digital Subtraction Angiography (DSA)**. However, due to the invasiveness and high cost of the procedure, it is not frequently used (Fig. 1) [3].

**Table 1: Various Radiological Methods for Assessing Collateral Circulation**

| |
|---|
| 1. Transcranial Doppler (TCD) |
| 2. Transcranial Color Duplex Scanning |
| 3. Routine, Single-Phase Computed Tomography (CT) |
| 4. Computed Tomography Angiography (CTA) |
| 5. Computed Tomography Perfusion (CTP) |
| 6. Non-contrast MRI Angiography (TOF-MRA) |
| 7. Contrast-enhanced MRI Angiography |
| 8. Digital Subtraction Angiography (DSA) |
| 9. Xenon Computed Tomography (Xenon-CT) |
| 10. Single-Photon Emission Computed Tomography (SPECT) |
| 11. Positron Emission Tomography (PET) |
| 12. MRI Perfusion (MRP) |

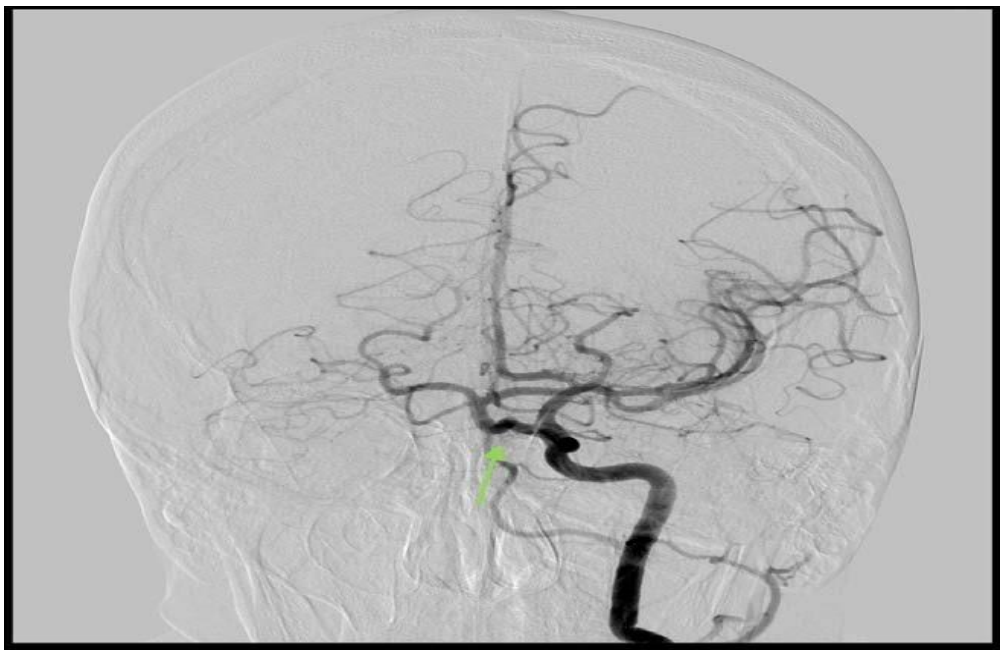


FIG. 1. DIGITAL SUBSTRACTION ANGIOGRAPHY(DSA)

**TCD**, as a non-invasive examination method, reflects the cerebral blood flow velocity, collateral status, and cerebrovascular reactivity in real-time. It is characterized by low cost, but the accuracy of TCD in diagnosing cerebrovascular anomalies is highly dependent on the operator's (radiologist's) experience. Collateral flow via the anterior communicating artery, posterior communicating artery, ophthalmic artery, and leptomeningeal arteries can be detected directly or indirectly by TCD. According to some studies, the sensitivity and specificity of TCD in detecting collateral flow via the anterior communicating artery and basilar artery were 95% and 87%, and 100% and 95%, respectively, compared to the gold standard, which was considered DSA.

FIG. 2. NON CONTRAST MRI ANGIOGRAPHY, TOF (TIME-OF-FLIGHT)

**TCD**, as a non-invasive examination method, reflects the cerebral blood flow velocity, collateral status, and cerebrovascular reactivity in real-time. It is characterized by low cost, but the accuracy of TCD in diagnosing cerebrovascular anomalies is highly dependent on the operator's (radiologist's) experience. Collateral flow via the anterior communicating artery, posterior communicating artery, ophthalmic artery, and leptomeningeal arteries can be detected directly or indirectly by TCD. According to some studies, the sensitivity and specificity of TCD in detecting collateral flow via the anterior communicating artery and basilar artery were 95% and 87%, and 100% and 95%, respectively, compared to the gold standard, which was considered DSA.

**TOF-MRA** (Non-contrast MRI Angiography) is another non-invasive method commonly used to assess the structure of cerebral collateral circulation. The reliability of TOF-MRA for assessing leptomeningeal collaterals is limited due to its relatively low spatial resolution. TOF-MRA is typically used to assess **first-order collaterals** in the Circle of Willis. In various studies, compared to DSA as the gold standard, the sensitivity and specificity of TOF-MRA for detecting collateral flow via the anterior circulation of the Circle of Willis were 83% and 77%, and for the posterior part of the Circle of Willis, 33% and 88%, respectively (Fig. 2) [4].

**CTA** is also a non-invasive method that has high accuracy in assessing the patency of arterial segments in the Circle of Willis, showing >90% concordance with DSA, but its sensitivity (53%) is limited for imaging hypoplastic arterial segments. Blood flow via collaterals may be delayed compared to normal antegrade flow. Thus, traditional single-phase CTA may underestimate the compensatory collateral flow. Currently, **Multi-Phase CTA** (or Dynamic CTA, or Four-Dimensional CTA) is increasingly used in clinical studies to assess cerebral collateral status [5].

Various visualization methods exist to assess the function of cerebral collateral circulation, such as cerebrovascular reserve using **TCD**, **Xenon-CT**, **SPECT**, **PET**, **CTP**, **QMRA**, traditional dynamic susceptibility contrast-enhanced **MR Perfusion (MRP)**, and **Arterial Spin Labeling (ASL)**. These visualization methods typically assess the direction/velocity/volume of cerebral blood flow or the perfusion status. Consequently, they accurately reflect the compensatory function of collateral blood flow. Some modern visualization methods can simultaneously detect both the structure and function of collateral circulation; for example, QMRA can reveal the direction of blood flow via collateral channels and quantitatively determine the total/regional cerebral blood flow.

Currently, there are many different methodological scales for assessing collateral circulation, which are adapted according to various radiological examination methods (Table 2).

| | |
|---|---|
| CT | 1. Miteff collateral grading method<br>2.Maas collateral grading method<br>3.Tan collateral grading system<br>4.The Alberta Stroke Program Early CT Score 20-point methodology<br>5.Regional leptomeningeal collateral (rLMC) score<br>6.ACA-MCA and PCA-MCA regional collateral score |
| MRI | 1. PCCS<br>2. Good CS and Poor CS<br>3. ASITN/SIR<br>4. 3 point scale by Tan<br>5. Present vs absent ACOMA<br>6. Presence or absence of FVH-DWI mismatch<br>7. FHV-ASPECTS<br>8. 5-point scale<br>9. TMACS<br>10. Flow map collateral grade based on ASITN/SIR<br>11. Maas scoring |
| DSA | 1. The ASITN/SIR collateral scale<br>2. Christoforidis collateral grading system |

**CTA-Based Grading Systems**

With the **Miteff collateral grading method** (Fig. 3), collateral status is assessed on maximum intensity projection reconstructions in axial, coronal, and sagittal planes of single-phase CTA in patients with **MCA occlusion** and is graded as: **Good** – if the main MCA branches are reconstituted distal to the occlusion, **Moderate** – if some MCA branches are visualized in the Sylvian fissure, **Poor** – if only distal superficial MCA branches are reconstituted.

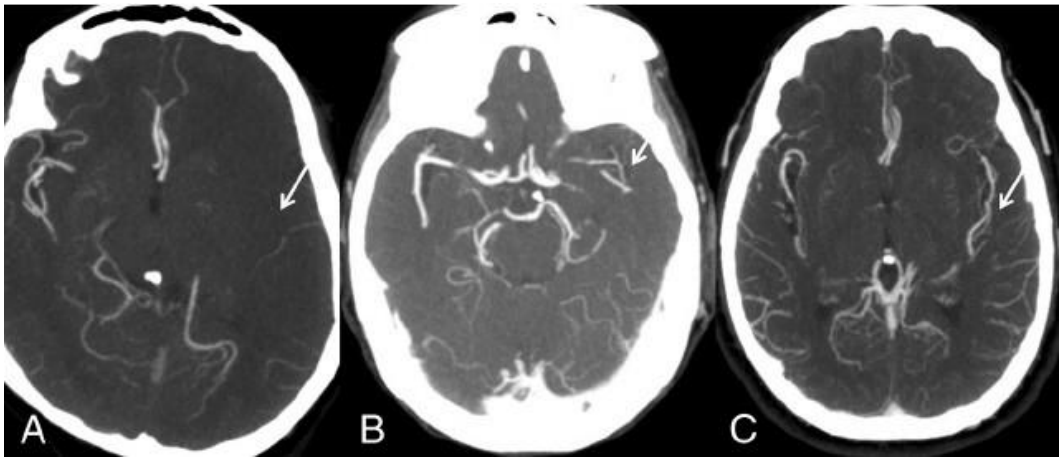
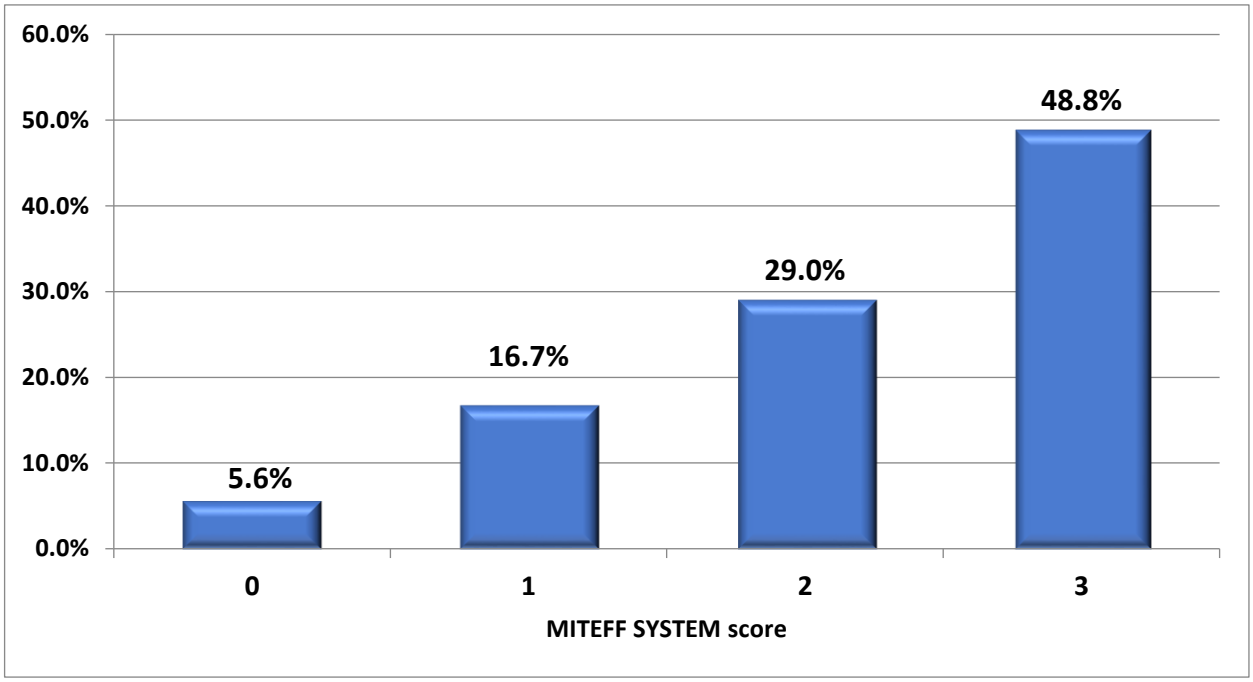
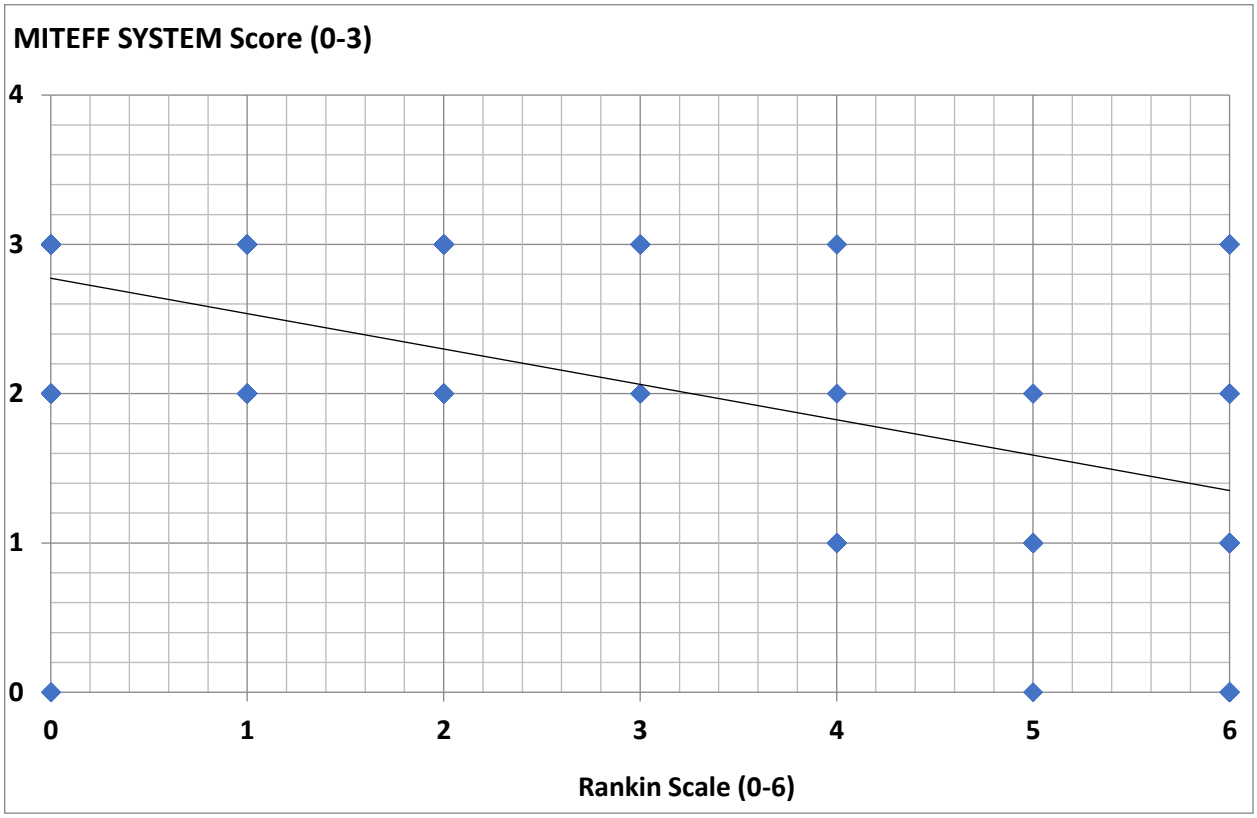



FIG. 3. Miteff System A – contrast in distal branches. B – vessels are visible in the sylvian fissure C – vessels are recanalized distal to the occlusion.




| MITEFF SYSTEM | N, % | Chi2; p |
|---|---|---|
| 0 | 9; 5.6% | 66.64; p<0.001 |
| 1 | 27; 16.7% | |
| 2 | 47; 29.0% | |
| 3 | 79; 48.8% | |




r = - 0.585, p<0.001

| SYSTEM | Poor outcome | Moderate outcome | Good outcome |
|---|---|---|---|
| MITEFF SYSTEM score – 0-1 | 34 (94.4%) | 0 (0.0%) | 2 (5.6%) |
| MITEFF SYSTEM score – 2-3 | 17 (13.5%) | 33 (26.2%) | 76 (60.3%) |
| OR (95%CI), p | 109.0 (24.0-495.9), p<0.001 | N/A | 25.8 (5.9-112.4), p<0.001 |

With the **Maas collateral grading method** (Fig. 4), the leptomeningeal vessels in the Sylvian fissure are assessed on CTA images and compared to the contralateral side: **1** – None, **2** – Less than the contralateral normal side, **3** – Equal to the contralateral normal side, **4** – More than the contralateral normal side, **5** – Hyper-abundant. The presence and condition of the anterior and

posterior communicating arteries are assessed as follows: **1** – Absent, **2** – Probably present, **3** – Very faint, **4** – Definitely present, **5** – Strong.

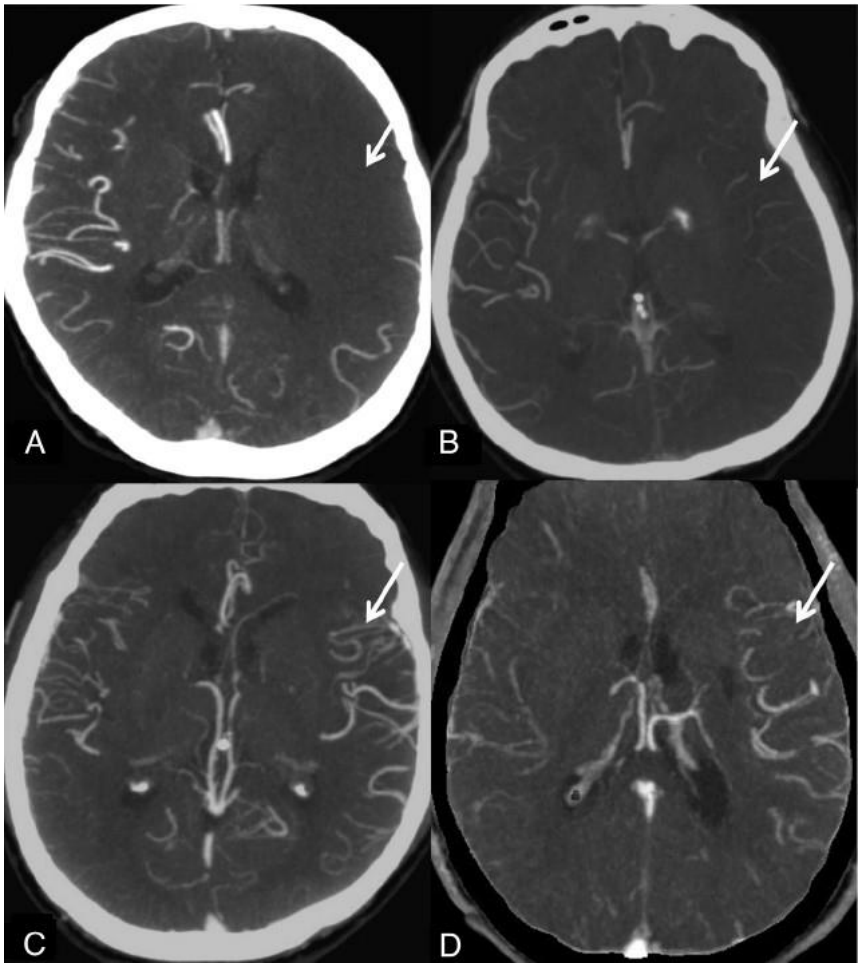
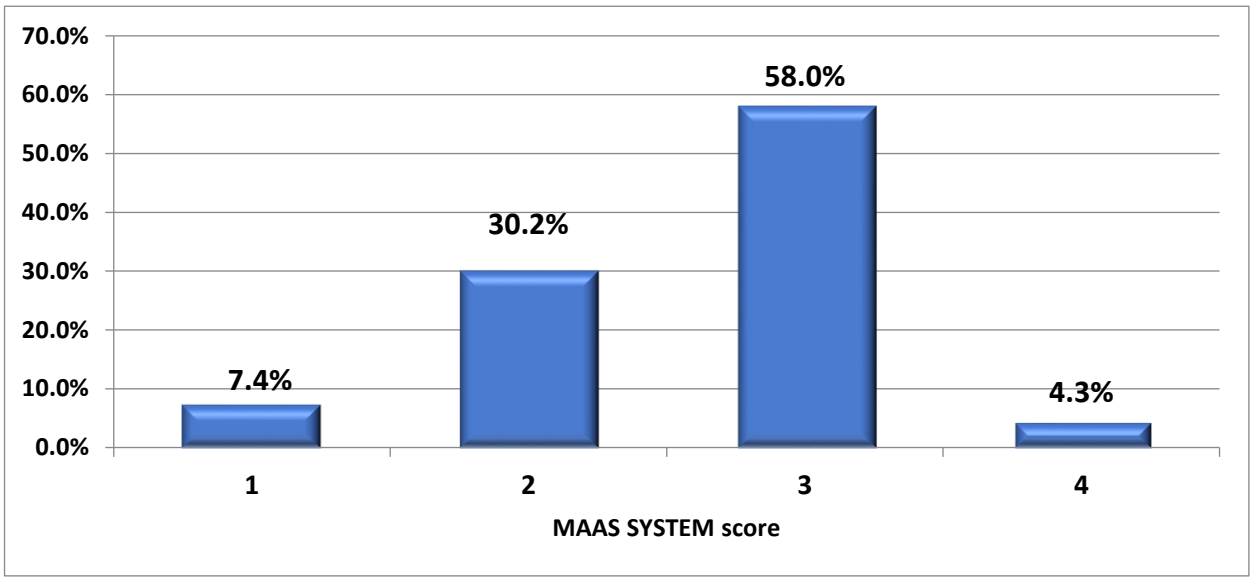
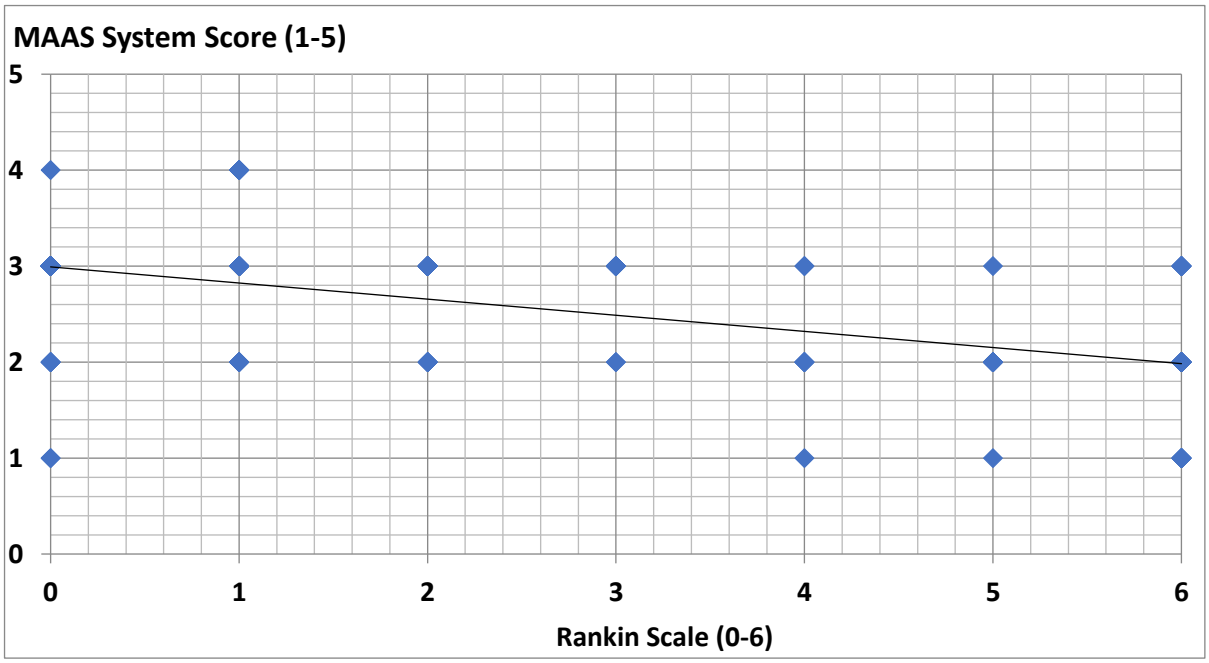



FIG. 4.Maas system. A – no vessels, B – less then contralateral side, C –more then contralateral side, D – – Hyper-abundant



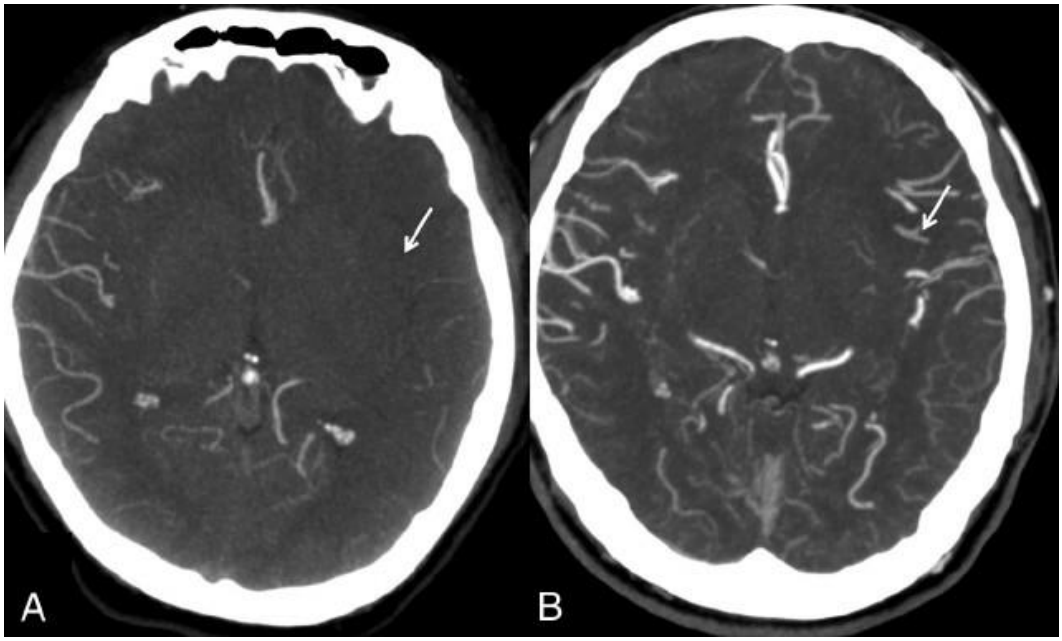
| MAAS SYSTEM | N, % | Chi2, p |
|---|---|---|
| 1 | 12; 7.4% | 120.22; p<0.001 |
| 2 | 49; 30.2% | |
| 3 | 94; 58.0% | |
| 4 | 7; 4.3% | |



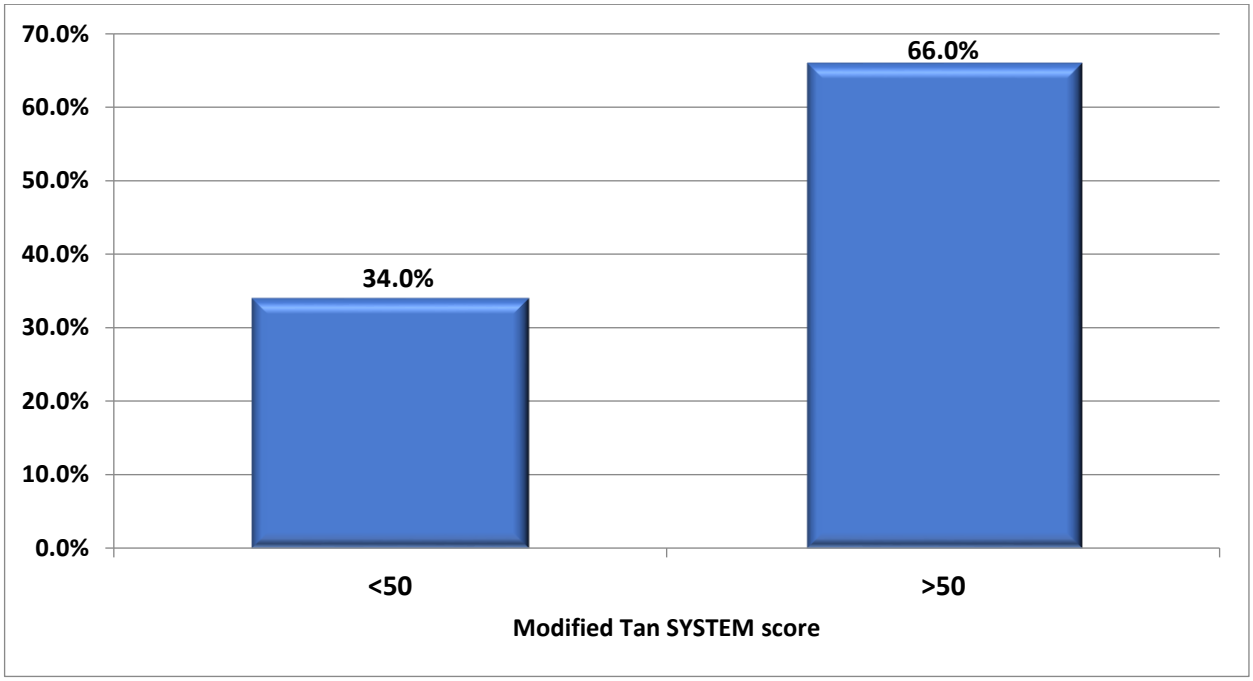

r = - 0.549, p<0.001

| SYSTEM | Poor outcome | Moderate outcome | Good outcome |
|---|---|---|---|
| MAAS SYSTEM score – 1-2 | 41 (67.2%)12 (19.7%) | 8 (13.1%) | 12 (19.7%) |
| MAAS SYSTEM score – 3-5 | 10 (9.9%) | 25 (24.8%) | 66 (65.3%) |
| OR (95%CI), p | 7.7 (3.6-16.3), p<0.001 | 2.2 (0.9-5.2), p=0.079 | 18.6 (8.0-43.4), p<0.001 |

The **Modified Tan Collateral Grading System** (Fig. 5) assesses leptomeningeal collateral status on source CTA images in maximum intensity projection reconstructions, good if there is more then 50% of MCA territory  and poor if there is less then 50% MCA territory.




sur. 5. **Modified Tan Collateral Grading System** A – MCA less then 50% MCA territory, B – more then 50% of MCA territory



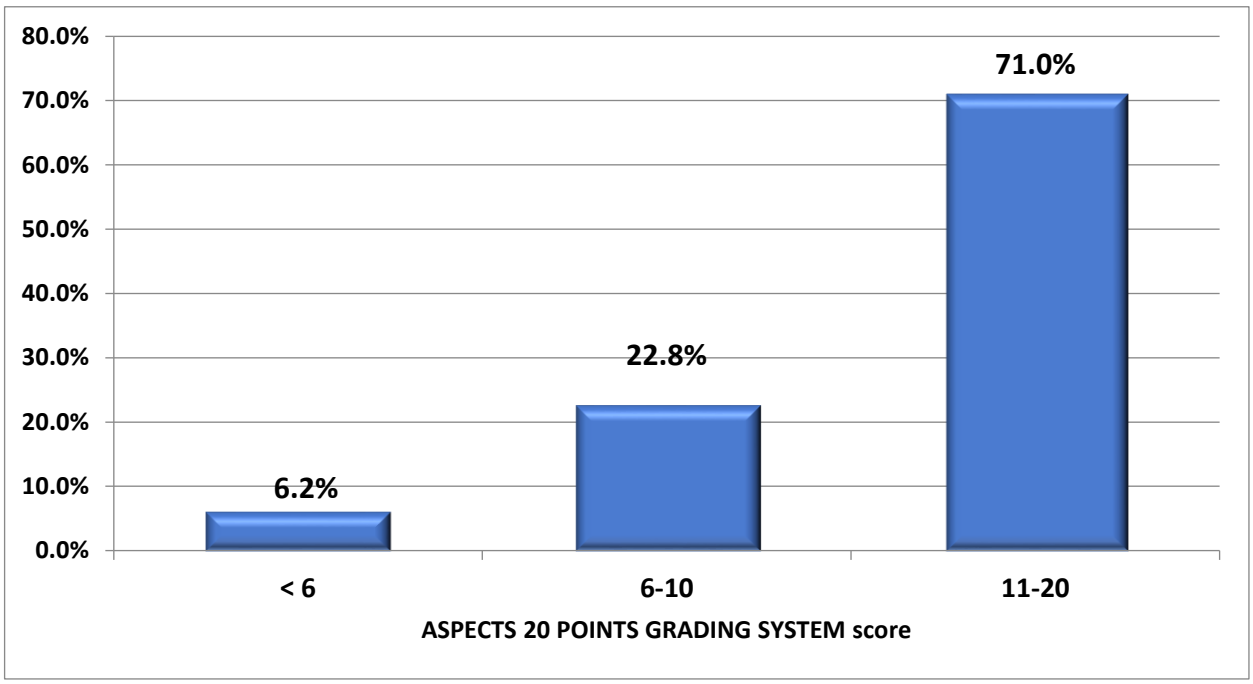

| Modified Tan Scale | N, % | Chi2-, p |
|---|---|---|
| < 50 | 55; 34.0% | 16.69; p<0.001 |

| | | |
|---|---|---|
| > 50 | 107; 66.0% | |

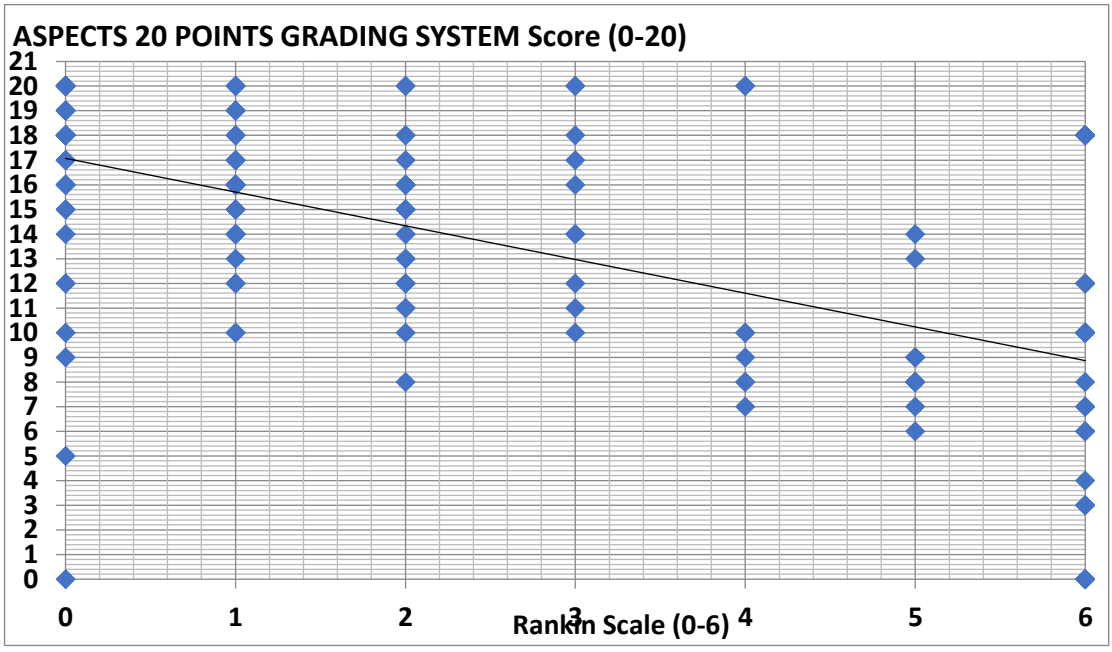
| SYSTEM | Poor outcome | Moderate outcome | Good outcome |
|---|---|---|---|
| Modified Tan SYSTEM score - <50 | 37 (67.3%) | 10 (18.2%) | 37 (67.3%)8 (14.5%) |
| Modified Tan SYSTEM score - >50 | 14 (13.1%) | 23 (21.5%) | 14 (13.1%)70 (65.4%) |
| OR (95%CI), p | 11.1 (4.8-26.0), p<0.001 | 1.2 (0.5-2.8), p=0.620 | 13.7 (6.2-30.3), p<0.001 |

The **Regional Leptomeningeal Collateral (rLMC) Score** (20-point scale) compares the degree of contrast opacification in arteries distal to an **M1 MCA occlusion** (internal carotid artery occlusion) in the symptomatic hemisphere to the contralateral hemisphere, using reformatted CTA reconstructions. A higher score indicates better collateral status. The degree of contrast opacification is graded as **0** (artery not visible), **1** (less pronounced), or **2** (equal to or more pronounced than the opposite hemisphere) for six **ASPECTS** cortical regions. the parasagittal **ACA** territory, and the basal ganglia. The areas in the Sylvian fissure are assigned a higher score of **0, 2, or 4**.

The **ACA-MCA and PCA-MCA Regional Collateral Score** assesses the extent and visibility of pial arteries in the **ACA-MCA and PCA-MCA regions** in stroke patients with **M1 MCA occlusion** ( intracranial internal carotid artery occlusion), using multi-phase reconstructions of Dynamic CTA. Collaterals in the ACA-MCA and PCA-MCA regions are each scored from 0-5 compared to the contralateral hemisphere, with the total score ranging from 0-10: **0** – Absent, **1** – Minimal, **2** – Vessel visibility and extent significantly reduced, **3** – Vessel visibility and extent moderately reduced, **4** – Vessel visibility and extent mildly reduced, **5** – Normal or increased visibility and extent.




| ASPECTS 20 POINTS GRADING SYSTEM | N, % | Chi2, p |
|---|---|---|
| < 6 | 10; 6.2% | 110.11; p<0.001 |
| 6-10 | 37; 22.8% | |
| 11-20 | 115; 71.0% | |



r = - 0.606, p<0.001

**DSA-Based Grading Systems**

Among the Digital Angiography methods, the **ASITN/SIR Collateral Scale** is the most frequently used. This method is the most widely recognized assessment system. The collateral scale developed by the **American Society of Interventional and Therapeutic Neuroradiology / Society of Interventional Radiology (ASITN/SIR)**, based on DSA, is graded from **0 to 4 points**: **0** – No collaterals visible in the ischemic area, **1** – Slow, peripheral filling of the ischemic area, with some defects, **2** – Rapid, peripheral filling of the ischemic area, with some defects, **3** – Slow, but complete filling of the ischemic area with blood flow in the late venous phase, **4** – Complete and rapid collateral flow in the ischemic area, driven by retrograde perfusion.

The **Christoforidis Collateral Grading System**, also based on DSA, assesses collateral status with **5 points**: **1** – The entire distal part of the occluded vessel is reconstituted by collaterals, **2** – The proximal part of the adjacent segment of the occluded vessel is reconstituted by collaterals, **3** – The distal part of the adjacent segment of the occluded vessel is reconstituted by collaterals, **4** – Blood flow separated by two segments from the closed vessel is reconstituted by collaterals, **5** – Minimal or practically non-reconstituted blood circulation.

**Conclusion**

There is a strong correlation between collateral circulation assessed by all four systems and final neurological outcome, assessed by the modified Rankin scale.for MITEFF SYSTEM r = - 0.585, p<0.001,for MAAS SYSTEM r = - 0.549, p<0.001,for Modified Tan SYSTEM score r=0.58828,P<0,001,for ASPECTS 20 POINTS GRADING SYSTEM r = - 0.606, p<0.001,

References:

1. Adhithyan R. Assessment of collateral status using Multiphasic CT Angiography in the acute anterior circulation ischemic Stroke: its correlation with Clinical and Radiologic outcomes (Doctoral dissertation, SCTIMST).
2. Baydemir R, Aykaç Ö, Acar BA, Kocabaş ZU, Milanlioğlu A, Eryildiz ES, Özdemir AÖ. Role of modified TAN score in predicting prognosis in patients with acute ischemic stroke

undergoing endovascular therapy. Clinical Neurology and Neurosurgery. 2021 Nov 1;210:106978.

3. Busto G, Morotti A, Carlesi E, Fiorenza A, Di Pasquale F, Mancini S, Lombardo I, Scola E, Gadda D, Moretti M, Miele V. Pivotal role of multiphase computed tomography angiography for collateral assessment in patients with acute ischemic stroke. La radiologia medica. 2023 Aug;128(8):944-59.
4. Cai Y, Gu Y, Wang Y, Wang P, Zhang L, Liu C, Chu J, Li H, Lu Z, Zhou Y, Liu H. A clinical prediction model for patients with acute large vessel occlusion due to underlying intracranial atherosclerotic stenosis. Clinical Neuroradiology. 2023 Jun;33(2):519-28.
5. Cao R, Jiang Y, Li L, Yang X, Wang H, Chen M, Chen J. Venous collaterals in acute ischemic stroke patients after endovascular treatments: a novel scoring system using 4D computed tomography angiography. Quantitative Imaging in Medicine and Surgery. 2022 Nov;12(11):5030.
6. Faber JE, Zhang H, Lassance-Soares RM, Prabhakar P, Najafi AH, Burnett MS, Epstein SE. Aging causes collateral rarefaction and increased severity of ischemic injury in multiple tissues. Arteriosclerosis, thrombosis, and vascular biology. 2011 Aug;31(8):1748-56.
7. Faber JE. Reprogrammed endothelial cells: cell therapy for coronary collateral growth?. Circulation research. 2012 Jan 20;110(2):192-4.
8. Fanou EM, Knight J, Aviv RI, Hojjat SP, Symons SP, Zhang L, Wintermark M. Effect of collaterals on clinical presentation, baseline imaging, complications, and outcome in acute stroke. American Journal of Neuroradiology. 2015 Dec 1;36(12):2285-91.
9. Fanou EM, Knight J, Aviv RI, Hojjat SP, Symons SP, Zhang L, Wintermark M. Effect of collaterals on clinical presentation, baseline imaging, complications, and outcome in acute stroke. American Journal
10. Hong L, Hsu TM, Zhang Y, Cheng X. Neuroimaging prediction of hemorrhagic transformation for acute ischemic stroke. Cerebrovascular Diseases. 2022 Jul 1;51(4):542-52.
11. Huang CC, Chiang HF, Hsieh CC, Chou CL, Jhou ZY, Hou TY, Shaw JS. Using deep-learning-based artificial intelligence technique to automatically evaluate the collateral status of multiphase cta in acute ischemic stroke. Tomography. 2023 Mar 16;9(2):647-56.
12. Maas MB, Lev MH, Ay H, Singhal AB, Greer DM, Smith WS, Harris GJ, Halpern E, Kemmling A, Koroshetz WJ, Furie KL. Collateral vessels on CT angiography predict outcome in acute ischemic stroke. Stroke. 2009 Sep 1;40(9):3001-5.

13. Maas MB, Lev MH, Ay H, Singhal AB, Greer DM, Smith WS, Harris GJ, Halpern E, Kemmling A, Koroshetz WJ, Furie KL. Collateral vessels on CT angiography predict outcome in acute ischemic stroke. Stroke. 2009 Sep 1;40(9):3001-5.
14. Maas MB, Lev MH, Ay H, Singhal AB, Greer DM, Smith WS, Harris GJ, Halpern E, Kemmling A, Koroshetz WJ, Furie KL. Collateral vessels on CT angiography predict outcome in acute ischemic stroke. Stroke. 2009
15. Miteff F, Levi CR, Bateman GA, Spratt N, McElduff P, Parsons MW. The independent predictive utility of computed tomography angiographic collateral status in acute ischaemic stroke. Brain. 2009 Aug 1;132(8):2231-8.