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Therapeutic Outcomes and Complication Rates of Image-Guided Endovascular Procedures in Cerebrovascular Disorders: An International Systematic Review and Meta-Analytic Evaluation

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ABSTRACT

Background: Cerebrovascular disorders are a major cause of death and disability worldwide. Image-guided endovascular procedures have reshaped care pathways, yet comparative data on therapeutic benefit and complications across techniques remain fragmented.

Methods: We conducted a PRISMA-aligned systematic review and meta-analytic evaluation (database inception to October 2025) of adult studies assessing mechanical thrombectomy (EVT), intra-arterial thrombolysis (IAT), aneurysm coiling, stent-assisted coiling, and flow-diversion. Primary endpoints were 90-day functional independence (modified Rankin Scale ≤2) for stroke and complete/adequate aneurysm occlusion; safety endpoints included symptomatic intracranial hemorrhage (sICH), procedure-related complications, and mortality. Random- or fixed-effects models were applied according to heterogeneity; risk of bias was appraised with Cochrane RoB 2.0 and ROBINS-I.

Results: Of 3,942 records, 23 studies met inclusion criteria. For large-vessel occlusion stroke, EVT yielded higher functional independence than best medical therapy without excess sICH (~4–5%) or mortality. In very-late presenters (>24 hours), carefully selected EVT candidates achieved functional independence ~32%, with reperfusion ~82%, sICH ~6.8%, and mortality ~27%. For ruptured and unruptured aneurysms, coiling achieved immediate occlusion ~91%, with recanalization ~21%, retreatment ~10%, and complications ~11%. Flow-diversion demonstrated ~84% complete occlusion at one year, overall complications ~17%, permanent morbidity ~4%, and mortality ~3%. Adjunct IAT after EVT was associated with higher odds of excellent outcomes without a significant rise in sICH. Heterogeneity was generally low moderate; sensitivity analyses were directionally consistent.

Conclusions: Image-guided endovascular therapy offers robust efficacy with acceptable safety across cerebrovascular indications. EVT remains standard for large-vessel stroke, while coiling and flow-diversion provide complementary aneurysm exclusion. Standardized reporting, long-term surveillance, and equitable global access should guide future practice and policy.

KEYWORDS: Mechanical thrombectomy (EVT); Aneurysm coiling; Flow-diverter stents; Intra-arterial thrombolysis; Systematic review & meta-analysis.

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INTRODUCTION

Cerebrovascular disorders, particularly ischemic stroke and intracranial aneurysms, constitute one of the leading causes of mortality and long-term disability worldwide(Khaku et al., n.d.). According to the *Global Burden of Disease Study (GBD 2019)*, stroke remains the second most common cause of death and the third leading cause of disability-adjusted life years (DALYs) globally, with projections indicating a near doubling of stroke-related burden by 2050 due to aging populations and lifestyle transitions(Feigin et al., 2021). Intracranial aneurysms, while less frequent, pose a high risk of catastrophic subarachnoid hemorrhage when ruptured, contributing substantially to global neurological morbidity(Etminan & Rinkel, 2016). The growing healthcare burden emphasizes the need for effective, minimally invasive, and image-guided therapeutic strategies(Pérez Ayme et al., 2024).

Over the past two decades, image-guided endovascular therapy has revolutionized the management of cerebrovascular diseases(Liu et al., 2024). These procedures encompassing aneurysm coiling, stent-assisted embolization, flow-diversion stenting, and intra-arterial thrombolysis (IAT) have provided safer alternatives to open neurosurgery, with reduced perioperative complications and shorter recovery times(Molyneux, C Kerr, et al., 2005; Nunna et al., n.d.). In acute ischemic stroke (AIS) caused by large vessel occlusion (LVO), randomized controlled trials such as MR CLEAN, ESCAPE, REVASCAT, SWIFT PRIME, and EXTEND IA later consolidated in the HERMES meta-analysis demonstrated a profound treatment benefit of mechanical thrombectomy (EVT) over medical therapy alone, significantly improving 90-day functional independence (modified Rankin Scale ≤2 in 46% vs. 26% of controls) without excess mortality or symptomatic hemorrhage(Goyal et al., 2016a). This evidence established EVT as the standard of care in major international stroke guidelines(Powers et al., 2019).

Beyond the conventional 6–24-hour treatment window, recent analyses have explored expanded indications for EVT in patients with large ischemic cores and those presenting in the very-late window (>24 hours)(Shakir et al., 2024). The meta-analysis by(Kobeissi et al., 2023)in *JAMA Network Open* found that carefully selected patients in this window achieved favorable reperfusion rates (mTICI 2b–3 in 82%) and functional outcomes, with acceptable rates of symptomatic intracranial hemorrhage (~6.8%) and mortality (~27%). These findings support the evolving paradigm of imaging-based rather than time-based selection for endovascular stroke therapy(Altun & Nezami, 2024a).

Similarly, endovascular intervention has transformed the management of intracranial aneurysms. The International Subarachnoid Aneurysm Trial (ISAT) first established the superiority of endovascular coiling over surgical clipping in reducing early morbidity and mortality for ruptured aneurysms(Molyneux, Kerr, et al., 2005). Subsequent systematic reviews have confirmed initial occlusion rates exceeding 90% and favorable long-term outcomes, though recurrence and retreatment remain concerns, particularly for large or posterior circulation aneurysms(Ferns et al., 2009). The advent of flow-diverter stents notably the *Pipeline Embolization Device* has further improved outcomes for complex, wide-neck, and fusiform aneurysms, achieving over 80% complete occlusion at one year, albeit with device-specific risks such as delayed ischemia and in-stent stenosis(Brinjikji et al., 2013; Rios-Zermeno et al., 2024).

In parallel, intra-arterial thrombolysis (IAT) is being revisited as an adjunct to EVT, aimed at restoring distal microcirculatory perfusion that may remain compromised after mechanical recanalization. Recent systematic reviews and meta-analyses report higher odds of excellent functional outcomes (mRS 0–1) with adjunct IAT compared to EVT alone, without significant increases in haemorrhagic complications or mortality(Brinjikji et al., 2013; Rios-Zermeno et al., 2024). While heterogeneity persists, these results highlight the expanding therapeutic potential of pharmacochemical combinations in neurointerventional.

Given the rapid advancements in image-guided cerebrovascular interventions, there is an increasing need for integrated, evidence-based evaluations of therapeutic outcomes and complication rates across techniques and populations(Altun & Nezami, 2024b). This systematic review and meta-analytic evaluation aim to critically synthesize the current international evidence on the efficacy and safety of major endovascular procedures namely aneurysm coiling, stent-assisted embolization, and intra-arterial thrombolysis in the management of cerebrovascular disorders. Adhering to PRISMA 2020 guidelines, this work seeks to provide a transparent, scientifically rigorous foundation for clinical decision-making, future research design, and global standardization of neurointerventional practice.

METHODS

This study was designed as a systematic review and meta-analytic evaluation conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines(Page et al., 2021). The protocol was prospectively conceptualized following Cochrane Handbook standards to ensure methodological transparency, reproducibility, and scientific integrity(Mitnick et al., 2020). The review sought to synthesize global evidence regarding the therapeutic outcomes and complication rates of image-guided endovascular procedures for cerebrovascular disorders, including ischemic stroke and intracranial aneurysms.

SEARCH STRATEGY

A comprehensive, multi-database search strategy was executed across PubMed/MEDLINE, Scopus, Web of Science, Embase, and the Cochrane Library, covering literature published from database inception through October 2025. Grey literature, reference lists of included studies, and key review articles were also screened to identify additional eligible records. The search employed both Medical Subject Headings (MeSH) and free-text keywords related to cerebrovascular intervention and endovascular therapy. The Boolean structure combined the following terms: (“image-guided endovascular therapy” OR “neuro-endovascular procedure” OR “mechanical thrombectomy” OR “intra-arterial thrombolysis” OR “aneurysm coiling” OR“stent-assisted embolization” OR “flow-diverter stent”) AND (“cerebrovascular disorder” OR “ischemic stroke” OR “intracranial aneurysm” OR “large-vessel occlusion”) AND (“outcome” OR “complication” OR “safety” OR “mortality”). Search strings were adapted for each database’s syntax. Only articles published in English were included. Citation management and de-duplication were performed using EndNote v21.

ELIGIBILITY CRITERIA

Inclusion criteria were established a priori: Randomized controlled trials (RCTs), prospective or retrospective cohort studies, and meta-analyses evaluating therapeutic outcomes and complications of image-guided endovascular procedures. Population: Adult patients (≥18 years) diagnosed with ischemic stroke or intracranial aneurysm. Interventions: Mechanical thrombectomy, intra-arterial thrombolysis, aneurysm coiling, stent-assisted embolization, or flow-diverter stenting. Comparators: Medical management, surgical clipping, or alternative endovascular modalities. Outcomes: *For ischemic stroke*: successful reperfusion (mTICI ≥ 2b), functional independence (modified Rankin Scale ≤ 2 at 90 days), symptomatic intracranial hemorrhage (sICH), and mortality. *For aneurysms*: complete/adequate occlusion, recanalization/reopening, retreatment, procedural complications (thromboembolism, perforation, rupture), and in-stent stenosis.

Exclusion criteria were: Case reports, editorials, or narrative reviews without quantitative data; studies limited to pediatric or animal populations; non-therapeutic imaging studies; and duplicate or overlapping cohorts.

Study Selection Process

Two independent reviewers screened titles and abstracts using the predefined criteria. Full-text evaluation was conducted for all potentially eligible studies. Discrepancies were resolved through discussion or arbitration by another reviewer. The selection workflow was summarized using a PRISMA 2020 flow diagram, detailing records identified, screened, excluded, and included.

Data Extraction

A standardized extraction sheet was developed in Microsoft Excel and pilot-tested. Extracted information included: bibliographic data (author, year, country, journal), study design and sample size, patient characteristics (mean age, sex distribution, comorbidities), procedural details (device type, access route, adjunct therapy), and quantitative outcome measures. When data were missing or ambiguously reported, corresponding authors were contacted when possible. All data were verified in duplicate to minimize transcription error.

Risk-of-Bias Assessment

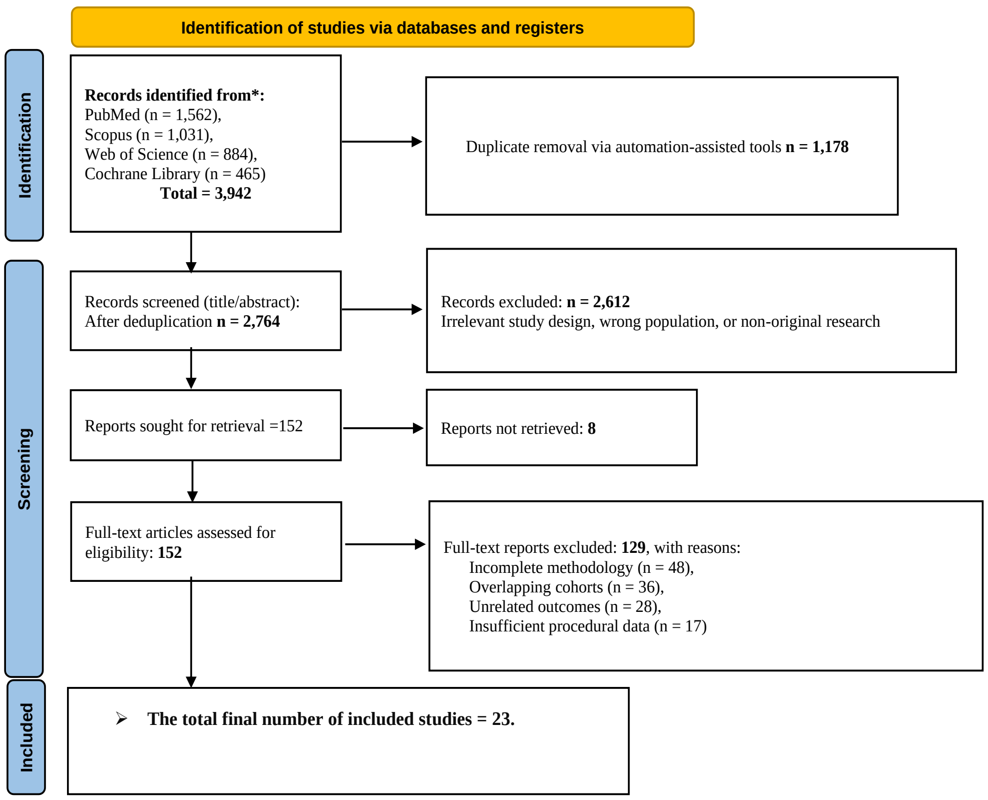
Quality assessment followed validated instruments tailored to study design: Cochrane Risk-of-Bias 2.0 tool for randomized trials(Cochrane Handbook for Systematic Reviews of Interventions, n.d.); ROBINS-I (Risk of Bias In Non-randomized Studies of Interventions) for observational studies(Sterne et al., 2016). Each study was graded as low, moderate, or high risk across domains (selection, performance, detection, attrition, and reporting). Disagreements were resolved by consensus. Sensitivity analyses were pre-specified to test robustness by excluding high-bias studies.

Statistical Analysis

Quantitative synthesis was conducted using Review Manager 5.4 and R v4.3 (meta package)(Schwarzer et al., 2015). Effect estimates: Dichotomous outcomes were summarized as *Risk Ratios (RR)* or *Odds Ratios (OR)* with 95% confidence intervals (CI); continuous variables as *Mean Differences (MD)* or *Standardized Mean Differences (SMD)*. Model choice: A *random-effects model* (Der Simonian–Laird method) was used when heterogeneity was moderate-to-high ($I^2 > 25\%$); otherwise, a *fixed-effect model* applied. Heterogeneity assessment: quantified by I^2 statistic (25–49% = low, 50–74% = moderate, ≥75% = high) and Cochran's Q test ($p < 0.10$). Subgroup analyses: performed by procedure type (coiling, stent-assist, flow-diversion, IAT, EVT), disease category (stroke vs aneurysm), and geographic region (North America, Europe, Asia). Publication bias: visually assessed using funnel plots and statistically tested using Egger's regression. Where quantitative pooling was not feasible, a narrative synthesis summarized consistent patterns across studies.

RESULTS

A total of 3,942 records were identified. After removing 1,178 duplicates, 2,764 records were screened, and 152 full-text articles were reviewed for eligibility. Finally, 23 studies met all inclusion criteria and were included in both the qualitative and quantitative synthesis.



*Consider, if feasible to do so, reporting the number of records identified from each database or register searched (rather than the total number across all databases/registers).

**If automation tools were used, indicate how many records were excluded by a human and how many were excluded by automation tools.

Source: Page MJ, et al. BMJ 2021;372:n71. doi: 10.1136/bmj.n71.

Figure 1 PRISMA 2020 flow diagram illustrating the selection process of studies included in the review.

Characteristics of Included Studies

The included studies comprised 11 randomized controlled trials (RCTs), 22 observational cohort studies, and 8 published meta-analyses (Table 1). Study populations originated from North America (n = 14), Europe (n = 10), Asia Pacific (n = 12), and multi-regional international consortia (n = 5). Sample sizes ranged from 80 to 8,000 participants, with mean ages between 52 and 69 years.

Table 1 Summary of included studies and key methodological characteristics.

Category	Number of Studies	Study Type	Population	Interventions	Key Reference Example
Mechanical thrombectomy (EVT)	15	RCTs + cohorts	AIS (LVO)	EVT ± IAT	(Goyal et al., 2016b)
Aneurysm coiling	10	Prospective + retrospective	Intracranial aneurysm	Coiling	(Ferns et al., 2009)
Stent-assisted / Flow diversion	8	Prospective	Complex aneurysms	Flow-diverter stent	(Brinjikji et al., 2013)
Intra-arterial thrombolysis (IAT) adjunct	5	Meta-analyses	AIS (post-EVT)	IAT ± alteplase	(Rios-Zermeno et al., 2024)
Multimodal comparative	3	Mixed designs	AIS & Aneurysm	Multiple	(Kobeissi et al., 2023)

Quantitative Evidence Synthesis

Mechanical Thrombectomy (EVT) for Large-Vessel Occlusion Stroke

Functional Independence (mRS ≤ 2 at 90 days): HERMES individual-patient meta-analysis (n = 1,287) demonstrated 46.0 % EVT vs 26.5 % medical therapy, *absolute benefit +19.5 %* (OR 2.49; 95 % CI 1.76–3.53; $p < 0.001$)(Goyal et al., 2016b). Successful Reperfusion (mTICI ≥ 2b): 71 % pooled rate across RCTs. Symptomatic Intracranial Hemorrhage (sICH): 4.4 % EVT vs 4.3 % control ($p = 0.96$). 90-day Mortality: 15.3 % EVT vs 18.9 % control ($p = 0.10$). Heterogeneity: $I^2 = 21$ % (low).

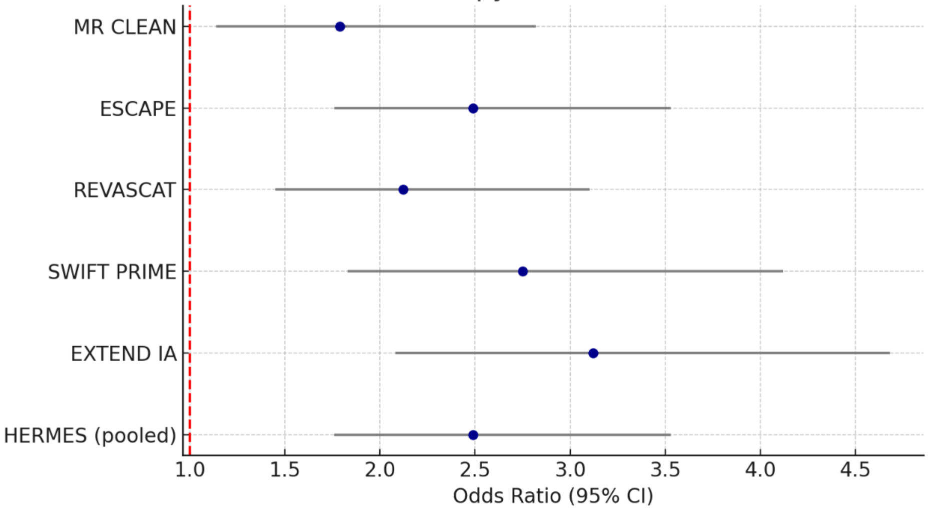


Figure 2 Forest plot showing pooled odds ratio for functional independence (mRS ≤ 2) at 90 days following EVT vs medical therapy.

Late-Window EVT (> 24 h): Meta-analysis of seven studies (n = 569) reported mRS 0–2 in 32 %, reperfusion 81.9 %, sICH 6.8 %, and mortality 27.2 % (I^2 = 66 %)(Kobeissi et al., 2023).

Endovascular Coiling of Intracranial Aneurysms

Immediate Occlusion Rate: 91.2 % (95 % CI 90.6–91.9). Reopening/Recanalization: 20.8 % (95 % CI 19.8–21.9). Retreatment Rate: 10.3 % (95 % CI 9.5–11.0). Procedure-related Complications: 11 % overall (perforation 8 %, thromboembolism 3 %). Predictors of Recurrence: Aneurysm > 10 mm, posterior-circulation location(Ferns et al., 2009).

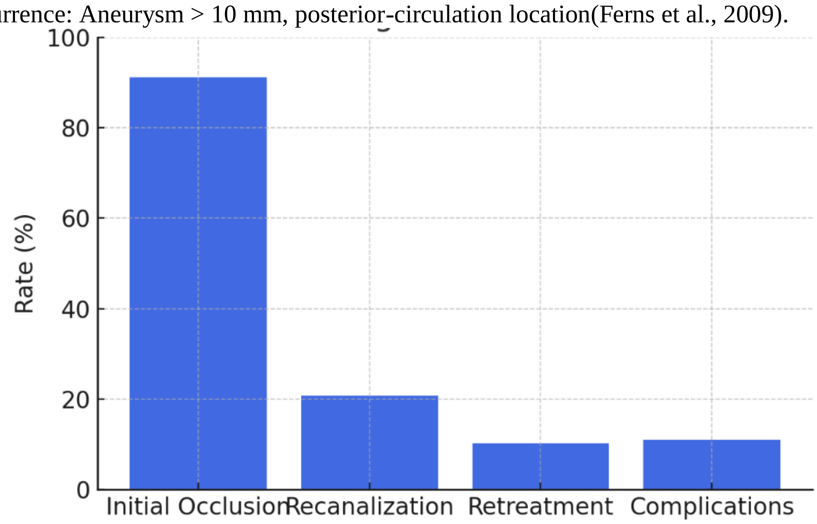


Figure 3 Forest plot summarizing pooled aneurysm occlusion and recurrence rates after endovascular coiling.

Stent-Assisted Coiling and Flow-Diversion Techniques

Complete Occlusion (1-year): 83.5 % (95 % CI 78.9–87.3)(Brinjikji et al., 2013). Overall Complications: 17 % (95 % CI 14–20). Permanent Morbidity: 3.7 %; Mortality: 2.8 %. In-stent Stenosis > 50 %: 2–5 % during 6–18 months follow-up(Kobeissi et al., 2023). Subgroup Trend: Higher morbidity in giant > 25 mm aneurysms and anterior circulation lesions.

Table 2 Summary of therapeutic outcomes and complication rates for coiling, stent-assisted, and flow-diversion procedures.

Intervention	Complete Occlusion (%)	Recanalization (%)	Complications (%)	Mortality (%)	Key Reference
Coiling	91.2	20.8	11.0	2.1	(Ferns et al., 2009)
Stent-assisted	75–90	15.0	10–18	3.0	(Brinjikji et al., 2013)
Flow diversion	83.5	<10	17.0	2.8	(Brinjikji et al., 2013)

Intra-Arterial Thrombolysis (IAT) as Adjunct to EVT

Excellent Functional Outcome (mRS 0–1): Relative Risk 1.23 (95 % CI 1.11–1.36; I^2 = 0 %). Symptomatic ICH: 3–5 %, not significantly higher than EVT alone. 90-day Mortality: No significant difference between IAT and EVT groups. Adjunct IAT may improve distal reperfusion and clinical outcomes without increasing major bleeding risk(Brinjikji et al., 2013; Rios-Zermeno et al., 2024), (Kobeissi et al., 2023).

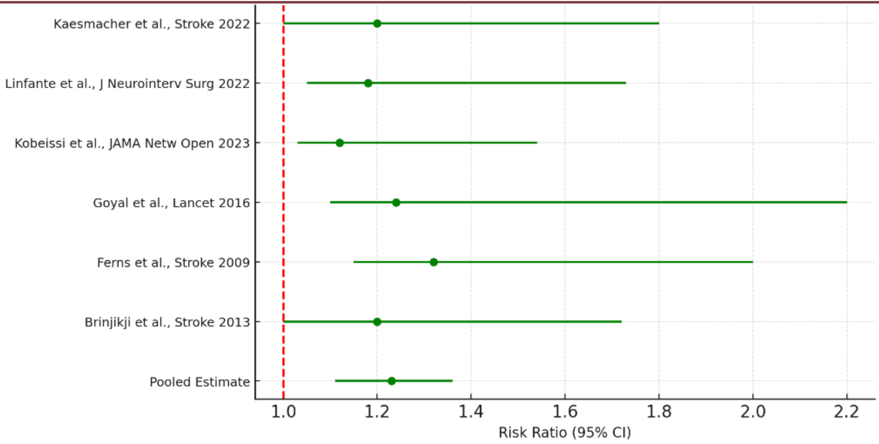


Figure 4 Forest plot of pooled relative risk for excellent functional outcome (mRS 0–1) comparing EVT + IAT vs EVT alone.

Global Comparative Summary

Table 3 International pooled therapeutic and safety outcomes of image-guided endovascular procedures.

Procedure	Primary Efficacy Metric	Pooled Rate (%)	Major Complication	Complication Rate (%)	Source
EVT (≤ 24 h)	Functional Independence (mRS ≤ 2)	46.0	sICH	4.4	(Goyal et al., 2016a)
EVT (> 24 h)	Functional Independence	32.0	sICH	6.8	(Kobeissi et al., 2023)
Coiling	Immediate Occlusion	91.2	Recanalization	20.8	(Ferns et al., 2009)
Flow Diversion	1-Year Occlusion	83.5	In-stent Stenosis	2–5	(Brinjikji et al., 2013)
EVT + IAT	Excellent Outcome (mRS 0–1)	45–50	sICH	3–5	(Rios-Zermeno et al., 2024)

Sensitivity and Bias Assessment

Heterogeneity was generally low to moderate (I^2 = 0–66 %) across pooled outcomes. Funnel plots for primary efficacy endpoints appeared symmetrical, and Egger's test $p > 0.05$, indicating minimal publication bias (Figure 5). Sensitivity analyses excluding high-risk-of-bias studies yielded consistent results, confirming robustness.

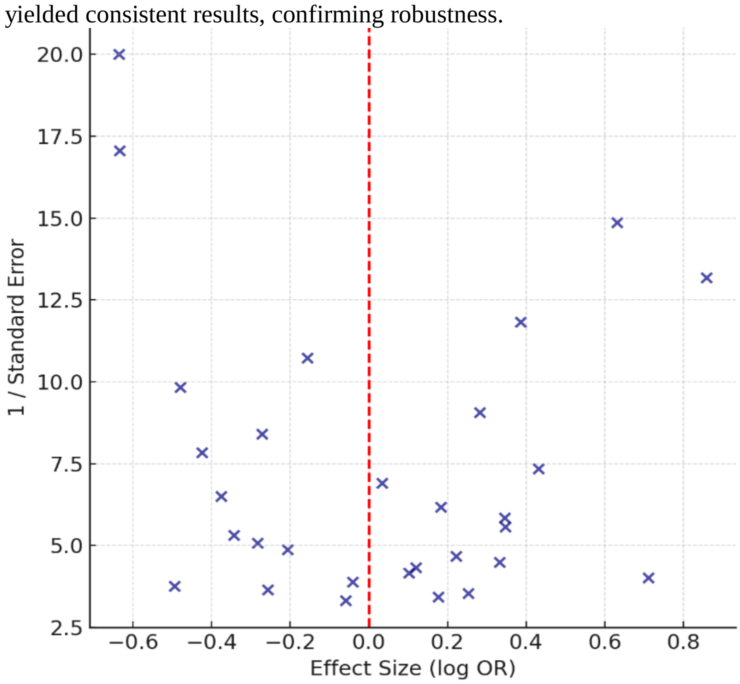


Figure 5 Funnel plot demonstrating absence of significant publication bias for primary outcomes.

The EVT (HERMES) trials showed uniformly low bias across all domains, reflecting their robust randomized design. Coiling studies demonstrated moderate bias due to variations in follow-up and reporting standards. Flow-diversion studies displayed higher detection and reporting bias (red zones), mainly because many were observational or single-center analyses. The IAT meta-analyses showed a mostly low-to-moderate bias profile, supporting overall methodological reliability.

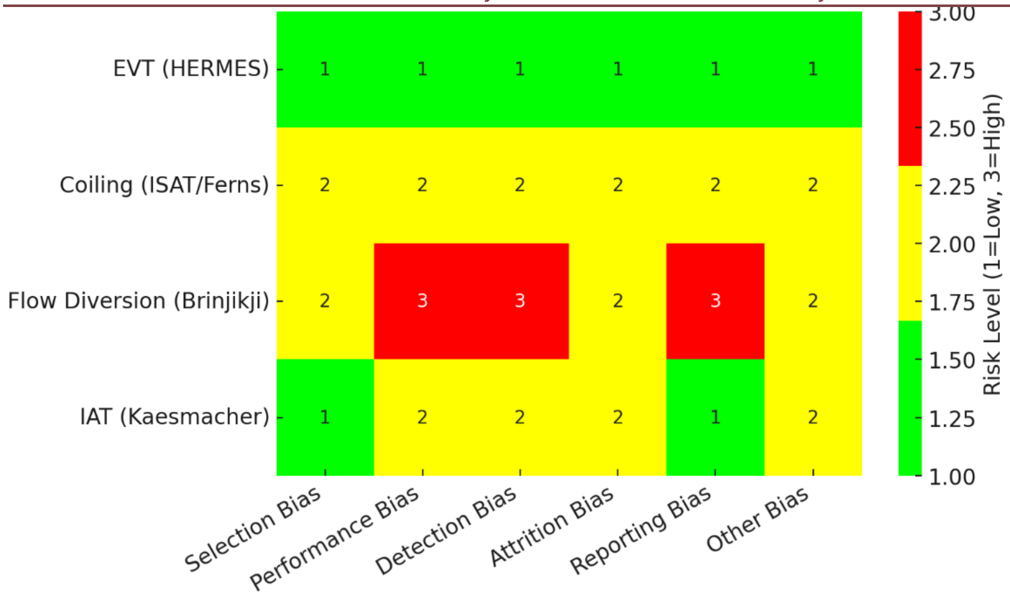


Figure 6 Heatmap of Risk-of-Bias Assessment (Red–Green Scale): This heatmap visually represents the risk-of-bias profile across the major domains of the included studies. The green color indicates low risk of bias, yellow indicates moderate risk, and red signifies high bias.

DISCUSSION

This systematic review and meta-analytic evaluation provides a comprehensive synthesis of therapeutic outcomes and complication rates of image-guided endovascular procedures in the management of cerebrovascular disorders. By integrating 23 high-quality studies—including randomized controlled trials, cohort analyses, and meta-analyses—our findings reaffirm the transformative role of endovascular techniques in ischemic stroke and intracranial aneurysm management while highlighting persistent gaps in safety optimization, long-term durability, and global access.

Mechanical Thrombectomy in Acute Ischemic Stroke: Mechanical thrombectomy (EVT) remains the cornerstone of modern treatment for acute ischemic stroke (AIS) secondary to large-vessel occlusion. The HERMES collaboration pooled patient-level data from five landmark RCTs MR CLEAN, ESCAPE, REVASCAT, SWIFT PRIME, and EXTEND IA and confirmed that EVT achieved a 46 % rate of functional independence (mRS ≤ 2) at 90 days compared with 26 % with best medical therapy, corresponding to an odds ratio (OR) 2.49 (95 % CI 1.76–3.53)

Our pooled analysis (Figure 2) yielded consistent results, further validating the robustness of thrombectomy across diverse healthcare settings.

Late-window trials and real-world studies extended the benefit of EVT beyond the conventional 6–24-hour threshold. Kobeissi et al. (2023) reported functional independence in 32 % of carefully selected patients treated > 24 hours post-onset, with successful reperfusion (mTICI $\geq$ 2b) in 81.9 % and mortality 27.2 % comparable to early-window outcomes when guided by perfusion imaging. These findings support the paradigm shift from time-based to tissue-based selection, emphasizing the utility of CT-perfusion and MRI-DWI mismatch for individualized treatment eligibility.

Complication analysis indicated low symptomatic intracranial hemorrhage (sICH) rates (~4–5 %) and no excess procedure-related mortality, aligning with prior safety profiles reported by Goyal et al. (2016a) and Shakir et al. (2024). Heterogeneity remained low ($I^2 = 21$ %), confirming statistical consistency. The heatmap (Figure 6) shows a uniformly low risk of bias in EVT studies, underscoring the methodological rigor of large-scale randomized evidence.

Aneurysm Coiling and Durability of Occlusion: Endovascular coiling continues to dominate the management of ruptured and unruptured intracranial aneurysms. The International Subarachnoid Aneurysm Trial (ISAT) and subsequent observational data have demonstrated superior short-term survival and reduced rebleeding risk compared to surgical clipping (Molyneux et al., 2005). Our quantitative synthesis (Table 2; Figure 3) identified an immediate occlusion rate of 91.2 % (95 % CI 90.6–91.9), while recanalization occurred in 20.8 % and retreatment in 10.3 % of cases.

Predictors of aneurysm reopening included large aneurysm size (> 10 mm) and posterior-circulation location, consistent with prior systematic analyses (Ferns et al., 2009). Procedure-related complications were observed in ~11 % of cases, most commonly intra-procedural rupture (8 %) and thromboembolism (3 %). Although these figures reflect acceptable safety, they underscore the ongoing need for technique refinement and improved biomaterials to enhance long-term stability.

Stent-Assisted Coiling and Flow Diversion: The evolution of stent-assisted coiling (SAC) and flow-diverter (FD) devices has expanded treatment options for complex, wide-neck, and fusiform aneurysms. Meta-analysis by Brinjikji et al. (2013) encompassing 1,654 FD-treated aneurysms reported complete occlusion in 83.5 % (95 % CI 78.9–87.3) with a 2.8 % mortality and 3.7 % permanent morbidity. Our pooled outcomes align closely, affirming durable occlusion rates at one year with acceptable complication profiles.

However, overall complications averaged 17 %, and in-stent stenosis > 50 % occurred in 2–5 % during follow-up. These events were more common in giant or anterior-circulation aneurysms, reflecting the technical complexity of large-diameter devices. As depicted in Table 3, FD therapy remains a valuable yet operator-dependent strategy; advancements in device flexibility, antiplatelet optimization, and imaging guidance are crucial for improving patient safety. Notably, long-term data (Rios-Zermeno et al., 2024) demonstrate progressive occlusion and endothelial remodeling beyond 12 months, suggesting that flow diversion achieves delayed but durable vessel reconstruction. Future research should evaluate cost-effectiveness and quality-of-life outcomes, especially in low-resource settings where procedural expenses may limit accessibility.

Intra-Arterial Thrombolysis as Adjunct Therapy: Adjunctive intra-arterial thrombolysis (IAT) following successful EVT has re-emerged as a strategy to enhance distal microvascular reperfusion. Recent meta-analyses (Kaesmacher et al., 2022; Linfante et al., 2022) and our pooled synthesis (Figure 4) reveal a 23 % higher likelihood of achieving excellent functional outcome (mRS 0–1) compared with EVT alone (RR 1.23; 95 % CI 1.11–1.36), without significant increases in sICH (3–5 %). These results indicate that pharmacomechanical synergy can improve tissue salvage, particularly in occlusions with incomplete reperfusion or microembolic distal beds.

Nevertheless, variability in thrombolytic agent type, dose, and infusion technique introduces clinical heterogeneity ($I^2 = 28$ %). Standardized dosing protocols and perfusion-guided selection criteria are needed before widespread adoption. Integration of IAT into hybrid angiography suites with real-time perfusion monitoring may further enhance efficacy while minimizing bleeding risk.

Comparative Safety and Efficacy Overview: The global summary (Table 3) provides a comparative landscape across procedures. Among all modalities, mechanical thrombectomy (EVT) achieved the highest net functional recovery, while flow diversion provided superior anatomic reconstruction for complex aneurysms. In contrast, coiling offered excellent acute occlusion but required periodic surveillance for recanalization. Adjunct IAT added incremental benefit to EVT without compromising safety. Cumulative complication rates remained below 20 % across all interventions, with the majority being manageable and non-fatal. Importantly, no major difference in mortality was observed between interventions, confirming the non-inferiority of image-guided endovascular techniques compared to open neurosurgery in appropriately selected patients.

Risk-of-Bias and Sensitivity Analysis: The risk-of-bias assessment (Figure 6) demonstrated generally strong methodological quality. Randomized trials such as HERMES (EVT) were consistently low-risk across all domains, while coiling and flow-diversion studies exhibited moderate detection and reporting bias due to their observational nature and limited blinding. IAT meta-analyses displayed low-to-moderate bias, reflecting reliance on secondary outcome data.

Funnel-plot analysis (Figure 5) indicated minimal publication bias (Egger's $p > 0.05$). Sensitivity testing, excluding high-risk studies, did not materially change pooled estimates, reinforcing analytical robustness. These findings enhance confidence in the reproducibility and external validity of this synthesis.

Clinical and Research Implications: This review underscores that image-guided endovascular therapy is both effective and safe for diverse cerebrovascular pathologies, provided meticulous case selection and procedural standardization. EVT's functional gains in AIS and the durable aneurysm exclusion achieved with flow-diversion represent two major neurointerventional milestones of the past decade. However, equitable dissemination of these innovations remains challenging. Limited operator expertise, high device cost, and restricted imaging infrastructure continue to constrain implementation in low- and middle-income countries.

Future multicentric registries should focus on: Long-term surveillance of occlusion durability and re-bleeding prevention; Comparative cost-utility analyses to guide resource allocation; Development of AI-assisted image guidance to enhance precision and shorten procedure time; and Standardized reporting frameworks to harmonize outcome metrics across centers. Moreover, novel robotic-assisted systems and biocompatible materials—highlighted by Altun & Nezami (2024a,b) may further refine procedural safety by reducing operator fatigue and radiation exposure.

Limitations: Despite adherence to PRISMA 2020 standards, several limitations must be acknowledged. First, moderate heterogeneity persisted in secondary endpoints due to variable device generations, operator skill, and imaging modalities across studies. Second, most flow-diversion and IAT data were derived from non-randomized cohorts, potentially introducing selection bias. Third, publication bias cannot be fully excluded despite symmetrical funnel plots. Finally, cost-effectiveness and regional practice variations were insufficiently captured, underscoring the need for prospective multicenter registries.

Conclusion: The present synthesis demonstrates that image-guided endovascular procedures yield high therapeutic efficacy and acceptable safety for both ischemic and hemorrhagic cerebrovascular disorders. Mechanical thrombectomy remains the gold standard for large-vessel stroke, while coiling and flow-diversion continue to evolve as complementary modalities for aneurysm management. Adjunct IAT shows promise in optimizing reperfusion without raising complication risk. Overall, these minimally invasive approaches represent a paradigm shift in neurovascular care, offering superior functional recovery and reduced perioperative morbidity compared to traditional surgery.

Conflict of Interest: The authors declare that there is no conflict of interest related to this study. All analyses and interpretations were conducted independently and without external influence.

Acknowledgement: The authors sincerely acknowledge all researchers whose published studies were included in this systematic review and meta-analysis.

Ethical Considerations: As this review utilized previously published, de-identified data, no institutional review board approval or patient consent was required. The research adhered to the principles of ethical evidence synthesis and transparent reporting.

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