

LONG-TERM EFFICACY, SAFETY, AND RECURRENCE RATES OF COILING, STENT-ASSISTED COILING, AND FLOW DIVERSION IN UNRUPTURED INTRACRANIAL ANEURYSMS: A SYSTEMATIC REVIEW

Suria VH ^{1*}, Tandionugroho S ^{2,3}, Drajat E ^{2,3}, Hertyanto S ^{2,3}, Darmawan MR ^{2,3}, Fazharyasti V ^{2,3}, Putranto TA ^{2,3}

¹ Department of Radiology, Faculty of Medicine, Universitas Pembangunan Nasional Veteran Jakarta, Jakarta, Indonesia

² Department of Radiology, Gatot Soebroto Army Hospital, Jakarta, Indonesia.

³ Faculty of Medicine, Department of Radiology, Universitas Pembangunan Nasional Veteran Jakarta, Jakarta, Indonesia.

*Corresponding author:

Vincentius Handy Suria, Department of Radiology, Faculty of Medicine, Universitas Pembangunan Nasional Veteran Jakarta, Jl. RS Fatmawati, Pondok Labu, Kecamatan Cilandak, Kota Jakarta Selatan, Daerah Khusus Ibukota Jakarta 12450.

Email: vhandy1811@gmail.com

DOI: <https://doi.org/10.32896/cvnsv8n3.1-15>

Submitted: 01.07.2026

Accepted: 17.08.2026

Published: 30.09.2026

ABSTRACT:

Background: Unruptured intracranial aneurysms (UIA) affect approximately 2%–3% of adults, and their management must balance rupture prevention against periprocedural risk. This systematic review compares the long-term efficacy, safety, and recurrence of coiling, stent-assisted coiling (SAC), and flow diversion (FD). **Methods:** Following PRISMA guidelines, a comprehensive search yielded 18 eligible studies (RCTs, prospective/retrospective cohorts, and propensity-score matching) covering more than 4,000 procedures. Risk of bias, assessed with RoB 2, NOS, ROBINS-I, and MINORS, ranged from moderate to high. **Results:** Coiling achieved 63.0%–76.8% complete occlusion with the lowest permanent morbidity (0.27%) but the highest recurrence (37.1%), reduced by 8.4% with hydrogel coils. SAC gave superior occlusion (90%–94.1%) in wide-neck aneurysms and stable long-term recanalization (8.0% at >24 months) but higher first-year ischemic complications (8.8% vs 2.2%). FD provided the best progressive durability (80.7%–81.81%) with near-zero recanalization and only 1.2% periprocedural neurological morbidity using new-generation coated devices. **Conclusion:** Optimal UIA management is individualized by aneurysm size and morphology: coiling for small aneurysms (high safety, high recurrence), SAC for wide-neck aneurysms (improved efficacy, moderate first-year ischemic risk), and FD for complex or giant aneurysms (durable occlusion, near-zero recurrence, minimal morbidity).

Keywords : Intracranial Aneurysm, Embolization Therapeutic, Endovascular Procedures, Stents, Treatment Outcome.

INTRODUCTION

Intracranial aneurysms are a global health burden and a central focus of neurointerventional radiology. The worldwide prevalence of unruptured intracranial aneurysms (UIA) is roughly 2%–3% of adults [1,2]. National data for Indonesia remain limited, although stroke-center registries suggest a rising case load; because Indonesian patients show distinct cardiovascular risk profiles and angiographic rupture predictors, early detection and prophylactic intervention are especially relevant in developing countries [3].

The core dilemma is choosing the timing and modality of preventive treatment, given the risk of rupture that presents clinically as aneurysmal subarachnoid hemorrhage (aSAH) [4,5]. Rupture is devastating: AHA/ASA guidance cites 30%–40% mortality, mostly in the early bleeding phase, while more than half of survivors retain permanent deficits from secondary events such as vasospasm, hydrocephalus, or rebleeding [4]. Management therefore aims to prevent hemorrhage without adding procedural morbidity [5].

As interventional technology has matured, endovascular therapy has largely replaced open surgery. Coiling was the long-standing standard but suffers high recurrence and recanalization in large, giant, or wide-neck lesions. These limitations drove stent-assisted coiling (SAC), which prevents coil herniation into the parent vessel, and later flow diversion (FD), which reconstructs vessel hemodynamics [5,6]. Although both improve durable occlusion, they mandate dual antiplatelet therapy with attendant bleeding and thromboembolic risks [5,6]. This review compares the long-term efficacy, safety, and recurrence of conventional coiling, SAC, and FD in UIA to clarify the optimal balance among occlusion, complications, and recanalization, and to guide modality

selection by aneurysm morphology and patient condition [5,6].

METHODOLOGY

This systematic review compared the long-term efficacy, safety, and recurrence of conventional coiling, stent-assisted coiling (SAC), and flow diversion (FD) in UIA. Eligible participants were adults (≥ 18 years) with a radiologically confirmed UIA at treatment. Included studies assessed or compared these endovascular options and reported at least one outcome among efficacy, safety, or recurrence; accepted designs were randomized controlled trials (RCTs), prospective and retrospective cohorts, and large multicenter clinical registries.

Excluded were studies of patients with ruptured aneurysms (aSAH) at intervention and those addressing techniques outside the three targets—open microsurgery, isolated balloon-assisted coiling without an SAC/FD comparator, and intrasaccular devices such as the Woven EndoBridge (WEB). Also excluded were case reports, very small case series (< 15 – 20 patients), narrative reviews, conference abstracts without full text, letters, expert opinions, animal experiments, in-vitro silicone-model and computational fluid dynamics (CFD) studies, and non-English or inaccessible articles.

Boolean searches covered PubMed, ScienceDirect, JSTOR, Semantic Scholar, and Google Scholar using: (((unruptured OR intact OR non-ruptured OR nonruptured) AND (“intracranial aneurysm*” OR “cerebral aneurysm*” OR “brain aneurysm*”)) OR “unruptured intracranial aneurysm*”) AND (coil* OR “endovascular coiling” OR “stent-assisted coil*” OR “stent assisted coil*” OR “flow diversion” OR “flow diverter*” OR “flow diverting”). Reporting followed the PRISMA guidelines (Figure 1): identification yielded 4,030 records; 216 duplicates were removed, leaving 3,814 for

screening, of which 3,796 were excluded as irrelevant; all 18 retrieved reports were assessed for eligibility and 18 were included.

Risk of bias used validated, design-specific instruments: RoB 2 for RCTs (low–moderate), the Newcastle–Ottawa Scale (NOS) for retrospective cohorts (low–moderate), ROBINS-I for non-randomized comparative studies (low–moderate to moderate), and MINORS for single-arm studies (moderate to high), as summarized in Table 1.

RESULTS

From 4,030 initially identified records, 18 studies met the inclusion criteria, together contributing 4,453 patients and approximately 6,600 treated unruptured intracranial aneurysms, with methodological quality from low risk (RCTs) to moderate–high (retrospective cohorts). Study designs and sample sizes are listed in Table 2.

The pooled cohort showed typical UIA demographics ages 18 to 83 years, peaking in the fifth-to-seventh decades, with a female predominance consistently exceeding 70% across large multicenter series. Comorbidity carried greater prognostic weight than age: a Charlson Comorbidity Index (CCI) above 4 strongly predicted post-procedural morbidity, and a prior ischemic stroke or cerebrovascular accident (CVA) independently raised periprocedural ischemic risk, demanding dual-antiplatelet adjustment before intervention (Table 3).

Long-term effectiveness stratified by modality, size, and hemodynamics (Table 4). Simple coiling produced immediate total occlusion in 63.0%, with a neck remnant in 22.5% and an aneurysm remnant in 14.6%; in small UIAs (≤ 7 mm), complete occlusion reached 76.8%. Second-generation hydrogel coils cut composite adverse outcomes by 8.4% and required fewer coils (5.04 vs 6.93 for bare platinum).

SAC excelled in wide-neck lesions: the Alpha stent reached 97.1% technical success with 91.4% complete occlusion (RROC I) and 8.6% RROC II at six months, while Neqstent-assisted coiling gave 90% immediate complete occlusion rising to 94.1% adequate occlusion at medium-term follow-up, with a mean packing density of 26.2%. FD delivered progressive occlusion, 81.81% with the Pipeline Vantage (Shield Technology) and 80.7% with the modified Derivo 2 Heal at a mean of six months—and far lower in-stent stenosis for the Lattice Flow Diverter (1.8%) than the conventional Pipeline Embolization Device (14.5%).

Safety reflected a trade-off between device sophistication and antiplatelet prophylaxis (Table 5). Silent embolic infarction (SEI) on diffusion-weighted imaging (DWI) reached 50% after Neuroform Atlas stenting, and one-year clinical ischemic stroke was higher with SAC (8.8%) than simple coiling (2.2%), correlating with an aneurysm neck ≥ 4 mm. Tirofiban significantly improved postoperative cognition by curbing microemboli. Intraprocedural rupture (IPR) was lethal but rare ($\sim 0.87\%$, 19 of 2,172); a balloon guiding catheter (BGC) reduced post-IPR fatal morbidity from 44.4% to 0%. Small-aneurysm simple coiling carried 10.1% technical complications yet only 0.27% permanent deficit and 0% mortality, while the modified Derivo 2 Heal kept neurological morbidity as low as 1.2% with 99% implantation success. A CCI above 4 again strongly predicted adverse outcomes, confirming that morbidity is not driven by age alone.

Recurrence tracked with material apposition at the neck (Table 6). Pure simple coiling showed the highest recanalization, particularly in giant UIAs, although newer hydrogels reduced major recurrence by 8.4%. For SAC, long-term (>24 months) recanalization stabilized at 8.0%, with maximum UIA size and parent-artery curvature angle as the dominant

predictors. FD offered the most durable construct, with recanalization approaching 0% beyond 12 months once solid occlusion was achieved, reflecting a permanent neoendothelial bridge sealing the aneurysm ostium.

Table 7 gives a head-to-head comparison of coiling, SAC, and FD across optimal anatomy, occlusion efficacy, safety, and recurrence, providing an objective basis for individualized endovascular management of UIA.

DISCUSSION

Effective UIA care balances durable occlusion against minimal periprocedural morbidity [1,2]. Synthesis of the 18 studies reveals a clear paradigm shift from simply filling the intra-aneurysmal space toward comprehensive hemodynamic reconstruction [5,6].

Conventional simple coiling remains very safe, especially for small narrow-neck UIAs (≤ 7 mm), where it achieved 76.8% complete occlusion at the lowest permanent deficit rate of 0.27% [7]. Its morbidity here (2.2%–10.1%) is well below the 9.1% early-era endovascular complication rate of the International Study of Unruptured Intracranial Aneurysms (ISUIA) [8], reflecting progress in catheterization and coil materials. Coil compaction nonetheless persists, with angiographic remnant filling up to 37.1% [9], partly offset by second-generation hydrogel coils that improve packing density and cut adverse outcomes by 8.4% [10,11].

For wide-neck aneurysms, SAC supplies the mechanical scaffold that prevents material herniation [12] and enables immediate complete occlusion above 90% [13,14]. However, SAC carries an 8.8% clinical ischemic risk and SEI incidence up to 50% [15,16], exceeding the roughly 3.4% permanent ischemic risk of the UCAS Japan registry [17] likely reflecting the

higher proportion of complex, wide-neck lesions in our SAC group.

FD, by contrast, offers unmatched durability through natural endothelialization [18]. Its progressive occlusion exceeding 80% at six months aligns with the meta-analysis of Brinjikji et al. [19], who reported 76% at six months rising to 91% at twelve [19]. FD's suppression of recanalization makes it the leading choice for complex or giant aneurysms where coiling often fails [20], and recent anterior-circulation cohorts confirm that although SAC gives better immediate occlusion, FD minimizes retreatment via biological stability [21].

A “safety paradox” emerges because the complexity of SAC and FD obliges dual antiplatelet therapy (DAPT) [4,16]. Thromboembolic events were not purely device-related but also reflected anatomy (neck ≥ 4 mm) and comorbidity burden [15,22]; a CCI above 4 predicted poor outcomes more accurately than chronological age [23], echoing the CLARITY registry's emphasis on systemic risk-based patient selection [24]. Neuroprotection with tirofiban meaningfully attenuated microemboli [25], and although IPR is rare (0.87%), a BGC reduced fatality to 0% [26].

Several limitations apply. The mix of designs from RCTs to single-arm retrospective cohorts introduces variability in data quality, while differing device deployment precludes operator blinding and invites selection bias, and non-uniform follow-up limits standardized long-term analysis. Future multicenter prospective trials should define protocols for DAPT tapering after SAC and FD.

CONCLUSION

Optimal management of UIA cannot be generalized; it depends heavily on aneurysm size and morphology, and treatment must be individualized to balance efficacy, safety, and recurrence.

Conventional coiling remains the first choice for small aneurysms, with a superior safety profile and very low permanent morbidity (0.27%) but only moderate occlusion (63.0%–76.8%) and high recurrence (37.1%). SAC is specifically indicated for wide-neck aneurysms, improving immediate occlusion (90%–94.1%) and reducing long-term recurrence to 8.0%, despite an 8.8% first-year clinical ischemic risk from device thrombogenicity. FD is strongly recommended as standard care for complex or giant aneurysms, providing high long-term occlusion (80.7%–81.81%), recanalization approaching zero through permanent vascular remodelling, and minimal periprocedural morbidity (1.2%). No single modality suits every case; neurointerventional success rests on matching device type to each patient's vascular anatomy to secure the safest, most effective outcome.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

FUNDING

This research received no specific grant from any funding agency.

REFERENCES:

1. Cras TY, Bos D, Ikram MA, Vergouwen MDI, Dippel DWJ, Voortman T, et al. Determinants of the presence and size of intracranial aneurysms in the general population: the Rotterdam Study. *Stroke*. 2020;51(7):2103-2110. <https://doi.org/10.1161/STROKEAHA.120.029296>
2. Vlak MHM, Algra A, Brandenburg R, Rinkel GJE. Prevalence of unruptured intracranial aneurysms, with emphasis on sex, age, comorbidity, country, and time period: a systematic review and meta-analysis. *Lancet Neurol*. 2011;10(7):626-636. [https://doi.org/10.1016/S1473-3099\(11\)70109-0](https://doi.org/10.1016/S1473-3099(11)70109-0)
3. Swatan JP, Sani AF, Kurniawan D, Swatan H, Husain S. What are the predictors of intracranial aneurysm rupture in Indonesian population based on angiographic findings? Insight from intracranial aneurysm registry on three comprehensive stroke centres in Indonesia. *Stroke Res Treat*. 2022;2022:4787048. <https://doi.org/10.1155/2022/4787048>
4. Connolly ES, Rabinstein AA, Carhuapoma JR, Derdeyn CP, Dion J, Higashida RT, et al. Guidelines for the management of aneurysmal subarachnoid hemorrhage. *Stroke*. 2012;43(6):1711-1737. <https://doi.org/10.1161/STR.0b013e3182587839>
5. Venturini M, Scalise M, Di Cosmo L, Cossa C, Andreella N, Micieli C, et al. Flow diversion vs. coiling for large and giant intracranial aneurysms: a systematic review and meta-analysis. *J Clin Med*. 2026;15(4):1357. <https://doi.org/10.3390/jcm15041357>
6. Hong Y, Wang YJ, Deng Z, Wu Q, Zhang JM. Stent-assisted coiling versus coiling in treatment of intracranial aneurysm: a systematic review and meta-analysis. *PLoS One*. 2014;9(1):e82311. <https://doi.org/10.1371/journal.pone.0082311>
7. Im SH, Han MH, Kwon OK, Kwon BJ, Kim SH, Kim JE, et al. Endovascular coil embolization of 435 small asymptomatic unruptured intracranial aneurysms: procedural morbidity and patient outcome. *AJNR Am J Neuroradiol*. 2009;30(1):79-84. <https://doi.org/10.3174/ajnr.A1290>
8. Wiebers DO. Unruptured intracranial aneurysms: natural history, clinical

- outcome, and risks of surgical and endovascular treatment. *Lancet*. 2003;362(9378):103-110.
[https://doi.org/10.1016/S0140-6736\(03\)13860-3](https://doi.org/10.1016/S0140-6736(03)13860-3)
9. Pierot L, Spelle L, Vitry F, Pasco A, Bonneville JF, Barreau X, et al. Immediate anatomic results after the endovascular treatment of unruptured intracranial aneurysms: analysis of the ATENA series. *AJNR Am J Neuroradiol*. 2010;31(1):140-144.
<https://doi.org/10.3174/ajnr.A1745>
 10. Poncyljusz W, Zarzycki A, Zwarzany Ł, Burke TH. Bare platinum coils vs. HydroCoil in the treatment of unruptured intracranial aneurysms - a single center randomized controlled study. *Eur J Radiol*. 2015;84(2):261-265.
<https://doi.org/10.1016/j.ejrad.2014.11.002>
 11. Taschner CA, Chapot R, Costalat V, Machi P, Courthéoux P, Barreau X, et al. Second-generation hydrogel coils for the endovascular treatment of intracranial aneurysms: a randomized controlled trial. *Stroke*. 2018;49(3):667-674.
<https://doi.org/10.1161/STROKEAHA.117.018707>
 12. Kim J, Kim JJ, Kim SW, Choi J, Kim H, Kim J, et al. Safety and efficacy of the novel Alpha stent for the treatment of intracranial wide-necked aneurysm. *Sci Rep*. 2024;14(1):8723.
<https://doi.org/10.1038/s41598-024-59363-2>
 13. Islim FI, Saleem N, Patankar T. Large single-center experience with short-term follow-up of Neqstent-assisted coiling. *AJNR Am J Neuroradiol*. 2024;45(5):605-611.
<https://doi.org/10.3174/ajnr.A8187>
 14. Ulusoy BSS, Altay ÇM, Onay M, Binboga AB, Kaya M. Initial experiences of the Optima coil system in intracranial aneurysm treatment: surgical and interventional approach to safety and efficacy in terms of cerebral arteries. *Acta Cir Bras*. 2025;40:e403425.
<https://doi.org/10.1590/acb403425>
 15. Hetts SW, Turk A, English JD, Dowd CF, Mocco J, Prestigiacomo C, et al. Stent-assisted coiling versus coiling alone in unruptured intracranial aneurysms in the Matrix and Platinum Science trial: safety, efficacy, and mid-term outcomes. *AJNR Am J Neuroradiol*. 2014;35(4):698.
<https://doi.org/10.3174/ajnr.A3755>
 16. Shin S, Hwangbo L, Lee TH, Ko JK. Silent embolic infarction after Neuroform Atlas stent-assisted coiling of unruptured intracranial aneurysms. *J Korean Neurosurg Soc*. 2023;67(1):42.
<https://doi.org/10.3340/jkns.2023.0091>
 17. Morita A, Kirino T, Hashi K, Aoki N, Fukuhara S, Hashimoto N, et al. The natural course of unruptured cerebral aneurysms in a Japanese cohort. *N Engl J Med*. 2012;366(26):2474-2482.
<https://doi.org/10.1056/NEJMoa1113260>
 18. Schwab R, Kabbasch C, Goertz L, Kaschner M, Weiss D, Loehr C, et al. The Derivo 2 Heal embolization device in the treatment of ruptured and unruptured intracranial aneurysms: a retrospective multicenter study. *Clin Neuroradiol*. 2024;35(1):25-34.
<https://doi.org/10.1007/s00062-024-01446-8>
 19. Brinjikji W, Murad MH, Lanzino G, Cloft HJ, Kallmes DF. Endovascular treatment of intracranial aneurysms with flow diverters: a meta-analysis. *Stroke*. 2013;44(2):442-447.

- <https://doi.org/10.1161/STROKEAHA.112.678151>
20. Xia JL, Li GL, Liu HE, Feng-Fei X, Gu XD. Flow-diverting device versus coil embolization for unruptured intracranial aneurysm: a meta-analysis. *Medicine* (Baltimore). 2021;100(24):e26351. <https://doi.org/10.1097/MD.00000000000026351>
21. Martinez-Galdamez M, Galván-Fernández J, Perez-Sanchez LI, Schüller-Arteaga MA, Vasconez-Muñoz FA, Sanchez-Lite I, et al. Stent-assisted coiling vs. flow diversion in unruptured anterior circulation aneurysms: a single-center cohort study. *Brain Sci*. 2025;15(12):1290. <https://doi.org/10.3390/brainsci15121290>
22. Won YD, Kim YD, Ban SP, Kwon OK. Factors predicting recanalization following stent-assisted coil embolization of unruptured intracranial aneurysms with long-term follow-up. *Front Neurol*. 2024;15:1351940. <https://doi.org/10.3389/fneur.2024.1351940>
23. O'Neill AH, Chandra RV, Slater LA, Chong W, Xenos C, Danks AR, et al. Influence of comorbidities on treatment of unruptured intracranial aneurysms in the elderly. *J Clin Neurosci*. 2019;62:38-45. <https://doi.org/10.1016/j.jocn.2019.01.013>
24. Cognard C, Pierot L, Anxionnat R, Ricolfi F. Results of embolization used as the first treatment choice in a consecutive nonselected population of ruptured aneurysms: clinical results of the Clarity GDC study. *Neurosurgery*. 2011;69(4):837-841. <https://doi.org/10.1227/NEU.0b013e3182257b30>
25. Bao X, He P, Liu X, Xu W, Yu D, Chen F, et al. Effect of tirofiban on cognitive function in patients with unruptured intracranial aneurysms after endovascular embolization. *Br J Hosp Med (Lond)*. 2025;86(7). <https://doi.org/10.12968/hmed.2025.0260>
26. Aoki K, Murayama Y, Tanaka Y, Ishibashi T, Irie K, Fuga M, et al. Risk factors and management of intraprocedural rupture during coil embolization of unruptured intracranial aneurysms: role of balloon guiding catheter. *Front Neurol*. 2024;15:1343137. <https://doi.org/10.3389/fneur.2024.1343137>
27. Çelebioğlu EC, Blevrakis E, Yilmaz M, Doğan İ, Duruk Erkent F, Kortun Ş, et al. Efficacy and performance of the new Pipeline Vantage flow diverter stent with Shield Technology: short-term results of a single-center experience. *Sci Prog*. 2025;108(2):1-14. <https://doi.org/10.1177/00368504251349714>
28. Huang C, Ma G, Tong X, Feng X, Wen Z, Huang M, et al. Comparison of Pipeline embolization device versus Tubridge embolization device in unruptured intracranial aneurysms: a multicenter, propensity score matched study. *J Neurointerv Surg*. 2025;17:467-474. <https://doi.org/10.1136/jnis-2024-021623>
29. Coley S, Sneade M, Clarke A, Mehta Z, Kallmes D, Cekirge S, et al. Cerecyte Coil Trial: procedural safety and clinical outcomes in patients with ruptured and unruptured intracranial aneurysms. *AJNR Am J Neuroradiol*. 2012;33(3):474-480. <https://doi.org/10.3174/ajnr.A2836>

TABLE LEGENDS:

Table 1. Risk-of-Bias Assessment

No.	Primary Author (Year)	Bias Assessment Instrument	Level of Bias Risk
1	O'Neill et al. (2019) [23]	Newcastle–Ottawa Scale (NOS)	Moderate
2	Poncyłjusz et al. (2015) [10]	Cochrane Risk of Bias 2 (RoB 2)	Low – Moderate
3	Bao et al. (2025) [25]	ROBINS-I	Low – Moderate
4	Bao et al. (2025) [25]	ROBINS-I	Moderate
5	Çelebioğlu et al. (2025) [27]	MINORS	High
6	Ulusoy et al. (2025) [14]	MINORS	Moderate – High
7	Schwab et al. (2024) [18]	MINORS	Moderate
8	Won et al. (2024) [22]	Newcastle–Ottawa Scale (NOS)	Low
9	Huang et al. (2025) [28]	ROBINS-I	Low – Moderate
10	Kim et al. (2024) [12]	MINORS (Prospective)	Moderate
11	Islim et al. (2024) [13]	MINORS	High
12	Aoki et al. (2024) [26]	Newcastle–Ottawa Scale (NOS)	Moderate
13	Shin et al. (2023) [16]	ROBINS-I	Moderate
14	Hetts et al. (2014) [15]	ROBINS-I	Low – Moderate
15	Im et al. (2009) [7]	MINORS	Moderate – High
16	Coley et al. (2012) [29]	Cochrane Risk of Bias 2 (RoB 2)	Low
17	Pierot et al. (2010) [9]	MINORS (Prospective)	Low
18	Taschner et al. (2018) [11]	Cochrane Risk of Bias 2 (RoB 2)	Low

Table 2. Study Characteristics

No.	Primary Author (Year)	Study Design	Sample Size (N)
1	O'Neill et al. (2019)	Retrospective cohort (single-center)	123 patients
2	Poncyłjusz et al. (2015)	Randomized controlled trial (RCT)	96 patients
3	Bao et al. (2025)	Retrospective observational (PSM)	PSM-matched pairs
4	Bao et al. (2025)	Retrospective comparative	125 patients
5	Çelebioğlu et al. (2025)	Single-arm retrospective	21 patients (22 aneurysms)
6	Ulusoy et al. (2025)	Single-arm retrospective cohort	64 patients
7	Schwab et al. (2024)	Multicenter observational cohort	84 patients
8	Won et al. (2024)	Retrospective cohort	399 patients
9	Huang et al. (2025)	Multicenter comparative (PSM)	1,025 (275 pairs evaluated)
10	Kim et al. (2024)	Single-arm prospective	35 patients
11	Islim et al. (2024)	Single-arm retrospective cohort	20 patients
12	Aoki et al. (2024)	Multicenter retrospective cohort	>2,000 (2,172 aneurysms)
13	Shin et al. (2023)	Retrospective comparative cohort	124 patients (96 SAC, 28 control)
14	Hetts et al. (2014)	Post-hoc analysis (from RCT)	361 patients
15	Im et al. (2009)	Retrospective cohort	370 patients (435 aneurysms)
16	Coley et al. (2012)	Randomized controlled trial (RCT)	500 patients
17	Pierot et al. (2010)	Multicenter prospective observational	622 patients (694 aneurysms)
18	Taschner et al. (2018)	Randomized controlled trial (RCT)	484 patients

Table 3. Patient Characteristics

No.	Primary Author (Year)	Age	Gender	Comorbidity / Clinical Risk Factors
1	O'Neill et al. (2019)	Mean 70.6 ± 4.1 y (≥65 y)	F 73.1% / M 26.9%	Charlson Comorbidity Index (CCI); CCI > 4 independently predicts poor outcomes
2	Poncyłjusz et al. (2015)	—	—	—
3	Bao et al. (2025)	—	—	Confounders balanced by propensity score matching (PSM)
4	Bao et al. (2025)	—	—	—
5	Çelebioğlu et al. (2025)	—	—	—
6	Ulusoy et al. (2025)	Mean 53.34 ± 14 y	F 57.8% / M 42.2%	—
7	Schwab et al. (2024)	Mean 58.7 y	F 73.8% / M 26.2%	—
8	Won et al. (2024)	Mean 56.0 y	F 78.9% / M 21.1%	—
9	Huang et al. (2025)	—	—	Prior ischemic stroke analyzed as a clinical variable
10	Kim et al. (2024)	Adults	—	—
11	Islim et al. (2024)	—	—	—
12	Aoki et al. (2024)	—	—	Logistic regression adjusted for age and sex
13	Shin et al. (2023)	—	—	Advanced age explored as a risk for silent embolic infarction (SEI)
14	Hetts et al. (2014)	—	—	Prior CVA/stroke independently predicts ischemic complications
15	Im et al. (2009)	—	—	—
16	Coley et al. (2012)	18–70 y	—	—
17	Pierot et al. (2010)	Mean 51.2 ± 11.3 y	F 72.2% / M 27.8%	Age ≥65 y significantly lowers the chance of total occlusion
18	Taschner et al. (2018)	18–75 y	—	—

Table 4. Long-Term Effectiveness (Occlusion / Technical Success)

No.	Primary Author (Year)	Conventional Coiling	Stent-Assisted Coiling (SAC)	Flow Diversion (FD)
1	O'Neill et al. (2019)	—	—	—
2	Poncyłjusz et al. (2015)	Equivalent density with 5.04 coils (hydro) vs 6.93 (bare)	—	—
3	Bao et al. (2025)	—	—	Good, equivalent occlusion (LFD vs PED)
4	Bao et al. (2025)	—	—	—
5	Çelebioğlu et al. (2025)	—	—	Complete occlusion 81.81% (Pipeline Vantage)
6	Ulusoy et al. (2025)	Adequate occlusion 92.8% (density 26.2%)	—	—
7	Schwab et al. (2024)	—	—	Optimal occlusion 80.7% (device success 99%)
8	Won et al. (2024)	—	—	—
9	Huang et al. (2025)	—	—	Short-term complete occlusion PED > Tubridge
10	Kim et al. (2024)	—	Complete occlusion (RROC I) 91.4% (success 97.1%)	—
11	Islim et al. (2024)	—	Immediate 90%; adequate (6 mo) 94.1%	—
12	Aoki et al. (2024)	—	—	—
13	Shin et al. (2023)	—	—	—
14	Hetts et al. (2014)	—	—	—
15	Im et al. (2009)	Complete occlusion 76.8%	—	—
16	Coley et al. (2012)	—	—	—
17	Pierot et al. (2010)	Complete occlusion 63.0%	—	—
18	Taschner et al. (2018)	—	—	—

Table 5. Procedural Safety (Complications / Morbidity / Mortality)

No.	Primary Author (Year)	Conventional Coiling	Stent-Assisted Coiling (SAC)	Flow Diversion (FD)
1	O'Neill et al. (2019)	Complication risk influenced by CCI > 4	—	—
2	Poncyłjusz et al. (2015)	—	—	—
3	Bao et al. (2025)	—	—	—
4	Bao et al. (2025)	Silent cerebral infarction (SCI) lower with tirofiban	—	—
5	Çelebioğlu et al. (2025)	—	—	—
6	Ulusoy et al. (2025)	—	—	—
7	Schwab et al. (2024)	—	—	Neurological morbidity 1.2%
8	Won et al. (2024)	—	—	—
9	Huang et al. (2025)	—	—	Complications comparable: PED vs Tubridge
10	Kim et al. (2024)	—	Neurological complications (hemiparesis) 2.9%	—
11	İslim et al. (2024)	—	—	—
12	Aoki et al. (2024)	IPR 0.87%; fatal morbidity 44.4% (no BGC) vs 0% (BGC)	—	—
13	Shin et al. (2023)	SEI comparable	SEI 50%	—
14	Hetts et al. (2014)	Ischemic complications (1 y) 2.2%	Ischemic complications (1 y) 8.8%	—
15	Im et al. (2009)	Technical complications 10.1%; permanent deficit 0.27%; mortality 0%	—	—
16	Coley et al. (2012)	Poor outcomes 4.2% (Cerecyte) vs 0% (bare platinum)	—	—
17	Pierot et al. (2010)	—	—	—
18	Taschner et al. (2018)	—	—	—

Table 6. Recurrence and Recanalization Rates

No.	Primary Author (Year)	Conventional Coiling	Stent-Assisted Coiling (SAC)	Flow Diversion (FD)
1	O'Neill et al. (2019)	—	—	—
2	Ponczyk et al. (2015)	No significant medium-term difference	—	—
3	Bao et al. (2025)	—	—	In-stent stenosis 1.8% (LFD) vs 14.5% (PED)
4	Bao et al. (2025)	—	—	—
5	Çelebioğlu et al. (2025)	—	—	—
6	Ulusoy et al. (2025)	—	—	—
7	Schwab et al. (2024)	—	—	—
8	Won et al. (2024)	—	Long-term recanalization 8.0%	—
9	Huang et al. (2025)	—	—	—
10	Kim et al. (2024)	—	—	—
11	Islim et al. (2024)	—	—	—
12	Aoki et al. (2024)	—	—	—
13	Shin et al. (2023)	—	—	—
14	Hetts et al. (2014)	—	—	—
15	Im et al. (2009)	—	—	—
16	Coley et al. (2012)	—	—	—
17	Pierot et al. (2010)	Neck remnant 22.5%; aneurysm remnant 14.6%	—	—
18	Taschner et al. (2018)	Composite risk reduced 8.4% with hydrogel	—	—

Table 7. Comprehensive Comparative Summary

Clinical Parameter	Conventional Coiling	Stent-Assisted Coiling (SAC)	Flow Diversion (FD)
Optimal characteristics	Small aneurysms (≤ 7 mm), narrow neck, dome-to-neck ratio >1.5	Wide-neck and complex bifurcation aneurysms	Complex, giant, dysplastic aneurysms; definitive vascular remodelling
Long-term efficacy (occlusion)	Moderate–high: immediate complete 63.0% (general) to 76.8% (small UIA); optimized by hydrogel coils (5.04 vs 6.93 coils)	Very high: complete $>90\%$ (91.4%–94.1%) at 6 mo; high packing density without coil herniation	Progressive, very high: complete 80.7%–81.81% at ~6 mo; improves over time via endothelialization
Safety (morbidity / complications)	Safest, minimal prophylaxis: technical complications 10.1% but permanent deficit only 0.27% with 0% mortality; 1-y ischemia 2.2%	High thromboembolic risk: 1-y ischemia 8.8%; SEI on DWI up to 50%; strict dual antiplatelet required	Moderate–very safe (new generation): neurological morbidity down to 1.2% with surface-coated devices
Recurrence / recanalization	Highest: remnant filling 37.1% (neck 22.5%, sac 14.6%); drops 8.4% with hydrogel coils	Low: long-term recanalization 8.0%; driven by UIA size and parent-artery curvature	Lowest ($\approx$ zero): permanent remodelling; in-stent stenosis only 1.8% (Lattice FD)

FIGURE LEGENDS:

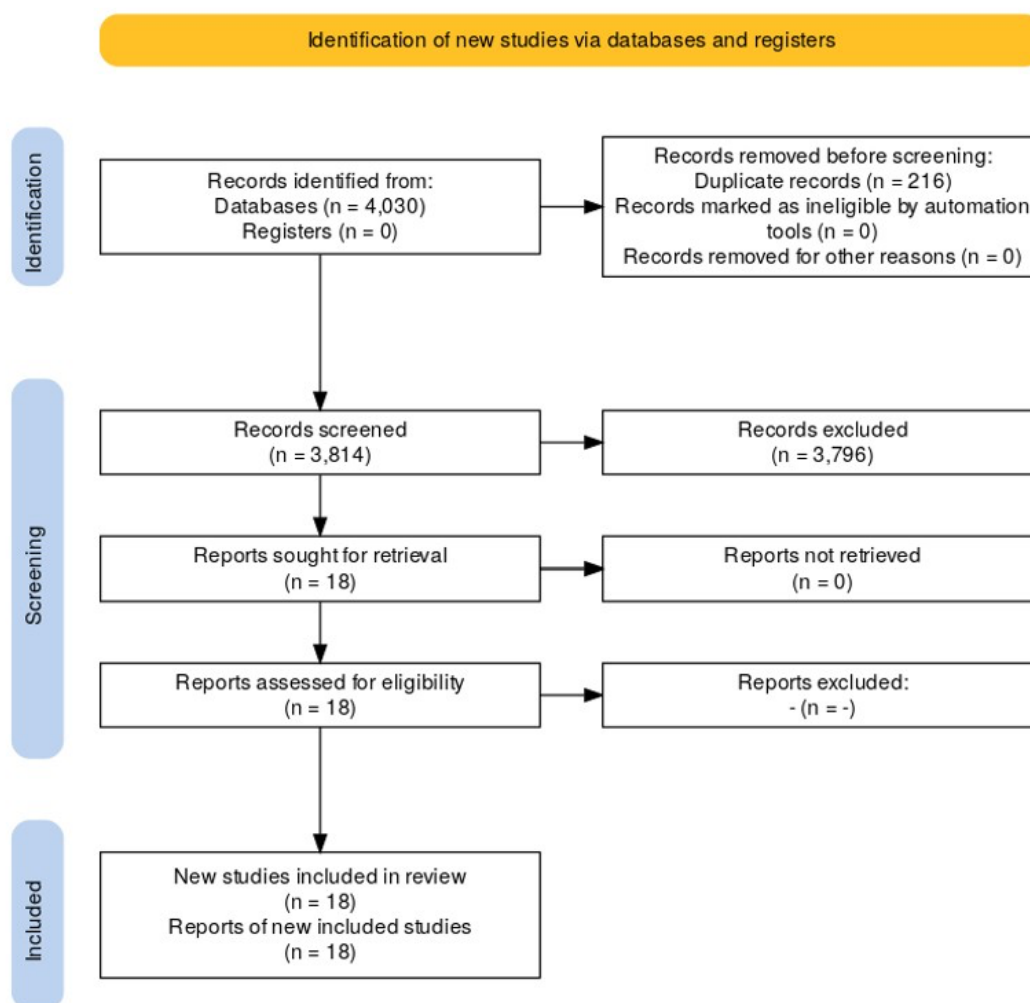


Figure 1. PRISMA Flowchart