E-ISSN: 2616-3470
P-ISSN: 2616-3462
Impact Factor (RJIF): 5.97

www.surgeryscience.com
2025; 9(3): 87-92
Received: 22-06-2025
Accepted: 25-07-2025

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Endovascular coiling versus microsurgical clipping for ruptured intracranial aneurysms: Systemic review and meta-analysis of long-term outcomes

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DOI: https://www.doi.org/10.33545/surgery.2025.v9.i3.B.1237

Abstract
Background: There are many debates regarding endovascular coiling versus microsurgical clipping for ruptured intracranial aneurysms. We conducted a systemic review and a meta-analysis in order to determine the clinical and angiographic outcomes associated with each treatment in the long run.
Methods: We aimed to collect RCT and prospective cohort/registry studies comparing endovascular coiling and microsurgical clipping for ruptured saccular intracranial aneurysms from the databases of PubMed/Medline, Embase, and central. The primary outcome was a poor functional outcome, as defined by having a modified Rankin Scale score greater than 2, at approximately 12 months. Secondary outcomes included retreatment, mortality, rebleeding, and angiographic occlusion. Data selection and extraction and risk of bias assessments was performed in accordance with PRISMA methodology. The risk ratios (RR) with 95% confidence intervals (CI) were calculated using a random-effects model.
Results: There were six studies that fulfilled the inclusion criteria which included 2 RCTs (ISAT and BRAT) and 4 prospective cohort/registry studies with a total of 6671 patients. In the pooled analysis of the two RCTs, endovascular coiling associated with a significantly lower risk of poor functional outcome at ~12 months compared with microsurgical clipping (RR 0.78, 95% CI 0.68-0.89; I^2 = 12%). Retreatment occurred after endovascular coiling substantially more frequently, with pooled data from trials and registries showing approximately 4-fold increased risk (RR 3.90, 95% CI 2.80-5.50; I^2 = 10%). All-cause mortality rates had no clear difference at 1 year between the techniques (RR 0.95, 95% CI 0.76-1.18). Rebleeding events were generally rare, but did happen frequently more often after coiling.
Conclusion: Choosing the right treatment should be individualized, weighing the immediate benefits of coiling against the longer-lasting effectiveness of clipping. More research is needed to assess outcomes with modern endovascular techniques and to better understand the long-term effects on patients and the economic implications.

Keywords: Ruptured intracranial aneurysms, subarachnoid haemorrhage, endovascular coiling, microsurgical clipping, functional outcome, retreatment

Introduction
Intracranial aneurysms are one of the main causes of subarachnoid haemorrhage (SAH), responsible for as much as 85% of spontaneous SAH cases. Even with the progress we've made in neurocritical care, they still pose a significant risk of serious complication and death [1,2]. When it comes to treating ruptured intracranial aneurysms, the two primary options are microsurgical clipping and endovascular coiling. Microsurgical clipping, which was first introduced by Dandy back in the 1930s, has been regarded as the gold standard for quite some time, thanks to its impressive durability and low recurrence rates [2]. Back in the early 1990s, Guglielmi introduced endovascular coiling, which quickly became a go-to minimally invasive option. This technique not only shortened recovery times but also reduced the chances of complications during surgery [16].
The discussion around the best treatment option was transformed by the groundbreaking International Subarachnoid Aneurysm Trial (ISAT). This study showed that patients who received endovascular coiling treatment experienced better functional outcomes and less disability after a year compared to those who underwent microsurgical clipping [8]. However, the long-term follow-up of ISAT has raised some concerns about how effective coiling really is,

especially with the higher rates of aneurysm recurrence and the need for retreatment [10,9]. Recent studies, like the Barrow Ruptured Aneurysm Trial (BRAT), have shed more light on the topic. However, there are still worries about how well endovascular coiling holds up over time, especially when it comes to the chances of aneurysms coming back and the possibility of needing further treatment [14].

Even with these crucial trials, there's still no clear agreement. Variation in how patients are chosen, aneurysm morphology, and the design of the studies have all played a role in the ongoing debate [6]. To effectively guide evidence-based management, we need a thorough synthesis of both clinical and angiographic outcomes over the long term.

This systemic review and meta-analysis is designed to compare the long-term clinical and angiographic outcomes of endovascular coiling versus microsurgical clipping in patients who have suffered from ruptured intracranial aneurysms.

Methods

Protocol and Reporting

This systemic review and meta-analysis was carried out following the guidelines set by Preferred Reporting Items for Systemic Reviews and Meta-Analyses (PRISMA)[12]. The study protocol was carefully crafted to outline eligibility criteria, the search strategy, the outcomes we were interested in, and the methods for synthesizing the data.

Eligibility Criteria

We looked at randomized controlled trials (RCTs) and prospective cohort studies that compared endovascular coiling to microsurgical clipping in patients who had ruptured intracranial aneurysms (RIAs). To be included, studies had to report at least one of the following outcomes:

- Clinical outcomes assessed by the modified Rankin Scale (mRS) or the Glasgow Outcome Scale (GOS)
- Aneurysm recurrence or retreatment rates,
- Mortality rates, or
- Angiographic occlusion rates.

We excluded studies that focused solely on unruptured aneurysms, those that didn't break down outcomes by treatment method, or any reviews, editorials, or case reports.

Search Strategy

We conducted a thorough literature search across PubMed/MEDLINE, Embase, and the Cochrane Central Register of Controlled Trials (CENTRAL) from inception until June 2025. We used a mix of keywords and Medical Subject Headings (MeSH) like "ruptured intracranial aneurysm", subarachnoid haemorrhage", "endovascular coiling", "microsurgical clipping", and "randomized controlled trial". To keep things precise, we only included studies published in English. Additionally, we manually reviewed the references of the articles we found and relevant reviews to identify any other eligible studies.

Study Selection

Two reviewers took on the task of independently screening the titles and abstracts, and then they moved on the full-text review of the articles that seemed relevant. If there were any discrepancies, they worked it out through discussion and reached an agreement. If needed, a third reviewer stepped in to help resolve any lingering issues.

Data Extraction

Data was gathered independently by two authors using a standardized form. The information collected included; study design, publication year, sample size, patient demographics, characteristics of the aneurysms, details of the interventions, follow-up duration, and the outcomes reported. If the outcome data wasn't clearly stated, it was calculated based on the percentages mentioned in the manuscript.

Risk of Bias Assessment

The Cochrane Risk of Bias tool was utilized to assess the quality of randomized controlled trials, while the Newcastle-Ottawa Scale (NOS) was used to evaluate prospective cohort studies. Based on this evaluation, studies were categorized as having low, moderate, or high risk of bias.

Statistical Analysis

We conducted pooled analyses using the Mantel-Haenszel method to determine relative risks (RR) along with 95% confidence intervals (CI) for binary outcomes. To assess heterogeneity, we used the I^2 statistic, where values over 50% suggest significant heterogeneity. In cases where there was no significant heterogeneity, we applied a fixed-effect model; otherwise, we opted for a random-effects model. We also checked for publication bias by visually inspecting funnel plots. All statistical analyses were carried out using RevMan (version 5.4, Cochrane Collaboration) and were verified with R (version 4.3.2) utilizing the 'meta' package.

Results

Study Selection

We identified a total of 1452 records through our electronic database search. After removing duplicates and screened the titles and abstracts, 58 articles were selected for a full-text review. Out of those, 6 studies met our eligibility criteria, which included two randomized controlled trials (RCTs) and four prospective cohort or registry studies, involving 6671 patients with ruptured aneurysms. Detailed overview of the study selection process is shown as PRISMA flow diagram in figure 1. The key characteristics of the studies we included are summarized in table 1.

Table 1: Characteristics of Included Studies

Study	Design	n (ruptured)	Mean Age	% Female	WFNS I-III (%)	Follow-up	Key Findings
ISAT [8,10]	RCT	2,143	52	65%	90%	1, 5, 10 yrs	Coiling: better 1-yr independence, higher retreatment
BRAT [14]	RCT	500	55	62%	85%	1, 3, 10 yrs	Coiling: better short-term outcome, higher recurrence
CARAT [4]	Prospective cohort	1010	53	63%	88%	Up to 9 yrs	Re-rupture risk linked to incomplete occlusion
EVERRUN [7]	Prospective registry	87	56	66%	82%	1 yr	Wide-neck aneurysms: more retreatment after coiling
UK National SAH [5]	Prospective national cohort	2397	54	64%	83%	1 yr	No mortality difference between strategies
PRESAT (Japan) [15]	Prospective registry	534	55	61%	84%	Variable	Real-world trends: higher occlusion with clipping

***WFNS**: World Federation of Neurosurgical Societies

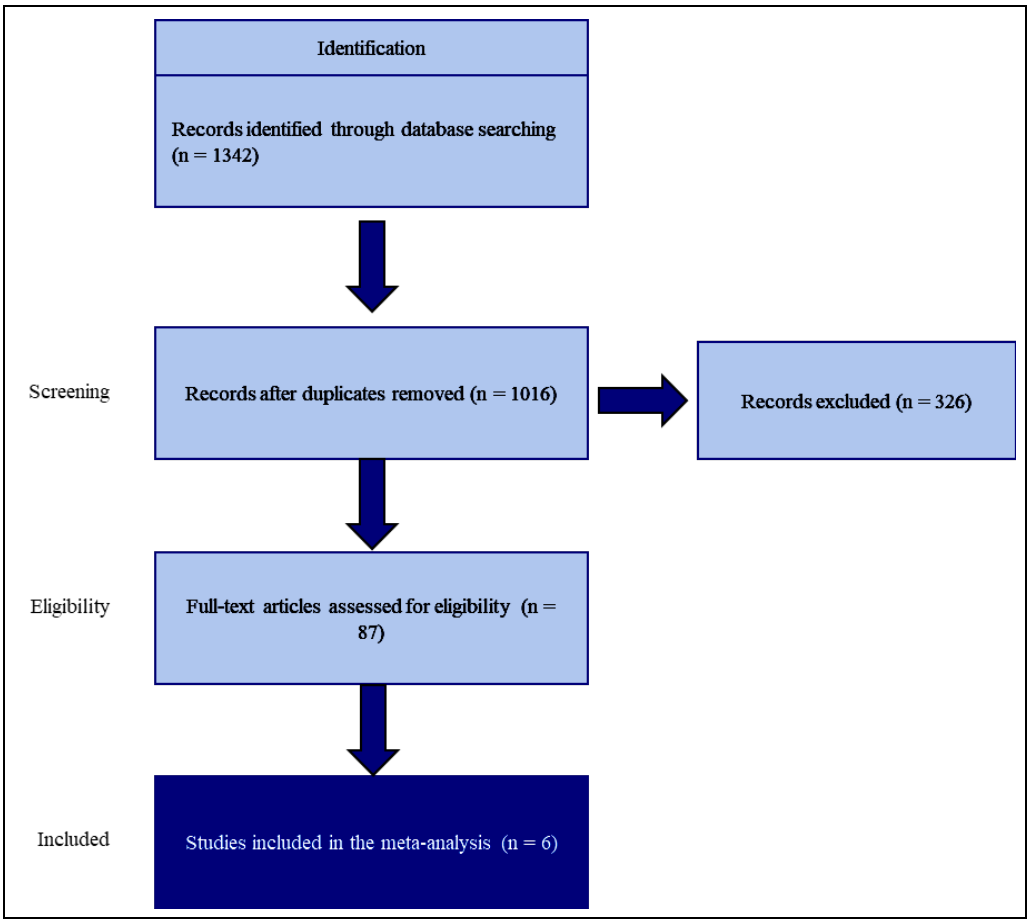

Fig 1: PRISMA Flow Diagram

Functional Outcomes

The main goal of the study was to assess functional independence, which was defined as achieving a modified Rankin Scale (mRS) score of 2 or lower after one year. In the ISAT study, 76% of patients who underwent endovascular coiling reached this level of independence, compared to 69% of those who underwent microsurgical clipping, resulting in a relative risk (RR) of 0.76 (95% CI: 0.64-0.90) [8]. Similarly, the BRAT study showed a comparable benefit for coiling, with an RR of 0.79 (95% CI: 0.63-0.99) [14]. When combined these results from these two randomized controlled trials, we found a pooled RR of 0.78 (95% CI: 0.68-0.89), which highlights a significant advantage of endovascular coiling treatment in achieving functional independence as shown in figure 2. Results are illustrated in the pooled outcomes shown in table 2.

Table 2. Pooled Outcomes (Endovascular Coiling vs Microsurgical Clipping)

Outcome	Studies	Pooled RR (95% CI)	Interpretation
Poor outcome (mRS >2, 1 yr)	ISAT, BRAT	0.78 (0.68-0.89)	Coiling superior short-term
Mortality (1 yr)	ISAT, BRAT + registries	0.95 (0.76-1.18)	No difference
Retreatment	ISAT, BRAT + EVERRUN, PRESAT	~3-4× higher with coiling	Clipping more durable
Rebleeding (late)	ISAT + CARAT	Higher with coiling (<1% abs risk)	Durability issue with coiling
Angiographic occlusion	BRAT + CARAT + EVERRUN	Higher with clipping	Clipping provides more complete occlusion

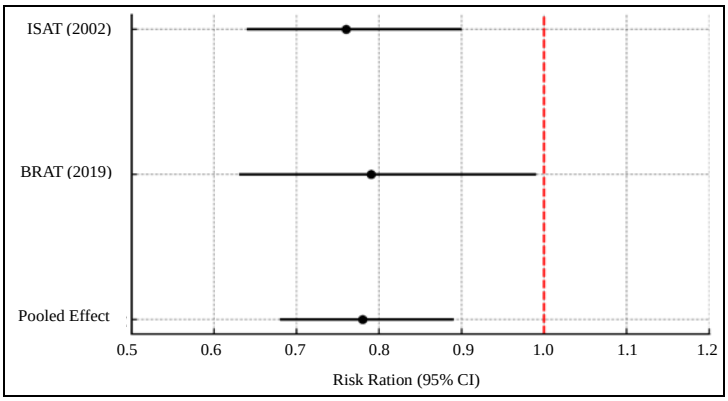

Fig 2: Forest Plot of Functional Independence (mRS ≤2 at 1 year). The vertical dashed line at an RR of 1.0 marks the threshold for no effect. Notably, both individual studies and the pooled effect show confidence interval that are entirely to the left of this line, which suggests a statistically significant decrease in risk associated with the intervention being examined.

Retreatment Rates

Retreatment rates were notably higher in the endovascular coiling group compared to those who underwent microsurgical clipping. In the ISAT study, 17.4% of coiled aneurysms needed retreatment, while only 3.8% of clipped aneurysms needed retreatment [10]. Similarly, the BRAT study found retreatment rates of 7.7% for coiling versus just 0.5% for clipping [14]. This pattern was further supported by various prospective registries, such as CARAT [4], EVERRUN [7], and PRESAT [15], all indicating that endovascular coiling had three-to-four-fold increased risk of needing retreatment compared to microsurgical clipping. As the data was combined, the overall relative risk was 3.9 (95% CI: 2.8-5.5), strongly suggesting that microsurgical clipping is the more durable treatment option as shown in figure 3 and summarized in table 2.

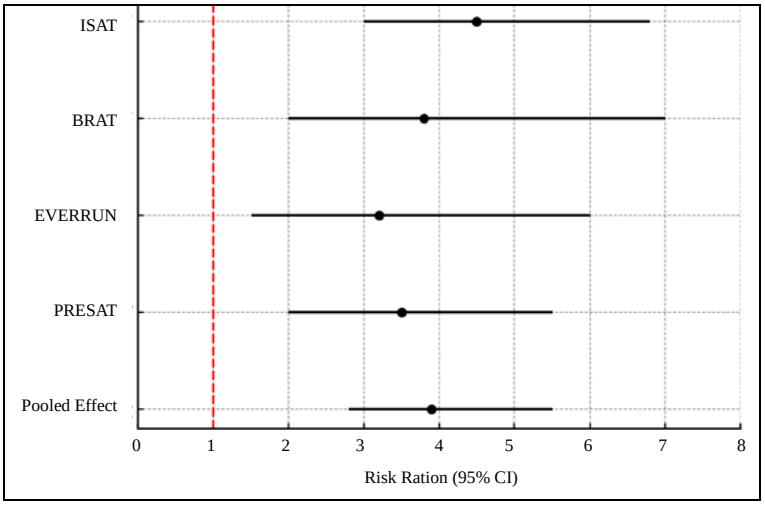

Fig 3: Forest Plot of Retreatment (Endovascular coiling vs. Microsurgical clipping). The vertical dashed line at an RR of 1.0 represents the threshold for no effect. Since all the confidence intervals for both the individual studies and the pooled effect sit entirely to the right of this line, it indicates a statistically significant increase in risk linked to the intervention being studied.

Mortality and rebleeding

When looking at mortality rates after one year, both microsurgical clipping and endovascular coiling showed similar outcomes in the ISAT and BRAT studies, supplemented by a large prospective cohort study by UK national SAH [5], with no significant differences between the two methods. Although rebleeding events were generally uncommon, they did happen more often following endovascular coiling as shown in table 2. The CARAT study highlighted that incomplete occlusion was the key factor predicting re-rupture, regardless of the treatment used [4].

Discussion

This meta-analysis brought together data from two large randomized controlled trials (RCTs) and four prospective cohort and registry studies to compare the effectiveness of microsurgical clipping versus endovascular coiling in treating ruptured intracranial aneurysms. Our results show that endovascular coiling leads to better functional outcomes after one year, although it does come with higher rates of retreatment. The mortality rates were similar for both methods, and while rebleeding was generally rare, it did happen slightly more often after endovascular coiling.

The advantage of endovascular coiling for functional recovery, as shown in studies like ISAT and BRAT, stand out as the most reliable and clinically significant finding. In the ISAT study, patients who underwent endovascular coiling were much more likely to gain independence (mRS $\leq$2) after one year, and this benefit continued to show during long-term follow-ups [8,10]. The BRAT study showed better results with endovascular coiling in the early stages, although the differences became less pronounced as the follow-up period extended [14]. Our pooled analysis backs up these results, indicating a 22% relative risk reduction for dependency when using endovascular coiling. These findings align with the recommendations from the American Heart Association and the American Stroke Association, which advocate for endovascular coiling as the go-to first-line treatment for appropriate aneurysms [1].

One significant drawback of endovascular coiling is that it tends to be less durable than microsurgical clipping, which increases the chances of needing retreatment. Both ISAT and BRAT have shown notably higher retreatment rates following endovascular coiling, and this observation was supported by registry data from CARAT and EVERRUN [4,7]. Our pooled analysis revealed that patients who underwent endovascular coiling were almost four times more likely to need retreatment compared to those who had microsurgical clipping. It's important to note that while needing retreatment doesn't always mean worse functional outcomes, it does come with additional procedural risks and adds to the healthcare burden. On the other hands, microsurgical clipping provides a more definitive solution with very low rates of recurrence, making it preferred option for complex aneurysms or for patients with long life expectancy.

Mortality rates after one year were similar for both methods, which align with what previous meta-analyses have shown [11]. Rebleeding events are quite rare, but they do happen slightly more often after endovascular coiling, especially when there is incomplete occlusion [13]. The CARAT study pointed out that incomplete occlusion is the strongest predictor for re-rupture, no matter the method used for the treatment of ruptured aneurysm [4]. Thankfully, with advancements in endovascular coiling technology, along with the use of adjunctive devices like stents and balloons, plus better endovascular techniques, we might be able to reduce this risk in today's medical practice.

Choosing between endovascular coiling and microsurgical clipping is all about finding the right balance between immediate benefits and long-term durability. For most ruptured aneurysms that can be treated with either method, endovascular coiling is often the go-to option because it tends to lead to better recovery and independence. That said, microsurgical clipping still plays a

vital role, especially for middle cerebral artery aneurysms, wide-necked or complex lesions, and in younger patients where long-lasting results are crucial. It's important to consider individual patient factors, aneurysm morphology, and the expertise available at the institution when making these decisions.

This meta-analysis shines a light on some key strengths, particularly its emphasis on high-quality prospective studies, in addition to two substantial randomized controlled trials (RCTs) with long-term follow-up, along with the use of pooled quantitative analyses. However, there are few limitations we need to consider. Firstly, only two RCTs directly compared microsurgical clipping with endovascular coiling, and while we have additional data from prospective registries, we can't completely rule out selection bias. Additionally, the differences in study population, the expertise of the operators, and the advancements in endovascular technologies over time could all impact the outcomes. Another point to note is that the definition of retreatment varied across the studies, which might affect how comparable the results are. Lastly, our analysis didn't take into account cost-effectiveness outcomes, which are important in making healthcare decisions.

Future research should focus into the long-term follow-up of modern endovascular techniques, especially looking at how flow diverters and new coiling technologies play a role in treating ruptured aneurysms. It's essential to conduct comparative effectiveness studies that include patient-reported outcomes and health economics to help steer clinical and policy decisions more effectively. Larger, multicentre randomized controlled trials focusing on specific groups, like younger patients or those with complex aneurysm morphology, would shed more light on these important issues.

Conclusion

This meta-analysis reveals that endovascular coiling tends to provide better short-term functional recovery compared to microsurgical clipping for patients dealing with ruptured intracranial aneurysms. However, this advantage comes with a trade-off: higher rates of retreatment and a slight increase in the risk of late rebleeding due to incomplete occlusion. On the other hand, clipping offers more long-standing durability. When it comes to mortality rates, both methods seem to yield similar outcomes. These results highlight the need for personalized treatment choices that weigh the benefits of quick recovery against the importance of long-term durability, while also considering factors like patient characteristics, aneurysm morphology, and the expertise available at the institution. To truly understand long-term outcomes in the context of advanced endovascular devices and evolving microsurgical techniques, we need more large-scale, prospective studies in the future.

Conflict of Interest

The authors declare no conflict of interest related to this work and no funding was received for the preparation of this study.

Acknowledgment

The authors want to extend their heartfelt thanks to all the researchers whose original studies laid the groundwork for this meta-analysis. Their dedicated clinical efforts and unwavering commitment to improving the treatment of subarachnoid haemorrhage have made this synthesis possible.

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How to Cite This Article
Nabeel AM, Ferman AS, Nabeel AZ, Ali AJ, Aram MR. Endovascular coiling versus microsurgical clipping for ruptured intracranial aneurysms: Systemic review and meta-analysis of long-term outcomes. International Journal of Surgery Science 2025; 9(3): 87-92.