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The Thrombolysis in Cerebral Infarction Grading Scheme: Historical Development, Evolution, and Current Status

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Abstract

Background— The Thrombolysis in Cerebral Infarction (TICI) grading scheme is the principal angiographic language used to describe reperfusion after endovascular treatment of acute ischemic stroke. It was introduced to standardize reporting in intra-arterial cerebral thrombolysis and was subsequently adapted to modern endovascular thrombectomy, where the therapeutic endpoint is restoration of downstream tissue perfusion rather than proximal arterial opening alone.

Objectives— To review the historical development, evolution, clinical validation, limitations, and current role of TICI, modified TICI (mTICI), TICI 2c, expanded TICI (eTICI), quantitative TICI (qTICI), and automated TICI assessment.

Methods— A narrative review was performed using seminal reporting standards, consensus statements, peer-reviewed angiographic grading studies, thrombectomy outcome analyses, meta-analyses, and current stroke quality-measure specifications. No formal systematic-review protocol or quantitative synthesis was undertaken.

Results— The original TICI scheme was proposed in 2003 and later became variably applied across studies, particularly at the boundary between partial and successful reperfusion. The 2013 consensus recommendations promoted mTICI as the standard reperfusion scale and helped establish mTICI 2b-3 as the conventional definition of successful reperfusion. With improving thrombectomy performance, the broad 2b category became insufficiently granular, leading to adoption of TICI 2c and eTICI. Outcome studies show a graded relationship between reperfusion quality and functional outcome, with TICI 2c/3 or eTICI 2c/3 frequently associated with better outcomes than TICI 2b alone. However, subgroup data in large-core and mild-symptom populations suggest that additional attempts to convert a satisfactory 2b result to complete reperfusion should be individualized.

Current Status— As of 2026, mTICI ≥2b remains the dominant operational benchmark for technical success and is embedded in contemporary stroke quality measures. More granular reporting with eTICI or mTICI 2c/3 is increasingly favored for clinical trials, core-lab adjudication, device evaluation, and procedural quality improvement.

Conclusions— TICI has evolved from a thrombolysis-era angiographic reporting tool into a central endpoint of endovascular stroke therapy. Current best practice is to document the full reperfusion grade, specify the scale used, and interpret the result alongside time to reperfusion, number of passes, first-pass effect, procedural complications, and patient-specific tissue context.

Keywords— Thrombolysis in Cerebral Infarction; TICI; modified TICI; expanded TICI; cerebral infarction; ischemic stroke; endovascular thrombectomy; reperfusion; recanalization.

INTRODUCTION

Endovascular therapy (EVT) for acute ischemic stroke has made angiographic reperfusion a central procedural endpoint. The Thrombolysis in Cerebral Infarction (TICI) grading scheme provides a shared vocabulary for describing how much of the vascular territory downstream from an arterial occlusion has been reperfused after treatment. The original TICI scale was introduced in 2003 as part of trial design and reporting standards for intra-arterial cerebral thrombolysis.[1] Although the scale was initially developed in the thrombolysis era, it

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became foundational for the endovascular thrombectomy era because it evaluates tissue-level reperfusion rather than simple reopening of the occluded artery.

The distinction between recanalization and reperfusion is essential. Recanalization refers to restoration of patency at the site of arterial occlusion, whereas reperfusion refers to restoration of antegrade blood flow into the distal arterial bed and ischemic tissue. A proximal artery may be recanalized while distal branch occlusions, emboli to new territories, delayed parenchymal blush, or no-reflow phenomena limit tissue reperfusion. For this reason, the angiographic endpoint most closely aligned with EVT benefit is the extent and speed of downstream reperfusion.

Over the past two decades, TICI has undergone several refinements. Early publications used the term inconsistently, leading to confusion about what constituted a successful angiographic result.[2-5] Consensus recommendations later standardized modified TICI (mTICI) as the preferred cerebral reperfusion scale.[6] More recently, TICI 2c and expanded TICI (eTICI) have been introduced to distinguish substantial reperfusion from near-complete and complete reperfusion.[7,12] This review summarizes the history, evolution, evidence base, current status, limitations, and future direction of the TICI grading scheme.

METHODS

This is a narrative review. Seminal publications were identified from the original TICI reporting standards, major commentaries on angiographic grading terminology, consensus statements, studies comparing TICI variants, thrombectomy outcome analyses, meta-analyses, qTICI and automated TICI studies, and current Joint Commission stroke measure specifications. Search concepts included "TICI," "modified TICI," "expanded TICI," "TICI 2c," "endovascular thrombectomy," "reperfusion," "recanalization," "quantitative TICI (qTICI)," and "automated TICI." References were selected for historical importance, definitional relevance, clinical outcome correlation, or current quality-measure relevance. Because this is a narrative rather than systematic review, no formal Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol, risk-of-bias assessment, or meta-analysis was performed.

Historical Origins: From Coronary TIMI to Cerebral TICI

The conceptual ancestry of TICI lies in the Thrombolysis in Myocardial Infarction (TIMI) scheme used in coronary reperfusion. Early stroke intervention studies borrowed coronary terminology, but the cerebral circulation required a more territory-based framework. Unlike a single coronary epicardial artery, the cerebral arterial tree contains branching distal vessels, collateral pathways, and tissue territories of highly variable eloquence. Restoration of flow into the downstream tissue bed, rather than patency of a single proximal segment, is therefore the clinically meaningful target.

Higashida and colleagues introduced the original TICI scale in 2003 as part of reporting standards for intra-arterial cerebral thrombolysis.[1] The scale retained a 0-to-3 structure: no perfusion, minimal penetration, partial perfusion, and complete perfusion. Grade 2 was subdivided into 2a and 2b. In the original scheme, TICI 2a described partial filling of less than two-thirds of the expected vascular territory, whereas TICI 2b described complete filling of the expected territory but with slower-than-normal perfusion.[1,4] This definition differed from later modified schemes, in which 2b became an extent-based category rather than a delay-based category.

Confusion soon emerged. Tomsick noted that TIMI, Thrombolysis in Brain Ischemia (TIBI), and TICI terminology could be difficult to apply consistently in acute stroke studies.[2] Kallmes later emphasized that inconsistent TICI usage could undermine comparison among trials and devices.[3] In a systematic review of TICI usage, Fugate and colleagues found substantial heterogeneity in how the term was defined, cited, and used across the literature.[4] Suh and colleagues further demonstrated that differences among TICI scale variants could alter grading and outcome prediction in a meaningful proportion of cases.[5]

Consensus Standardization and the Modified TICI Scale

The most influential standardization effort came from the Cerebral Angiographic Revascularization Grading collaborators and the Stroke Therapy Academic Industry Roundtable TICI task force. Their 2013 consensus statement recommended mTICI as the standard reperfusion grading scale for acute ischemic stroke and advised that mTICI stand for "modified Treatment in Cerebral Ischemia," reflecting the broader scope of EVT beyond thrombolysis.[6]

The consensus statement made two important conceptual moves. First, it prioritized reperfusion scales over pure recanalization scales for procedural success. Second, it defined mTICI 2b by the proportion of downstream territory reperfused. In clinical practice, mTICI 2b came to indicate reperfusion of more than half of the target downstream territory but less than complete reperfusion, while mTICI 3 indicated complete antegrade reperfusion.[6] This framework supported the now-familiar dichotomy of unsuccessful reperfusion, usually mTICI 0-2a, versus successful reperfusion, usually mTICI 2b-3.

The 2b threshold was pragmatic and clinically useful. It allowed trials, registries, and quality programs to define technical success and compare procedural performance. However, the same threshold also created a broad category. A patient with just over 50% reperfusion and another with almost complete reperfusion could both be classified as "successful," despite potentially different tissue outcomes and clinical trajectories.

TICI 2c and Expanded TICI

As stent retrievers, aspiration systems, combined techniques, and procedural workflows improved, mTICI ≥2b became more common. This success exposed the limitations of a

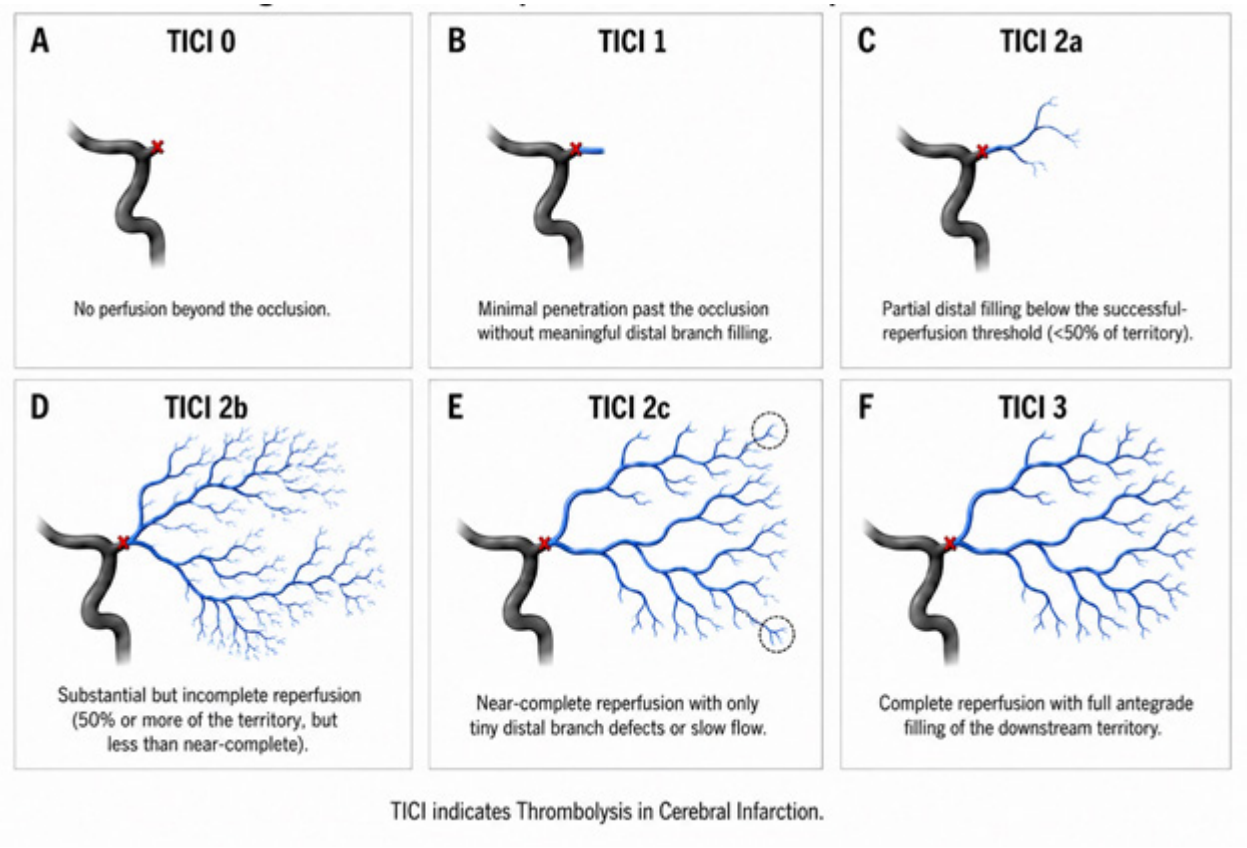


FIGURE 1: Schematic representation of Thrombolysis in Cerebral Infarction (TICI) reperfusion grades. TICI 0 indicates no perfusion beyond the occlusion; TICI 1, minimal penetration past the occlusion without meaningful distal branch filling; TICI 2a, partial distal filling below the successful-reperfusion threshold; TICI 2b, substantial but incomplete reperfusion; TICI 2c, near-complete reperfusion with only tiny distal branch defects or slow flow; and TICI 3, complete reperfusion with full antegrade filling of the downstream territory.

broad 2b category. Goyal and colleagues proposed adding TICI 2c to describe near-complete reperfusion, thereby distinguishing near-perfect angiographic results from lower-grade 2b reperfusion.[7] Subsequent studies supported this refinement by showing that near-complete reperfusion more closely resembled complete reperfusion than lower-grade 2b results in outcome association.[8-10]

The eTICI scale provided a more granular framework for modern EVT. It subdivides partial reperfusion into 2a, 2b50, 2b67, 2c, and 3 categories. In practical terms, eTICI 2b50 represents 50% to 66% reperfusion, eTICI 2b67 represents 67% to 89% reperfusion, eTICI 2c represents 90% to 99% reperfusion, and eTICI 3 represents complete reperfusion.[12,13] Figure 1 provides a schematic representation of the commonly used TICI reperfusion grades. The practical differences among original TICI, mTICI/TICI 2c, and eTICI definitions are summarized in Table 1. This granularity is particularly useful in trials and core-lab adjudication because it captures clinically meaningful differences that are obscured by a binary mTICI ≥2b endpoint.

Clinical Validation and Outcome Correlation

The persistence of TICI in stroke intervention reflects its clinical relevance: greater reperfusion is generally associated with better functional outcome. The conventional mTICI 2b-3 threshold became widely used because it identified a degree of reperfusion sufficient to correlate with improved outcomes and to serve as a trial and registry endpoint. Nevertheless, outcome analyses increasingly show that "successful" reperfusion is not homogeneous.

Several studies demonstrated that mTICI 3 outcomes are often superior to mTICI 2b outcomes. Dargazanli and colleagues found better functional outcomes after mTICI 3 than mTICI 2b reperfusion.[9] In an Contact Aspiration versus Stent Retriever for Successful Revascularization (ASTER) trial analysis, mTICI 2c/3 identified a subgroup with better functional outcomes than mTICI 2b.[10] A systematic review and meta-analysis by Kaesmacher and colleagues similarly found superior outcomes and safety profiles with TICI 3 compared with TICI 2b reperfusion.[11]

The Highly Effective Reperfusion Evaluated in Multiple Endovascular Stroke Trials (HERMES) collaboration provided important evidence for eTICI. Liebeskind and colleagues showed a graded relationship between increasing eTICI reperfusion and better functional outcome after EVT.[12] Real-world validation by Behme and colleagues supported the eTICI concept, concluding that the 7-point eTICI scale refined the broad mTICI 2b category and improved outcome prediction compared with conventional mTICI.[13] The Multicenter Randomized Clinical Trial of Endovascular Treatment for Acute Ischemic Stroke in the Netherlands

TABLE 1: Practical comparison of original TICI, mTICI, and eTICI definitions.

Grade	Original TICI concept	mTICI / TICI 2c concept	eTICI concept
0	No perfusion.	No antegrade reperfusion beyond the occlusion.	0% reperfusion.
1	Penetration past obstruction with minimal perfusion.	Minimal distal reperfusion without meaningful tissue perfusion.	Minimal reperfusion without significant distal branch filling.
2a	Partial perfusion, originally less than two-thirds of the affected territory.	Limited antegrade reperfusion, generally less than half of the target downstream territory.	1% to 49% reperfusion.
2b	Originally complete filling of the expected territory but slower than normal.	More than half of the target downstream territory reperfused but less than near-complete or complete reperfusion.	2b50: 50% to 66%; 2b67: 67% to 89% reperfusion.
2c	Not part of the original 2003 TICI scale.	Near-complete reperfusion, typically with only minor distal branch delay or small distal embolic defects.	90% to 99% reperfusion.
3	Complete perfusion with normal filling.	Complete antegrade reperfusion of the target downstream territory.	100% reperfusion.

TICI, Thrombolysis in Cerebral Infarction; mTICI, modified Treatment in Cerebral Ischemia; eTICI, expanded TICI.

TABLE 2: Milestones in the evolution of the TICI grading scheme.

Period	Milestone	Key contribution	Representative citation
2003	Original TICI reporting standards	Introduced a cerebral reperfusion scale for intra-arterial thrombolysis trials.	[1]
2007-2013	Recognition of terminology confusion	Highlighted inconsistent use of TIMI/TIBI/TICI and variable TICI definitions across studies.	[2-5]
2013	Consensus standardization	Recommended mTICI as the standard reperfusion grading scale and emphasized reperfusion over recanalization for procedural success.	[6]
2014-2018	TICI 2c and mTICI 2b refinement	Proposed near-complete reperfusion categories and showed outcome differences within the “successful” reperfusion range.	[7-11]
2019-2020	eTICI validation	Separated 2b50, 2b67, 2c, and 3 and demonstrated graded outcome association.	[12-14]
2021-present	Quantitative and automated assessment	Introduced qTICI and automated TICI tools to reduce visual subjectivity and improve reproducibility.	[15,19]
Current quality era	TICI integrated into performance measures	Maintains TICI ≥ 2B as a minimum technical success benchmark and incorporates time-to-reperfusion metrics.	[21-23]

eTICI, expanded TICI; mTICI, modified Treatment in Cerebral Ischemia; qTICI, quantitative TICI; TIBI, Thrombolysis in Brain Ischemia; TICI, Thrombolysis in Cerebral Infarction; TIMI, Thrombolysis in Myocardial Infarction.

(MR CLEAN) Registry analysis by LeCouffe and colleagues further examined whether eTICI 2b, 2c, or 3 should be the angiographic target and supported the clinical relevance of distinguishing near-complete from merely successful reperfusion.[14]

Meta-analytic evidence reinforces this direction. A network meta-analysis by Ghozy and colleagues reported that near-complete or complete revascularization, TICI 2c/3, was associated with higher rates of functional independence after EVT than lower successful reperfusion grades.[17] These data have moved the field toward viewing mTICI ≥2b as the minimum acceptable technical threshold, while increasingly treating TICI 2c/3 or eTICI 2c/3 as the preferred angiographic target when safely and efficiently achievable.

Current Status in Clinical Practice and Quality Measurement

In current clinical documentation, registry reporting, and performance measurement, mTICI or TICI ≥2b remains the dominant operational definition of technical success. The Joint Commission Comprehensive Stroke (CSTK)-08 measure describes the post-treatment TICI reperfusion grade and defines the target population as ischemic stroke patients with post-treatment reperfusion grade TICI 2b or higher in the vascular territory beyond the target arterial occlusion after mechanical endovascular reperfusion therapy.[21] The related data element defines TICI ≥2B as partial perfusion of at least 50% of the vascular distribution of the occluded artery or higher after treatment.[22]

Speed is now linked to the reperfusion endpoint. The Joint Commission CSTK-12 measure evaluates rapid effective reperfusion from skin puncture and identifies the numerator as patients achieving TICI 2b or higher for the primary vessel occlusion within 60 minutes of skin puncture.[23] Thus, contemporary quality measurement does not merely ask whether reperfusion occurred; it asks whether effective reperfusion occurred quickly. Table 2 summarizes the major milestones in the evolution of TICI from the original 2003 reporting standards to its current role in quality measurement.

For manuscripts and procedural reports, the strongest current approach is to document the full reperfusion grade rather than only dichotomizing success as ≥2b. A statement such as "final eTICI 2c after two passes, puncture-to-reperfusion time 38 minutes, no embolus to new territory" is more informative than "successful reperfusion achieved." Full-grade reporting allows comparison across devices, operators, centers, and trials, and it better reflects the clinical gradient of reperfusion quality.

The "Pursue Perfection" Debate

Although the field increasingly values near-complete and complete reperfusion, the decision to continue after mTICI 2b is not automatic. Additional device passes may improve distal reperfusion, but they also add time and may increase the risk of endothelial injury, vessel perforation, dissection, hemorrhage, distal embolization, or emboli to new territories. The optimal stopping point depends on the residual occlusion, amount and eloquence of salvageable tissue, collateral pattern, infarct core size, patient frailty, technical difficulty, and procedural duration.

Recent subgroup data illustrate this nuance. In a German Stroke Registry study of large ischemic anterior-circulation strokes, Winkelmeier and colleagues found that mTICI 3 was not associated with better 90-day functional outcome than mTICI 2b after matching, raising questions about the benefit-risk ratio of additional maneuvers in large-core patients.[18] In a 2026 analysis of patients with mild stroke symptoms and anterior-circulation large-vessel occlusion, Heitkamp and colleagues found similar excellent functional outcome rates after mTICI 2b and mTICI 3, suggesting that mTICI 2b may be an acceptable final result in selected mild-stroke patients.[20]

These findings do not negate the general value of complete reperfusion. Rather, they argue for individualized procedural judgment. A reasonable contemporary formulation is: attempt eTICI 2c/3 when it is technically feasible and safe without substantial delay, but accept mTICI 2b when further maneuvers are unlikely to reperfuse clinically meaningful tissue or when procedural risk begins to outweigh expected benefit.

Limitations of TICI Grading

TICI grading remains semi-quantitative and observer dependent. It is influenced by angiographic projection, injection technique, catheter position, frame rate, run duration, collateral filling, vasospasm, blood pressure, and the rater's estimate of the relevant downstream territory. Different observers may also disagree about whether residual delayed or absent filling represents a small distal branch defect, a substantial cortical territory, or tissue that is already infarcted and no longer accepts normal perfusion.

The score also does not directly incorporate procedural efficiency. A final eTICI 3 result after one pass and 18 minutes is biologically and operationally different from an eTICI 3 result after six passes and 90 minutes. Similarly, a final eTICI 2b result after one pass may be preferable to a marginally improved angiographic grade achieved only after multiple risky distal attempts. First-pass effect and first-pass excellent reperfusion metrics were developed to capture this combination of extent and speed; first-pass TICI 2c/3 has been proposed as a strong technical endpoint for future trials.[16]

Another limitation is that TICI does not account for tissue eloquence, infarct core size, penumbral volume, no-reflow, distal emboli to non-target territories, microvascular failure, or reperfusion injury. Two patients with the same score may have very different outcomes depending on whether the residual unreperfused region involves non-eloquent cortex, dominant language cortex, basal ganglia perforators, or already infarcted tissue. TICI should therefore be interpreted as an angiographic endpoint, not as a complete biological or clinical endpoint.

Future Directions

The future of reperfusion grading is likely to be more granular, more automated, and more context aware. qTICI provides a semi-automated quantitative assessment of brain tissue reperfusion on digital subtraction angiography and has shown prognostic value similar to eTICI.[15] Automated TICI approaches use image-processing or machine-learning methods to quantify reperfused pixels and compare post-treatment with pre-treatment angiographic appearances. A multicenter registry evaluation reported that automated quantitative reperfusion assessment was associated with visual eTICI and had similar functional outcome prediction.[19]

These tools may reduce interobserver variability and support large-scale registries, device trials, and quality dashboards. However, they should currently be regarded as adjuncts rather than replacements for expert interpretation. Automated scoring must still address acquisition variability, incomplete angiographic views, motion, collateral filling, tandem lesions, and posterior-circulation anatomy. Future systems may combine angiographic reperfusion grade with perfusion imaging, infarct-core estimates, collateral assessment, device-pass number, time metrics, and clinical severity to provide a multidimensional estimate of procedural success.

Practical Recommendations for Manuscripts and Procedure Reports

For research manuscripts, authors should specify the exact TICI variant used, define each grade, report whether grading was performed by operators or an independent core laboratory, and avoid using "TICI" generically when mTICI, TICI 2c, or eTICI is meant. Studies should report the full ordinal grade distribution rather than only the proportion achieving ≥2b. When possible, outcomes should be analyzed separately for 2b, 2c, and 3.

For clinical procedure reports, the final reperfusion grade should be linked to the primary target occlusion. When multiple occlusions or branches are treated, the report should clarify which vessel the grade refers to. The report should also document time from puncture to first achievement of ≥2b reperfusion, final reperfusion grade, number of passes, rescue therapy, emboli to new territory, and intraprocedural complications. This style of reporting aligns angiographic grading with contemporary quality measurement and gives treating clinicians a more complete picture of procedural success.

CONCLUSION

The TICI grading scheme has evolved from a 2003 reporting standard for intra-arterial thrombolysis into the principal angiographic endpoint of modern EVT for acute ischemic stroke. Its history mirrors the evolution of the field: from thrombolysis to thrombectomy, from recanalization to tissue reperfusion, from binary technical success to granular reperfusion quality, and from final angiographic appearance alone to integrated assessment of speed, safety, and procedural efficiency.

As of 2026, mTICI ≥2b remains the accepted minimum threshold for successful reperfusion in routine documentation, registries, and stroke quality measures. However, eTICI and the distinction between 2b, 2c, and 3 represent the direction of contemporary research and quality improvement. The best current use of TICI is to report the full reperfusion grade, specify the scale used, and interpret the result in the context of time to reperfusion, number of passes, patient-specific tissue at risk, and procedural safety.

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