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Coiling versus Clipping for the Treatment of Ruptured Cerebral Aneurysms: Meta-Analysis on the Effects on Post-Intervention Cognitive Outcomes

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Cognitive outcomes · Coiling · Clipping · Cerebral aneurysm · Meta-analysis

Abstract
Introduction: Cognitive impairment is a critical concern in patients after aneurysm repair. This meta-analysis aimed to compare the cognitive outcomes following two common treatment modalities for ruptured cerebral aneurysms: endovascular coiling and microsurgical clipping. ***Methods:*** A systematic search of PubMed, Embase, Scopus, and the Cochrane Library was conducted, without language restriction at the search stage, to identify relevant studies up to October 2024. Studies of adults with aneurysmal subarachnoid hemorrhage treated by coiling or clipping and reporting quantitative cognitive outcomes were included, provided a full text (or sufficient extractable data) was available from randomized controlled trials or observational studies. The primary outcome was cognitive function, measured using standardized mean differences (SMDs) across various domains such as memory, attention, and executive function. A random-effects model was applied to account for heterogeneity, and publication bias was assessed using Egger's regression and Begg and Mazumdar rank correlation tests. ***Results:*** Ten studies with a total of 1,044 participants were included. The pooled analysis demonstrated that coiling was associated with better short-term cognitive outcomes (SMD = 0.984, 95% CI = 0.639 to 1.330, $p < 0.000$), likely due to its minimally invasive nature. However, long-term cognitive outcomes were uncertain. Sensitivity and publication bias analyses confirmed the robustness of the findings, with no significant evidence of publication bias. ***Conclusion:*** This meta-analysis suggests that endovascular coiling is associated with better cognitive outcomes compared to microsurgical clipping in the treatment of ruptured cerebral aneurysms. Future research should focus on long-term follow-ups, standardized cognitive assessments, and investigating novel treatment strategies to further enhance cognitive outcomes after aneurysm repair.

Introduction

Cerebral aneurysms, characterized by the pathological dilation of intracranial arteries, pose significant risks, including the potential for rupture and subsequent hemorrhage, which can lead to severe neurological deficits or death. The management of these aneurysms has evolved significantly over the years, primarily

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focusing on two main treatment modalities: surgical clipping and endovascular coiling. Each method carries distinct advantages and disadvantages that can influence not only the immediate outcomes of the intervention but also the long-term cognitive health of patients [1, 2].

Surgical clipping involves a craniotomy where a clip is applied to the neck of the aneurysm to prevent blood flow into it, thereby reducing the risk of rupture. This technique is often associated with high rates of complete occlusion, making it a durable option for managing certain types of aneurysms. Studies have shown that clipping can lead to lower rates of rebleeding and higher long-term occlusion rates compared to coiling [3, 4]. However, it is an invasive procedure that may result in higher morbidity due to complications such as infection or neurological deficits post-surgery [5].

On the other hand, endovascular coiling is a minimally invasive technique that involves inserting coils into the aneurysm via a catheter. This method promotes thrombus formation within the aneurysm and reduces blood flow, effectively occluding it. Coiling has been associated with shorter recovery times and lower rates of immediate postoperative complications compared to clipping [6]. However, concerns regarding long-term efficacy persist, particularly regarding higher rates of re-rupture and incomplete occlusion when compared to surgical clipping [7, 8].

Cognitive impairment is a significant concern in patients with cerebral aneurysms who may already be at risk due to factors such as age or pre-existing neurological conditions. Many patients who achieve a “good” functional outcome on scales such as the modified Rankin Scale still exhibit persistent deficits in memory, attention, executive functioning, and processing speed, which can substantially affect quality of life and return to work [9–11]. The pathophysiology of these cognitive sequelae is multifactorial and includes early brain injury, global cerebral ischemia at ictus, delayed cerebral ischemia and vasospasm, neuroinflammation, hydrocephalus, and microstructural damage in cortico-subcortical networks [9, 12]. Beyond the hemorrhage itself, the choice of treatment modality may further modify neurocognitive outcomes. Microsurgical clipping requires craniotomy and brain retraction, with possible temporary vessel occlusion and a higher risk of frontal or other cortical infarcts, particularly in anterior communicating artery aneurysms [13–15]. These factors may predispose to impairments in executive function and memory. Endovascular coiling avoids craniotomy and brain retraction and is often associated with fewer overt perioperative infarcts, but may be accompanied by a burden of silent microembolic lesions on diffusion-weighted MRI, anesthesia-related effects, and the need for retreatment in incompletely occluded aneurysms, which could also influence cognitive trajectories [16–18].

Several single-center studies and small series have compared neuropsychological outcomes after clipping and coiling, but their findings are heterogeneous and often underpowered. Some reports suggest that patients treated with microsurgical clipping exhibit more severe or more frequent cognitive deficits than those treated with endovascular coiling, particularly in memory and executive domains [13, 14, 19]. In contrast, others have found more subtle or no clear modality-specific differences [17, 19]. Existing systematic reviews of aneurysm treatment have largely focused on mortality, disability, and angiographic outcomes, with cognition as a secondary or incompletely reported endpoint, and some are restricted to specific aneurysm locations (e.g., anterior communicating artery) [17, 20]. Consequently, there is still no consensus regarding the comparative impact of clipping versus coiling on post-procedural cognitive functioning in patients with ruptured intracranial aneurysms. Therefore, this meta-analysis aimed to systematically synthesize the available evidence on cognitive outcomes after microsurgical clipping versus endovascular coiling in adults treated for ruptured cerebral aneurysms. Specifically, we sought to quantitatively compare cognitive performance between treatment modalities across major neurocognitive domains (memory, attention, and executive function). Based on the mechanistic considerations outlined above, we hypothesized that endovascular coiling would be associated with more favorable short-term cognitive outcomes, while long-term differences between modalities would be less pronounced or uncertain.

Materials and Methods

This systematic review and meta-analysis were conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (see PRISMA checklist in the online suppl. File; for all online suppl. material, see https://doi.org/10.1159/000550308) [21]. The protocol of this meta-analytic systematic review was not prospectively registered in any database (e.g., PROSPERO), which we acknowledge as a limitation. However, the PICOS criteria, search strategy, and primary/secondary outcomes were defined a priori before screening and data extraction.

Inclusion and Exclusion Criteria

The eligibility criteria were defined a priori according to the PICOS framework (Population, Intervention, Comparator, Outcomes, Study design).

Inclusion Criteria

1. Population: adults with aneurysmal subarachnoid hemorrhage due to ruptured intracranial saccular aneurysm who underwent treatment with either microsurgical clipping or endovascular coiling for the index rupture. Mixed populations were eligible if ≥80% of patients had aneurysmal SAH or if data for the aneurysmal SAH subgroup could be extracted separately.
2. Intervention and comparator: endovascular coiling and microsurgical clipping performed for the ruptured aneurysm.
3. Outcomes: studies reporting quantitative cognitive outcomes (e.g., memory, attention, learning, executive functions, or global cognition) assessed with standardized neuropsychological or cognitive tests at any time point after treatment.
4. Study design: randomized controlled trials, prospective or retrospective cohort studies, and case-control studies.

Exclusion Criteria

We excluded the following:

- Studies focusing exclusively on unruptured aneurysms;
- Studies of non-aneurysmal subarachnoid hemorrhage (e.g., perimesencephalic or traumatic SAH) or other causes of hemorrhagic stroke (e.g., arteriovenous malformations, cavernous malformations, intracerebral hemorrhage unrelated to aneurysm rupture);
- Case reports, small case series with <10 patients per treatment group, reviews, editorials, conference abstracts without full text, and narrative commentaries;
- Studies not reporting any quantitative cognitive outcomes;
- Duplicate publications or overlapping cohorts (in which case the most complete or most recent report was retained); and
- Articles for which the full text or minimal extractable outcome data could not be obtained even after attempting to contact the corresponding author.

Search Strategy

A comprehensive literature search was conducted in PubMed, Embase, Scopus, and the Cochrane Library. The strategy combined controlled vocabulary terms (e.g., MeSH/Emtree) and free-text terms related to cognition, memory, learning, attention, endovascular coiling/embolization, surgical clipping, and intracranial aneurysm. Because each database uses different indexing and syntax, the search strings were tailored to each source (e.g., use of MeSH terms in PubMed and Emtree terms in Embase). The full search strategies for all databases, including Boolean operators and field tags, are provided in online supplementary Table S1.

In addition, we manually screened the reference lists of all included studies and relevant reviews to identify any further eligible articles. No language or time restrictions were applied at the search stage. The search was first performed in October 2024 and updated on exact date. We did not apply language or time restrictions at the search stage. The search was first run in October 2024 and updated in October 2025, immediately before data extraction and analysis, and no additional eligible studies were identified in the update. During screening, titles and abstracts in any language were considered. Potentially eligible full texts not available in English were assessed using translation (by professional translation where feasible). Records for which a reliable full-text translation or sufficient extractable data could not be obtained were excluded and recorded as "full text/translation unavailable" in the PRISMA flow diagram.

Study Selection and Data Extraction

All articles identified from the search strategy were imported into reference management software, and duplicates were removed. Two independent reviewers (reviewer 1 and reviewer 2) screened the titles and abstracts of all remaining articles, retrieving full-text versions of potentially relevant studies for further assessment. The PICOS-based eligibility criteria, including the absence of language restriction at the search stage and the requirement for an accessible full text or sufficient outcome data, were defined before screening was initiated.

Disagreements between reviewers were resolved through discussion or consultation with a third reviewer (reviewer 3). The data extracted from each eligible study included the following: author names, year of publication, sample size, study design, type of intervention (coiling or clipping), cognitive outcome measures, and the follow-up period.

Risk of Bias Assessment

Two reviewers independently assessed the risk of bias for each included study. For observational studies, we used the Newcastle-Ottawa Scale (NOS) [22], evaluating selection, comparability, and outcome/exposure domains. For the randomized controlled trials, we applied the Cochrane Risk of Bias 2 (RoB 2) tool [23], assessing bias arising from the randomization process, deviations from intended interventions, missing outcome data, measurement of outcomes, and selection of reported results. Any discrepancies were resolved by discussion or consultation with a third reviewer.

Statistical Analysis

Meta-analyses were performed using Comprehensive Meta-Analysis (CMA) version 3 software. Standardized mean differences (SMDs) were used to synthesize cognitive outcomes across studies with different measurement scales. A random-effects model was applied to account for variability between studies. Heterogeneity was assessed using the I^2 statistic and the precision interval approach, providing a more direct interpretation of heterogeneity. Potential publication bias was evaluated visually using funnel plots and tested statistically with Egger's and Begg's tests. The trim-and-fill method was employed to adjust for any missing studies in cases where publication bias was suspected. $p < 0.05$ was considered as statistically significant.

Results

The PRISMA flow diagram depicts the study selection process for the systematic review (Fig. 1). A total of 1,266 records were identified from databases, with 108 duplicates removed. After screening 1,158 records, 989 were excluded based on relevance. Out of the 169 reports sought for retrieval, all were retrieved and assessed for eligibility. A further 159 reports were excluded due to irrelevant content (147), unavailable data (7), or focusing on unruptured aneurysms (5). Consequently, 10 studies were included in the final review [13, 14, 24–31]. No additional studies were identified through other search methods, resulting in 10 included studies (Table 1) [13, 14, 24–31].

Figure 2 displays the results of a meta-analysis in a forest plot, summarizing the SMD in various studies along with their 95% CI. The analysis shows significant variability in the effect sizes across the studies, as indicated by the SMD values and the width of the confidence intervals. Most studies show a positive effect, with the summary effect size represented by the red diamond at the bottom. For instance, Beeckmans et al. [24] reported the highest effect size (2.436 SMD, 95% CI, 1.560 to 3.312, $p < 0.000$), suggesting a strong effect. In contrast, Latimer et al. [30] reported a much lower effect size (0.105 SMD, 95% CI, −0.733 to 0.943, $p = 0.805$), which was not statistically significant. The overall effect of the studies combined appears to be positive, as indicated by the pooled effect size (0.984 SMD, 95% CI, 0.639 to 1.330, $p < 0.000$), demonstrating a significant effect across the studies included in the analysis.

Figure 3 represents the results of a leave-one-out sensitivity analysis. In this analysis, each study is systematically removed from the meta-analysis one at a time, and the effect size (SMD) is recalculated for the remaining studies. The goal of this analysis is to assess the robustness of the overall effect size to the inclusion or exclusion of individual studies. The results show that removing any one study does not substantially change the overall effect size, as the recalculated SMDs are all fairly consistent with the original pooled effect (SMD = 0.984, 95% CI, 0.639 to 1.330, $p < 0.000$). Each recalculated effect size remains positive and significant, with narrow confidence intervals. The overall robustness of the meta-analysis is confirmed as the exclusion of any individual study does not significantly alter the overall conclusions of the analysis. The consistent pattern observed across the studies suggests that no single study is exerting an undue influence on the overall results, indicating a stable and reliable pooled effect.

Figure 4 depicts the precision interval analysis results. The precision interval is indicated by the horizontal line near the peak of the curve, with error bars showing the range of the confidence interval. The curve itself represents the distribution of effect sizes around the most likely or average effect size, centered at approximately 0.9 on the standardized difference in the means axis. The narrow confidence interval suggests that the estimate is fairly precise, meaning that the studies included in the analysis have produced relatively consistent effect sizes. The bell shape of the curve suggests that the effect sizes are normally distributed, with most studies yielding results close to the overall mean effect size. The wider tails of the curve indicate that fewer studies reported extreme effect sizes, either highly positive or negative. Overall, the precision interval analysis suggests that the estimated effect size is both statistically significant and precise, with a narrow range of plausible values for the true effect. This supports the robustness of the findings from the meta-analysis.

The funnel plot displays (Fig. 5) the SMD against the standard error for each study included in the meta-analysis. Each circle represents a study, and the diamond at the bottom represents the pooled effect size, with its width indicating the confidence interval. The

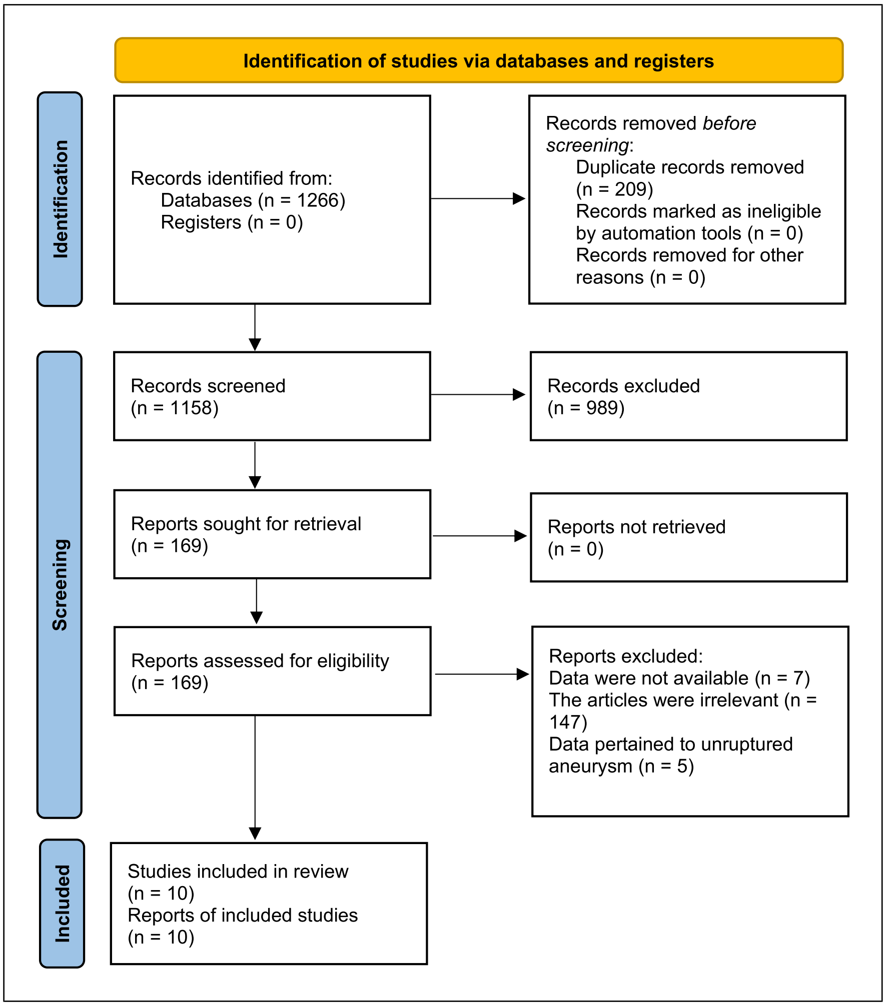


Fig. 1. PRISMA flow diagram illustrating the process of study selection for the systematic review.

plot shows that the studies are generally symmetrically distributed around the pooled effect size, which is close to an SMD of 1. This symmetry suggests there is little evidence of publication bias, as smaller studies with larger standard errors are not disproportionately scattered to one side of the pooled effect. While there is some slight asymmetry with a few studies showing smaller or negative effect sizes, this variation falls within expected bounds given the standard errors. Overall, the plot suggests a balanced distribution of studies, indicating that publication bias is not a major concern, and supporting the robustness of the meta-analysis results. In addition, the results from both the Begg and Mazumdar rank correlation test and Egger's regression intercept test suggest no significant evidence of publication bias in the included studies. The Begg and Mazumdar test produced Kendall's tau value of −0.155 (without continuity correction) and −0.133 (with continuity correction), but both the 1-tailed and 2-tailed *p* values were well above 0.05, indicating no statistically significant asymmetry. Similarly, Egger's regression intercept yielded an intercept value of −0.580 with a *p* value of 0.776 (2-tailed), further confirming the absence of statistically significant publication bias. The wide confidence intervals in Egger's test (−5.136 to 3.975) suggest substantial uncertainty in the intercept estimation, but the lack of statistical significance reinforces the conclusion that publication bias is unlikely to have affected the results of the meta-analysis.

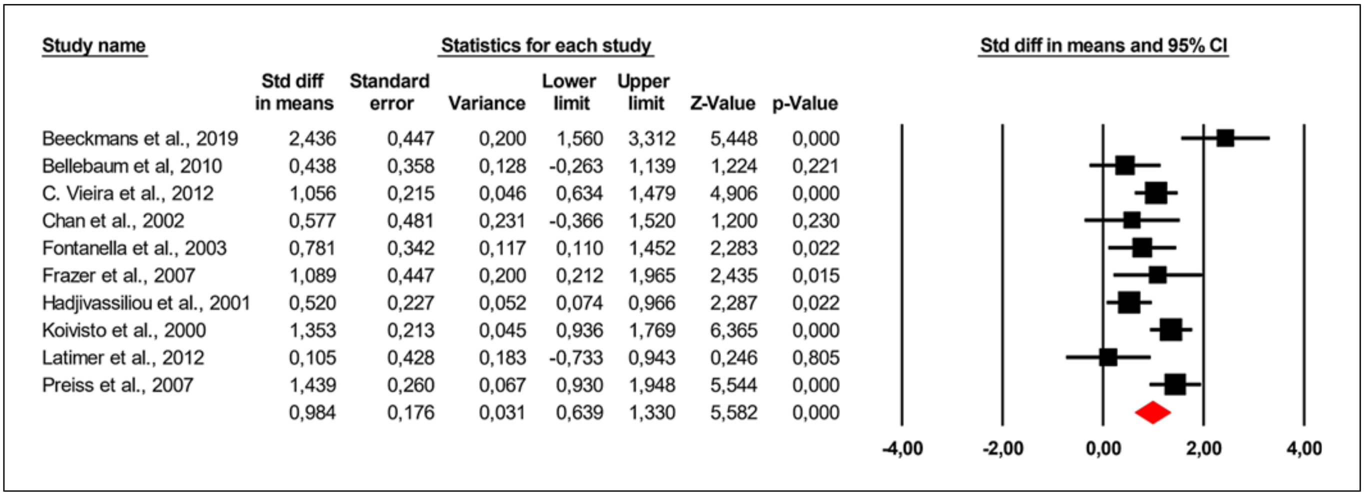
The findings in Table 2 provide an assessment of the methodological quality of various studies based on NOS criteria. Most studies received high marks for sample representativeness, suggesting that the samples used were generally appropriate for the populations being studied. However, nonrespondents were not always accounted for, with several studies failing to mention

Table 1. Study characteristics

Study	Year	Country	Study design	Sample size	Age range	Tools	Results summary
Beeckmans et al. [24] (2020)	2020	Belgium	Cross-sectional	35	18–50	Comprehensive neuropsychological test battery	EC shows better auditory-verbal and visuospatial memory
Bellebaum et al. [14] (2004)	2004	Germany	Prospective	32	18–65	Memory, attention, and executive tests	Clipping causes more impairments in memory and executive function
Vieira et al. [25] (2012)	2012	Brazil	Retrospective	151	30–65	Language, verbal memory	No significant difference in language and verbal memory
Chan et al. [26] (2002)	2002	Hong Kong	Cross-sectional	18	20–60	Memory, executive function tests	Patients with surgical clipping show severe impairment
Fontanella et al. [27] (2003)	2003	Italy	Cross-sectional	37	Mean: 55.3	Selective attention, verbal, and spatial memory	Surgery leads to worse memory and executive functions
Frazer et al. [28] (2007)	2007	UK	Prospective	23	Not specified	Comprehensive cognitive tests	Minimal cognitive difference between EC and SC
Hadjivassiliou et al. [13] (2001)	2001	UK	Prospective	80	30–60	Memory tests, MRI	Endovascular treatment shows better cognitive outcome
Koivisto et al. [29] (2000)	2000	Finland	Randomized Controlled trial	109	Not specified	Neuropsychological test scores, MRI	Similar neuropsychological outcomes at 1 year between EC and SC
Latimer et al. [30] (2013)	2013	UK	Retrospective	14	Not specified	Neuropsychological test battery	Fewer deficits in EC group; IQ tests favor EC
Preiss et al. [31] (2007)	2007	Czech Republic	Prospective	75	Not specified	WAIS-III, AVLT	No significant difference in cognitive outcomes between EC and SC

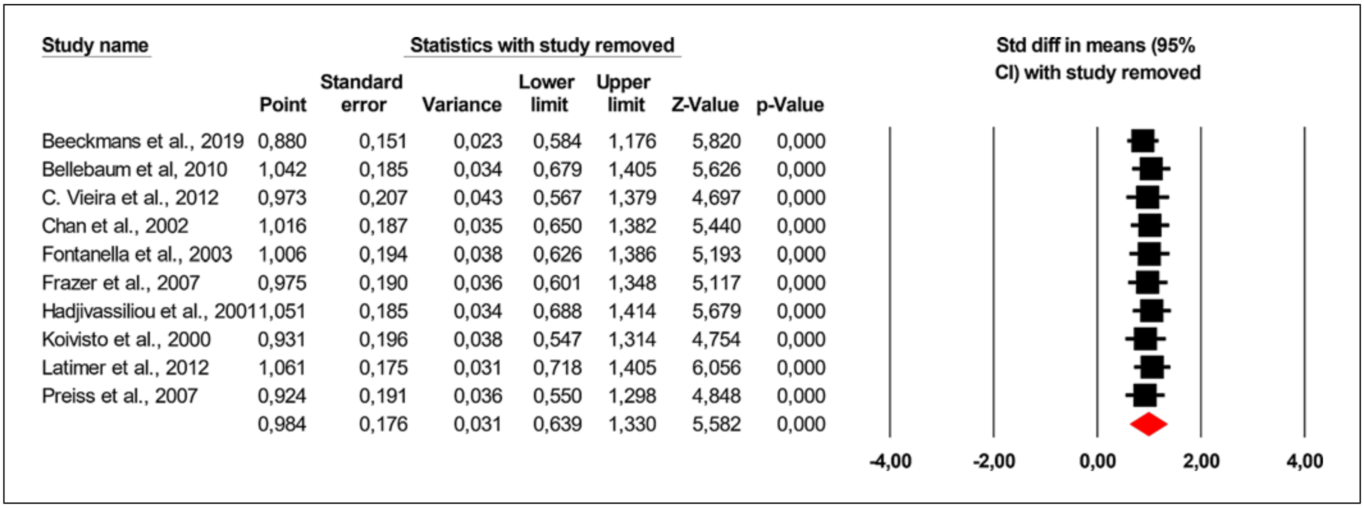
This table presents the main characteristics of the studies included in the analysis. It provides information about the study design, sample size, participant age range, and cognitive assessment tools. The table also includes a summary of the primary findings, highlighting the differences in neuropsychological outcomes between patients who underwent coiling (embolization) and those who underwent clipping (surgery) for aneurysm treatment. The results typically reflect the cognitive domains impacted by these treatments, such as memory, attention, and executive function.

how this issue was addressed, which may impact the generalizability of their results. Sample sizes varied significantly, from as few as 14 participants to as many as 151, with larger studies generally providing more robust findings. Exposure ascertainment methods were generally comprehensive, with most studies using neuropsychological or cognitive tests, although the specific tests varied by study. Control for confounding factors, such as age, gender, and premorbid IQ, was inconsistently applied, which may influence the reliability of the results. Outcome assessments were generally strong, focusing on a range of cognitive functions. Overall, the studies scored well, with total scores ranging from 6 to 8, indicating a good level of methodological rigor. Table 3 summarizes the Risk of Bias 2 assessment for the single RCT included in this review [29]. Overall, the trial was judged as having "some concerns" of bias, primarily due to incomplete reporting of the randomization procedure and allocation concealment, selective availability of neuropsychological outcome data, and lack of prospective protocol registration. In contrast, the risk of bias due to deviations from intended interventions and



Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Beeckmans et al., 2019	2,436	0,447	0,200	1,560	3,312	5,448	0,000
Bellebaum et al, 2010	0,438	0,358	0,128	-0,263	1,139	1,224	0,221
C. Vieira et al., 2012	1,056	0,215	0,046	0,634	1,479	4,906	0,000
Chan et al., 2002	0,577	0,481	0,231	-0,366	1,520	1,200	0,230
Fontanella et al., 2003	0,781	0,342	0,117	0,110	1,452	2,283	0,022
Frazer et al., 2007	1,089	0,447	0,200	0,212	1,965	2,435	0,015
Hadjivassiliou et al., 2001	0,520	0,227	0,052	0,074	0,966	2,287	0,022
Koivisto et al., 2000	1,353	0,213	0,045	0,936	1,769	6,365	0,000
Latimer et al., 2012	0,105	0,428	0,183	-0,733	0,943	0,246	0,805
Preiss et al., 2007	1,439	0,260	0,067	0,930	1,948	5,544	0,000
	0,984	0,176	0,031	0,639	1,330	5,582	0,000

Fig. 2. Forest plot depicting the standardized mean differences (SMDs) and 95% confidence intervals (CIs) for each study included in the analysis.



Study name	Point	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Beeckmans et al., 2019	0,880	0,151	0,023	0,584	1,176	5,820	0,000
Bellebaum et al, 2010	1,042	0,185	0,034	0,679	1,405	5,626	0,000
C. Vieira et al., 2012	0,973	0,207	0,043	0,567	1,379	4,697	0,000
Chan et al., 2002	1,016	0,187	0,035	0,650	1,382	5,440	0,000
Fontanella et al., 2003	1,006	0,194	0,038	0,626	1,386	5,193	0,000
Frazer et al., 2007	0,975	0,190	0,036	0,601	1,348	5,117	0,000
Hadjivassiliou et al., 2001	1,051	0,185	0,034	0,688	1,414	5,679	0,000
Koivisto et al., 2000	0,931	0,196	0,038	0,547	1,314	4,754	0,000
Latimer et al., 2012	1,061	0,175	0,031	0,718	1,405	6,056	0,000
Preiss et al., 2007	0,924	0,191	0,036	0,550	1,298	4,848	0,000
	0,984	0,176	0,031	0,639	1,330	5,582	0,000

Fig. 3. Results of the leave-one-out sensitivity analysis.

outcome measurement was considered low. These findings indicate that, while the randomized evidence contributes important data, its internal validity is not unequivocally low risk and should be interpreted with some caution.

Discussion

This meta-analysis compared the effects of endovascular coiling versus microsurgical clipping on post-intervention cognitive outcomes in patients treated for ruptured cerebral aneurysms. The analysis highlights key differences between the two treatment modalities, providing insights into their long-term impacts on cognitive function. Overall, the findings suggest that coiling and clipping have distinct cognitive outcomes, with coiling generally showing more favorable short-term cognitive effects but with less clarity on long-term performance.

Cognitive impairment after aneurysmal subarachnoid hemorrhage is multifactorial and reflects the combined impact of the initial bleed, delayed cerebral ischemia, neuroinflammation, hydrocephalus, and peri-procedural factors related to clipping or coiling. These mechanisms,

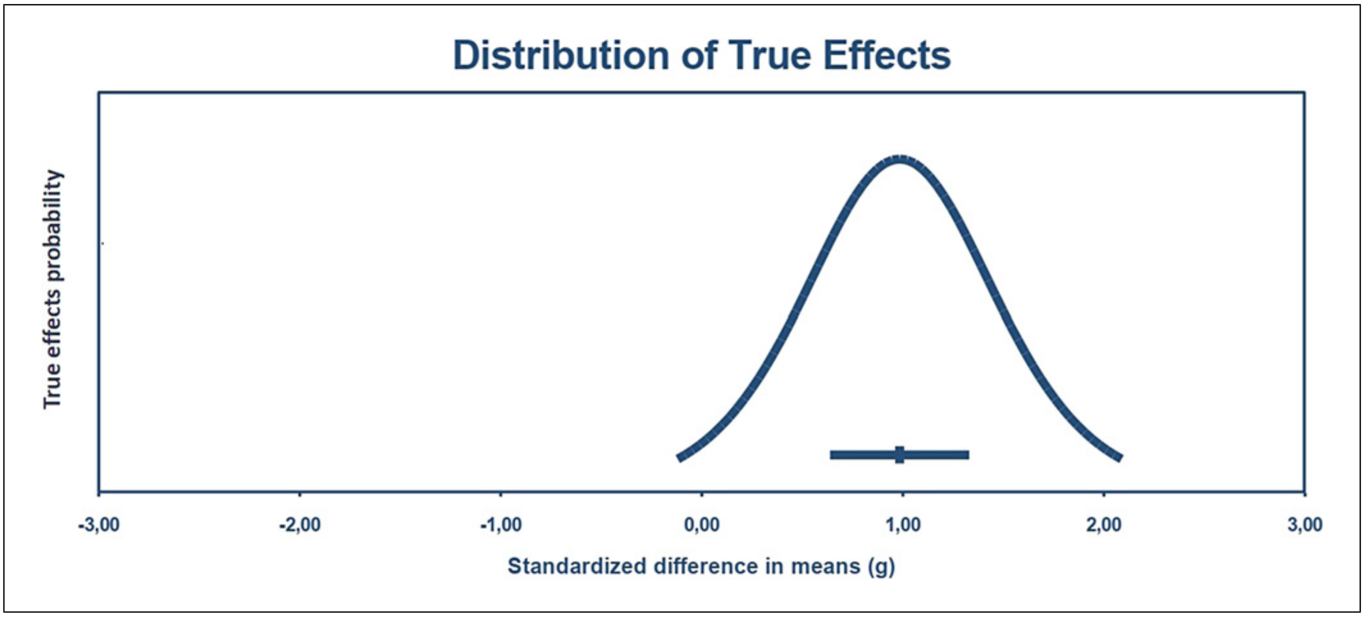


Fig. 4. Results of the precision interval analysis.

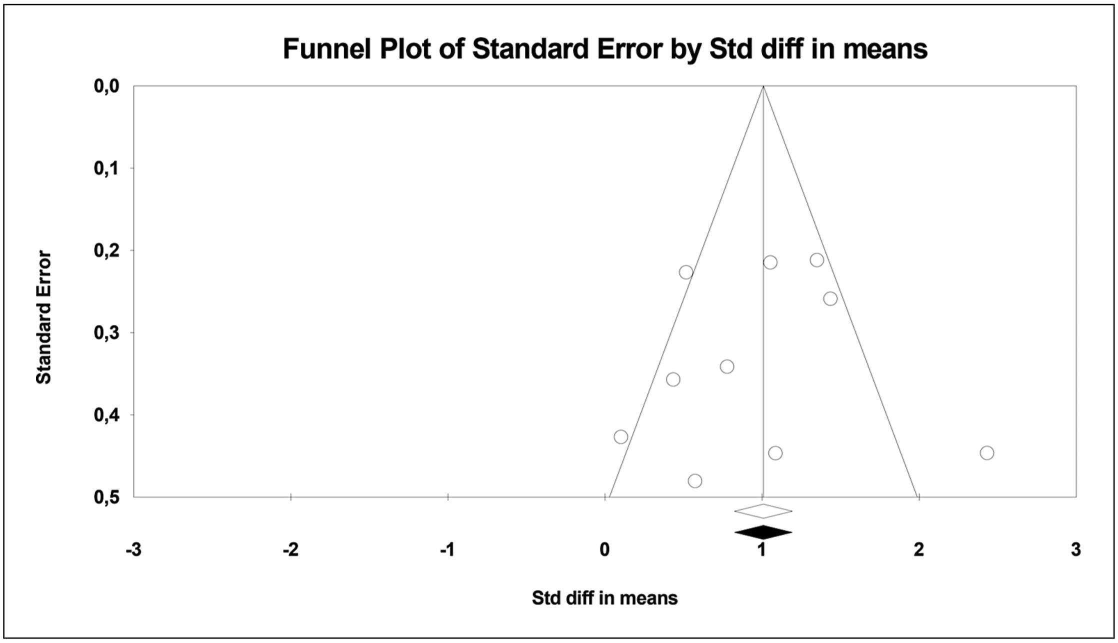


Fig. 5. Funnel plot of standard error by standardized difference in means (SMD).

which we have outlined in detail in the Introduction [19, 32, 33], provide a plausible biological basis for the cognitive differences we observed between treatment modalities, particularly in domains such as memory and executive function.

In the included studies, endovascular coiling was associated with better immediate postoperative cognitive outcomes compared to surgical clipping. This may be attributable to the minimally invasive nature of coiling, which results in shorter recovery times and reduced

Table 2. Methodological quality assessment

Study	Sample representativeness	Nonrespondents	Sample size	Ascertainment of exposure	Control for confounding	Outcome assessment	Total score
Beeckmans et al. [24] (2020)	Yes	Not mentioned	35	Comprehensive test battery	Age, gender	Auditory-verbal, visuospatial memory	7
Bellebaum et al. [14] (2004)	Yes	Not mentioned	32	Test battery	Age, aneurysm site	Verbal and visual memory, executive function	8
Vieira et al. [25] (2012)	Yes	Yes	151	Neuropsychological tests	Age, gender	Language, verbal memory	7
Chan et al. [26] (2002)	Yes	Not mentioned	18	Neuropsychological tests	Not mentioned	Executive function	6
Fontanella et al. [27] (2003)	Yes	Yes	37	Memory and language tests	Age, gender	Selective attention, memory	7
Frazer et al. [28] (2007)	Yes	Yes	23	Neuropsychological assessment	Not mentioned	Cognitive function tests	7
Hadjivassiliou et al. [13] (2001)	Yes	Yes	80	MRI, cognitive tests	Age, premorbid IQ	MRI and cognitive tests	8
Koivisto et al. [29] (2000)	Yes	Yes	14	Cognitive tests	Age, premorbid IQ	IQ, memory, and attention tests	8
Latimer et al. [30] (2013)	Yes	Yes	75	Cognitive tests	Not mentioned	Cognitive and personality tests	7

This table presents the methodological quality assessment of the studies using the Newcastle-Ottawa Scale (NOS). Each study is evaluated on several criteria, including the representativeness of the sample, handling of nonrespondents, sample size, the method of exposure ascertainment, control for confounders, and the reliability of the outcome assessment. The total score represents the overall quality of the study, with higher scores indicating better methodological rigor.

surgical trauma, possibly preserving cognitive functions such as memory, attention, and executive function better in the short term [6, 24]. Studies such as those by Vieira et al. [25] and Frazer et al. [28] demonstrated improved short-term cognitive performance following coiling compared to clipping, likely due to the lower physical and neuroanatomical disruption during the procedure.

However, the long-term cognitive effects of coiling remain less well understood. Several studies, including those by Hadjivassiliou et al. [13] and Preiss et al. [31], suggest that the long-term neuropsychological outcomes following coiling may not be as robust as initially expected, with concerns over higher rates of re-rupture and incomplete occlusion, which could contribute to cognitive decline over time. The durability of coiling compared to clipping remains a contentious issue, as studies such as the ISAT follow-up by Molyneux et al. [7] emphasize the need for long-term vigilance and possible reinterventions after coiling, which could influence cognitive recovery trajectories.

In contrast, surgical clipping, though associated with more invasive procedures and longer recovery periods, has demonstrated durable long-term outcomes, particularly in terms of aneurysm occlusion and prevention of rebleeding [5, 8]. Despite the higher risks of immediate postoperative cognitive deficits, as indicated in studies by Beeckmans et al. [24] and Fontanella et al. [27], the stability of clipping's occlusive effects might contribute

Table 3. RoB 2 assessment for RCTs

Domain	Risk of bias judgment	Support for judgment
Bias arising from the randomization process	Some concerns	Patients were randomly assigned using sealed envelopes to endovascular or surgical treatment. However, the method for generating the random sequence (e.g., computer-generated, random numbers table) and details on allocation concealment are not fully described, so the adequacy of the randomization process cannot be completely verified
Bias due to deviations from intended interventions	Low risk	The trial was analyzed according to intention-to-treat, and crossovers between treatment groups were reported and explored in sensitivity analyses. There is no evidence that deviations from intended interventions arose because of the trial context or that they were unbalanced between groups in a way that would bias the comparison
Bias due to missing outcome data	Some concerns	The authors report that no patients were lost to follow-up for the main clinical outcomes, but neuropsychological assessments were completed only in subsets of patients who were able and willing to perform all tasks. Although the numbers appear balanced between groups, it is unclear whether missing cognitive data are related to true outcome, which may introduce some risk of bias for cognitive endpoints
Bias in measurement of the outcome	Low risk	Clinical outcomes were assessed using the Glasgow Outcome Scale, and neuropsychological outcomes were measured with standardized tests administered by the same neuropsychologist. Outcomes are largely objective, and there is no indication that knowledge of treatment assignment would systematically influence measurement
Bias in selection of the reported result	Some concerns	The study protocol was not prospectively registered, and although multiple clinical, radiological, and neuropsychological outcomes are reported, it is unclear whether all prespecified outcomes and analyses are fully presented. Selective reporting of some results cannot be ruled out
Overall risk of bias	Some concerns	Taking all domains together, the main issues relate to incomplete information on the randomization process, potential bias from missing cognitive outcome data, and lack of prospective protocol registration. These lead to an overall judgment of “some concerns” rather than low risk of bias

This table summarizes the RoB 2 assessment for the single RCT included in this review [29]. RoB 2, Risk of Bias 2.

to more favorable cognitive outcomes in the longer term, potentially due to reduced risks of aneurysm recurrence.

The leave-one-out sensitivity analysis conducted in this meta-analysis confirmed the robustness of our findings, as no single study had an undue influence on the overall pooled effect size. This indicates that the observed cognitive differences between coiling and clipping are consistent across the included studies, adding to the reliability of our results. Moreover, the precision interval analysis showed that the effect size estimates are precise, with narrow confidence intervals, further supporting the robustness of the meta-analysis findings. This is significant as it highlights the consistency of cognitive outcomes across different study designs and patient populations, reinforcing the conclusion that coiling tends to offer better short-term cognitive outcomes, while clipping may provide more reliable long-term protection. Besides, the funnel plot demonstrated minimal publication bias, which strengthens the validity of the meta-analysis. The symmetrical distribution of studies suggests that the observed cognitive outcomes are likely reflective of the true effects of each treatment modality, further supporting the generalizability of these findings to clinical practice. Besides, the results of both the Begg and Mazumdar rank correlation test and Egger’s regression intercept test indicate no significant evidence of bias in the included studies. These findings strengthen the validity of the meta-analysis, ensuring that the cognitive outcomes reported are unlikely to be influenced by selective reporting or underrepresentation of studies with null or negative findings.

The finding that endovascular coiling is associated with more favorable short-term cognitive outcomes compared with microsurgical clipping has direct implications for treatment decision-making in ruptured aneurysm management. In patients with similar expected survival and angiographic suitability for either modality, clinicians may reasonably weigh the potential for better early cognitive recovery in favor of coiling, alongside established advantages in functional outcome and return to work reported in prior studies [14, 19]. Conversely, the more durable aneurysm occlusion and lower rebleeding risk associated with clipping [14, 34] may still justify surgery in younger patients, those with complex aneurysm anatomy, or where repeated endovascular procedures would be problematic. Importantly, our results suggest that preoperative counseling should explicitly address not only survival and disability but also expected cognitive trajectories – clarifying that coiling may offer a “softer” early cognitive course, whereas the long-term differences between modalities remain uncertain.

This meta-analysis, despite providing valuable insights into the cognitive outcomes following coiling and clipping for ruptured cerebral aneurysms, has several limitations. This meta-analysis has several important limitations that should be considered when interpreting the findings. First, clinical and methodological heterogeneity across studies represents the most influential constraint. The included cohorts differed in aneurysm location, timing of treatment, and peri-procedural management, and most studies were single-center with modest sample sizes. Although we used a random-effects model and performed sensitivity analyses, residual heterogeneity is likely and may partly account for the variability in effect sizes.

Second, variation in follow-up duration substantially affects interpretability. Some studies evaluated cognition only in the acute or subacute phase, whereas others assessed patient months to years after treatment. Because cognitive recovery and delayed decline after aneurysmal subarachnoid hemorrhage can unfold over a prolonged period, pooling time points inevitably blurs differences in the trajectory of recovery between clipping and coiling.

Third, there was considerable variability in cognitive assessment methods. The neuropsychological batteries ranged from brief screening tools to extensive test batteries, with differences in the domains emphasized (e.g., memory vs. executive function) and in the thresholds used to define impairment. This heterogeneity may lead to underestimation or overestimation of deficits in specific domains and limit the precision with which we can compare domain-specific outcomes across studies.

A particularly important limitation is the incomplete control for baseline cognitive status and hemorrhage severity, which are central determinants of outcome rather than minor confounders. Many of the included observational studies did not provide detailed premorbid cognitive data and only a subset adjusted for markers such as clinical grade at presentation, initial modified Fisher score, or early brain injury. Differences in baseline risk between patients selected for clipping versus coiling could therefore obscure or exaggerate true treatment-related cognitive effects.

In addition, the review protocol was not prospectively registered in an international database such as PROSPERO. Prospective registration is recommended to enhance transparency and reduce the risk of selective reporting; this represents a methodological limitation of the present work. For any future update of this review, we plan to ensure prospective registration.

Additional limitations include potential publication bias, despite negative formal tests; the predominance of studies from high-income countries, which may limit generalizability; and the relatively small number of eligible studies, particularly for long-term follow-up. Finally, the single randomized trial in this area was judged as having “some concerns” of bias using RoB 2, and the pooled estimates remain largely driven by observational data. Taken together, these limitations suggest that our results should be interpreted as hypothesis-generating and supportive of a signal favoring better short-term cognitive outcomes after coiling, rather than definitive evidence of modality superiority.

Conclusion

This meta-analysis provides a comprehensive comparison of the cognitive outcomes following endovascular coiling and microsurgical clipping in the treatment of ruptured cerebral aneurysms. Our findings suggest that coiling is generally associated with better short-term cognitive outcomes, likely due to its minimally invasive nature, while clipping may offer more durable long-term cognitive benefits by reducing the risks of aneurysm recurrence and rebleeding. Despite these differences, both procedures carry inherent risks of cognitive decline, influenced by factors such as ischemia, vasospasm, and the neurotoxic effects of subarachnoid hemorrhage. While this analysis adds to the growing body of evidence, the heterogeneity in study designs and follow-up periods highlights the need for caution in interpreting the results.

Clinicians should consider the individual patient's aneurysm characteristics, cognitive vulnerability, and long-term recovery goals when selecting a treatment modality.

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Statement of Ethics

A Statement of Ethics is not applicable because this study is based exclusively on published literature. The research did not involve any direct contact with human participants or collection of individual-level data and thus did not require ethical approval or informed consent. The meta-analysis was conducted in accordance with the PRISMA guidelines and the ethical principles of the World Medical Association Declaration of Helsinki.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

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Author Contributions

Quan Zhou: conceptualization, methodology, formal analysis, and writing – original draft. Haonan An: conceptualization, methodology, and formal analysis. Jinhua Gao: data curation, investigation, and writing – review and editing. Hao Zhang: data curation and writing – review and editing. Shiliang Wang: data curation and investigation. Songxia Xu: visualization and writing – review and editing. Feng Guo: validation, visualization, supervision, and writing – review and editing. All authors have read and approved the final manuscript (CRediT roles: https://credit.niso.org).

Data Availability Statement

All data generated or analyzed during this study are included in this article and its supplementary material. Further inquiries can be directed to the corresponding author.

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