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REVIEW

Neurosurgical clipping versus endovascular coiling for patients with ruptured anterior circulation aneurysms: A systematic review and meta-analysis

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Abstract
To compare the safety and efficacy of clipping and coiling in patients with ruptured anterior circulation aneurysms. A systematic search of four databases (PubMed, Web of Science, Cochrane Library, and Embase) was conducted to identify comparative articles on endovascular coiling and surgical clipping in patients with ruptured anterior circulation aneurysms. Meta-analyses were conducted using random-effects models. Nineteen studies, including 1981 patients, were included. The meta-analysis showed that neurosurgical clipping was associated with a lower incidence of retreatment (OR:0.28, 95% CI (0.11, 0.70), $P=0.006$) than endovascular coiling, which seemed to be a result of incomplete occlusion (OR:0.22, 95% CI (0.11, 0.45), $P<0.001$). Neurosurgical clipping was associated with lower mortality (OR:0.45, 95% CI (0.25, 0.82), $P=0.009$) at short-term follow-up than endovascular coiling. However, neurosurgical clipping showed a higher incidence of ischemic infarction (OR:2.28, 95% CI (1.44, 3.63), $P<0.001$) and a longer length of stay (LOS) (WMD:6.12, 95% CI (4.19, 8.04), $P<0.001$) after surgery than endovascular coiling. Furthermore, the pooled results showed no statistically significant differences between the two groups regarding poor outcome, long-term mortality, rebleeding, vasospasm, and hydrocephalus. Evidence from this systematic review illustrates that neurosurgical clipping may be superior to endovascular coiling for ruptured anterior circulation aneurysms. Large-scale RCTs should be conducted to verify these outcomes and provide results according to patient status.

Keywords Anterior circulation aneurysms · Neurosurgical clipping · Endovascular coiling · Meta-analysis

Introduction

Subarachnoid hemorrhage (SAH) from a ruptured intracranial aneurysm accounts for approximately 5% of all stroke cases and is associated with exceptionally high mortality and disability [1, 2]. Compared with previous studies, the worldwide crude incidence of SAH has decreased to approximately 7.9 per 100000 people but still shows large regional differences [3, 4].

Therefore, proper management of ruptured aneurysms is particularly important. Aneurysms of the anterior circulation appear more common than those of the posterior circulation [5]. Two definitive treatment modalities were used: microsurgical clipping and endovascular aneurysm coiling. In the last century, microsurgical clipping has become the gold standard for treating intracranial aneurysms. Over the past 20 years, improvements in and popularity of endovascular coiling techniques have led to significant controversy over the ideal treatment strategy for

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ruptured intracranial aneurysms [6–9]. Endovascular coiling avoids a large incision and craniotomy, thereby reducing the recovery time. Although surgical clipping is more invasive, permanent metal clips can be placed accurately on the neck of an aneurysm under a microscope to block the blood flow to the aneurysm, which is associated with better durability [8, 10]. The results of several recently published meta-analyses favor endovascular coiling as the primary modality for the treatment of intracranial aneurysms [8, 11–13]. However, these studies included a very important heterogeneous subgroup: anterior–posterior circulation. Intracranial aneurysms within posterior circulation pose a significant obstacle to microsurgical operation due to their deep location, complexity of anatomical exposure, limited space for manipulation, and floating complexity of adjacent structures [14]. Posterior circulation aneurysms are more likely to be treated with endovascular treatment. Therefore, it is not appropriate to extrapolate the results to aneurysms located in the anterior circulation. Moreover, in the last 10 years, many new high-quality studies have been conducted around the world. Therefore, we performed a meta-analysis to compare the efficacy and safety of clipping and coiling in patients with ruptured anterior circulation aneurysms based on existing published studies and a strictly limited inclusion population.

Material and methods

This study followed the recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [15] and SRMA [16]. Our protocol was registered with PROSPERO (CRD42022375852).

Data sources and searches

Two authors (H Q and J-H L) searched for comparative articles involving endovascular coiling and surgical clipping in patients with anterior circulation aneurysms. Where necessary, a third investigator (N-J W) reviewed the selection). The PubMed, Web of Science, Cochrane Library, and Embase electronic databases were searched for studies published up to December 2022. The search strategy combined search terms for clipping, coiling, and ruptured anterior circulation aneurysms, using multiple versions of medical terms and text words (Supplementary Materials, strategy). We imposed restrictions on text availability (full text only), species (humans only), and language (English only) and double-checked them. Reference lists of the retrieved articles were manually checked to identify other potentially eligible studies.

Inclusion and exclusion criteria

The inclusion criteria were as follows: (1) patients with ruptured anterior circulation aneurysms; (2) studies including endovascular coiling and surgical clipping; (3) studies comparing the results of clipping and clipping; and (4) studies reporting at least one of the following outcomes: poor outcome (modified Rankin scale (mRS; > 2) or Glasgow Outcome Scale (GOS; 1–3)), mortality, incomplete occlusion, rebleeding, hydrocephalus, ischemic infarction, vasospasm, retreatment and length of stay.

Studies were excluded if they evaluated the outcomes of endovascular coiling and surgical clipping without reporting our specified outcomes or if they included pediatric cases. Studies focusing on only one of these two methods were excluded. Moreover, we excluded studies that did not provide sufficient information for us to extract or calculate the absolute number of clinical events. We excluded patients with repeat or hybrid procedure, and included only those who underwent clipping or coiling for the first time after admission.

Data collection and quality assessment

The collected data included the name of the first author or study group, country, publication year, covered study period, study design, sample size, sex, mean age, follow-up duration, and reported outcomes. To assess the quality of the extracted data, the Newcastle–Ottawa scale was used for cohort studies, and the Jadad scale was utilized for randomized controlled trials. Two investigators (H Q and J-H L) independently extracted data. Discrepancies were resolved by senior authors (X-M D). Clinical outcomes that appeared in the hospital or within 30 days were defined as short-term outcomes.

Statistical analysis

The data were entered into Stata (version 17.0; StataCorp, TX, USA) and analyzed using a forest plot for visual estimation of the meta-analysis. The results of each study were assigned to binary frequency data, and the odds ratios and 95% confidence intervals were calculated and combined. The heterogeneity of all included studies was evaluated using Cochran's Q test and the I^2 statistic. Considering the prevalent clinical and statistical heterogeneity between the two groups, this meta-analysis only reported the random-effect model. All studies were included in sensitivity analyses to assess the robustness of the pooled results. Potential publication bias was assessed using the

Egger's and Begg's tests. Statistical significance was set at P-value < 0.05 unless otherwise specified.

Results

We identified 9541 articles, including 2932 from PubMed, 3665 from Web of Science, 392 from the Cochrane Library, and 2562 from Embase. After removing duplicates, screening titles and abstracts, and conducting a full-text review, 19 articles were selected for the final meta-analysis [17–35]. A Flow diagram of the data extraction strategy is shown in Fig. 1. Of the 19 studies, 2 were RCTs [27, 34], 2 were prospective cohort studies [17, 33], and the remaining 15 were retrospective studies [18–26, 28–32, 35]. The total study population comprised 1981 patients, of which 1019 were treated with surgical clipping and 962 were treated with endovascular coiling. Table 1 shows the baseline characteristics of the included studies.

Effectiveness outcome

Seventeen studies reported poor outcome. Meta-analysis of the data revealed no significant difference between the 2 groups in the rate of poor outcome at short-term (OR: 0.85, 95% CI (0.62, 1.18), $P = 0.343$), at 3 months (OR: 1.10, 95% CI (0.67, 1.81), $P = 0.711$), at 6 months (OR: 1.03, 95% CI (0.67, 1.59), $P = 0.859$), at 1-year follow-up, or more (OR: 1.20, 95% CI (0.86, 1.68), $P = 0.286$, Fig. 2). Seven studies with 653 patients reported the postoperative incomplete occlusion rate and the results showed that clipping was associated with a lower incidence of incomplete occlusion than coiling (OR:0.22, 95% CI (0.11, 0.45), $P < 0.001$, Fig. 3). Furthermore, six studies reported the retreatment rate of 645 participants, and the results showed that clipping was associated with a lower incidence of retreatment than coiling (OR:0.28, 95% CI (0.11, 0.70), $P = 0.006$, Fig. 4).

Safety outcome

Seven articles, including 673 patients, reported short-term mortality. Meta-analysis of the data revealed that clipping was associated with a lower incidence of short-term mortality than coiling (OR:0.45, 95% CI (0.25, 0.82); $P = 0.009$, Fig. 5). However, this advantage was no longer sustained at the 3-month follow-up or more (OR:0.78, 95% CI (0.54, 1.13), $P = 0.192$, Fig. 5), according to the meta-analysis of 12 studies. Ten studies with 1144 patients reported postoperative rebleeding. Meta-analysis showed that there was no significant difference between the two groups in the rate

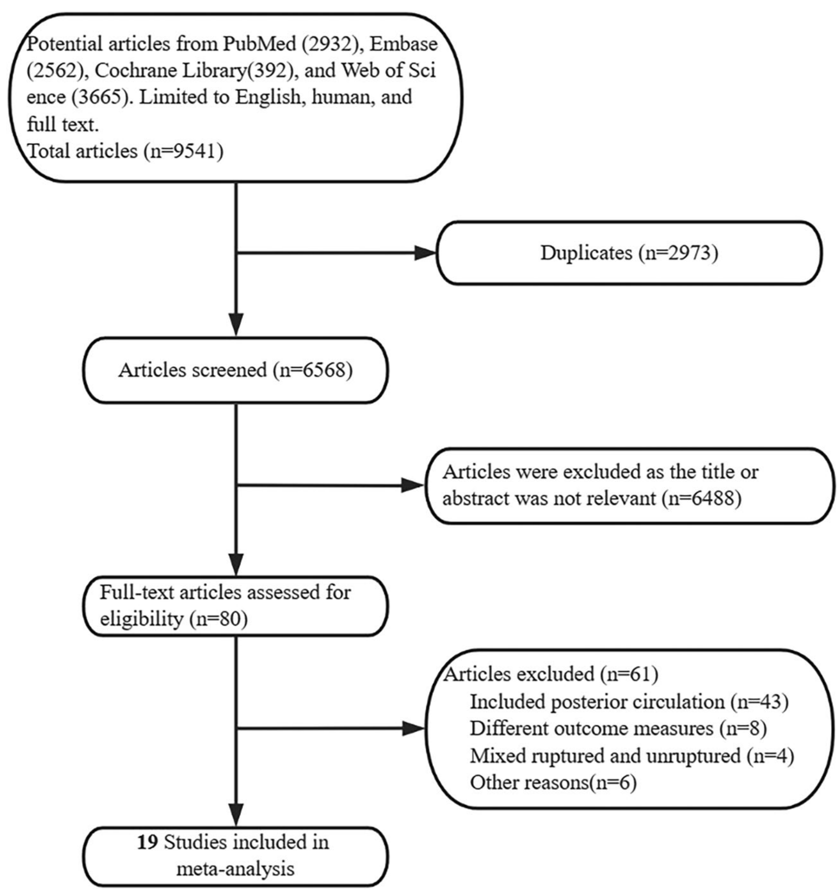


Fig. 1 Flow chart of the study selection process

Table 1 Baseline characteristics of included studies and patients

Study	Country	Publication years	Covered study period	Study design	Patients (n)		Gender (M/F)		Age (mean ± SD)		Jadad* or NOS score
					Clip	Coil	Clip	Coil	Clip	Coil	
Vanninen R	Finland	1999	1995–1997	prospective	52	46	NA	NA	NA	NA	7
Groden C	Germany	2001	1993–1999	retrospective	20	19	8/12	8/11	51.9 ± 15.99	54.26 ± 12.84	9
Niskane M	Finland	2004	1997–2000	retrospective	103	68	44/59	32/36	54 ± 13	54 ± 13	7
Suzuki S	Japan	2011	1987–2009	retrospective	55	13	23/32	6/7	58	56.6	7
Ayman ZA	Egypt	2013	2010–2011	prospective	15	15	NA	NA	NA	NA	8
de los Reyes K	USA	2013	2000–2009	retrospective	8	10	NA	NA	56(35–74)	55(41–66)	6
Liao CC	China	2013	2008–2009	retrospective	44	56	17/27	18/38	56.93 ± 13.75	57.91 ± 11.89	8
Moon K	USA	2015	2003–2007	RCT	91	39	NA	NA	NA	NA	4*
Park KY	S.Korea	2015	1997–2012	retrospective	46	38	18/28	18/20	54.1 ± 10.93	53.4 ± 10.95	7
Wadd IH	Pakistan	2015	2010–2013	RCT	70	70	28/42	28/42	51.00 ± 10	52.5 ± 10	3*
Heit JJ	USA	2017	2010–2014	retrospective	50	50	24/26	19/31	50(41–58)	55(48–63.75)	6
Shen J	China	2019	2013–2018	retrospective	65	29	20/45	11/18	59.92 ± 10.603	65.86 ± 11.597	8
Taweesom-boonyat C	Thailand	2019	2002–2018	retrospective	105	84	27/78	16/68	56.5 ± 11.4	64.3 ± 13.9	7
Zhao B	China	2019	2008–2015	retrospective	65	46	29/36	22/24	55.5 ± 11.1	54.5 ± 11.2	7
Bäcker HC	Hungary	2020	2010–2011	retrospective	45	71	24/21	33/38	53(28–75)	49(33–70)	7
Ghorba M	Iran	2020	2011–2016	retrospective	42	38	18/24	13/25	58.6	58	8
Ba YF	China	2021	2017–2020	retrospective	30	38	12/18	14/24	50.1 ± 7.8	52.5 ± 7.5	7
Harris L	UK	2021	2012–2018	retrospective	19	113	7/12	56/67	57.9 ± 13.6	57.6 ± 15.4	7
Lee SH	S.Korea	2022	2010–2020	retrospective	94	119	46/48	66/53	53.5 ± 13.4	60.3 ± 13.2	6

F = female, *M* = male, *RCT* = randomized controlled trial

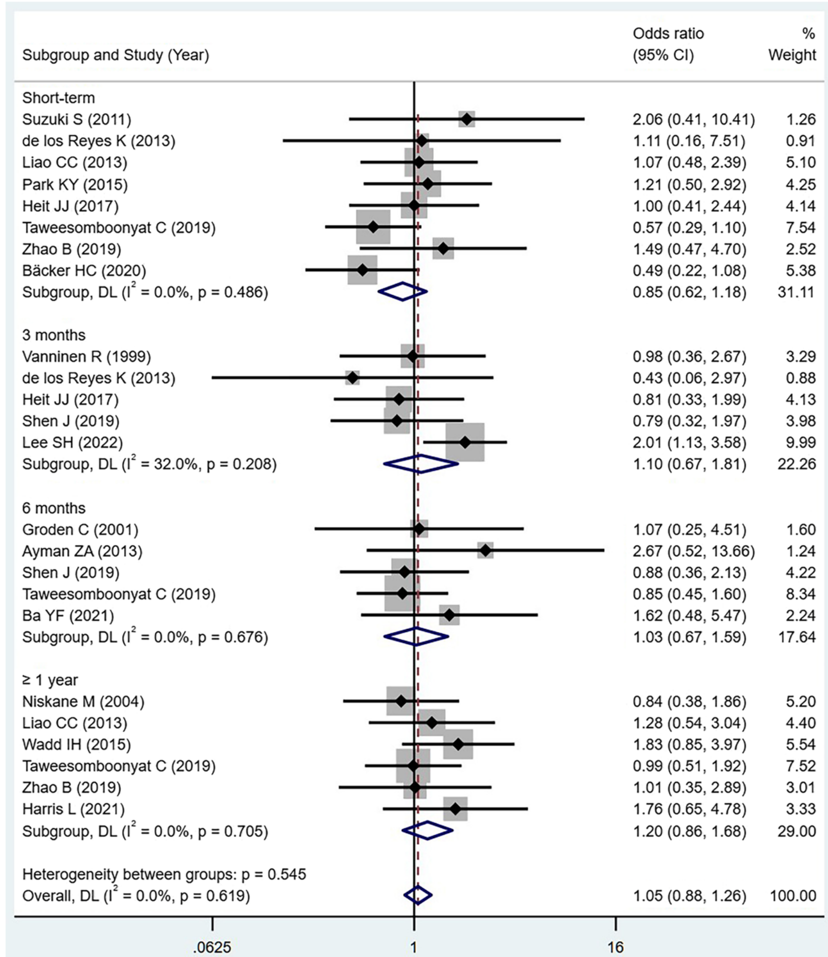


Fig. 2 Forest plot of odds ratio (OR) of poor outcome with clipping versus coiling

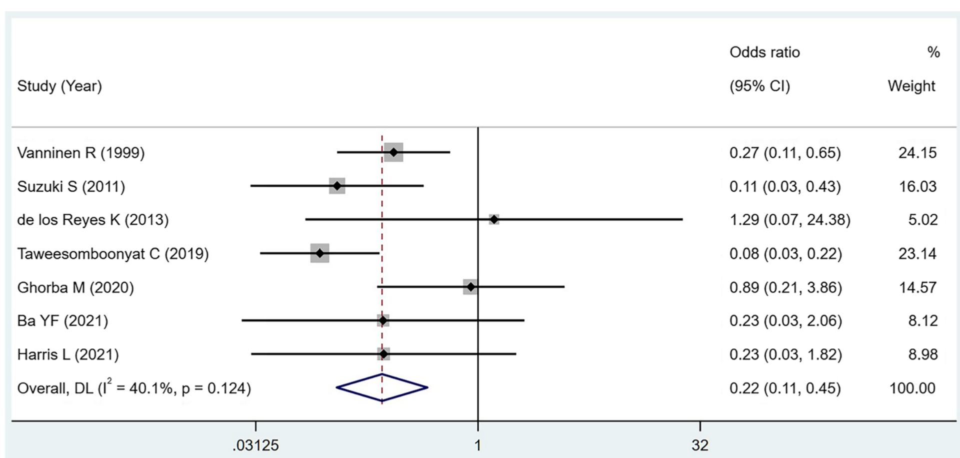


Fig. 3 Forest plot of odds ratio (OR) of incomplete occlusion with clipping versus coiling

of rebleeding (OR:0.75, 95% CI (0.42, 1.36), $P=0.345$, Fig. 6). Nine articles, including 832 patients, reported on postoperative vasospasm. Meta-analysis of the data revealed no significant difference between the two groups in the rate of vasospasm (OR:1.16, 95%CI (0.67, 2.01), $P=0.600$, Fig. 7). Six studies with 585 patients reported postoperative ischemic infarction and the results showed that clipping was associated with a higher incidence of ischemic infarction compared to coiling (OR:2.28, 95% CI (1.44, 3.63), $P<0.001$, Fig. 8).

Six studies involving 694 patients reported postoperative hydrocephalus. Meta-analysis of the data revealed no significant

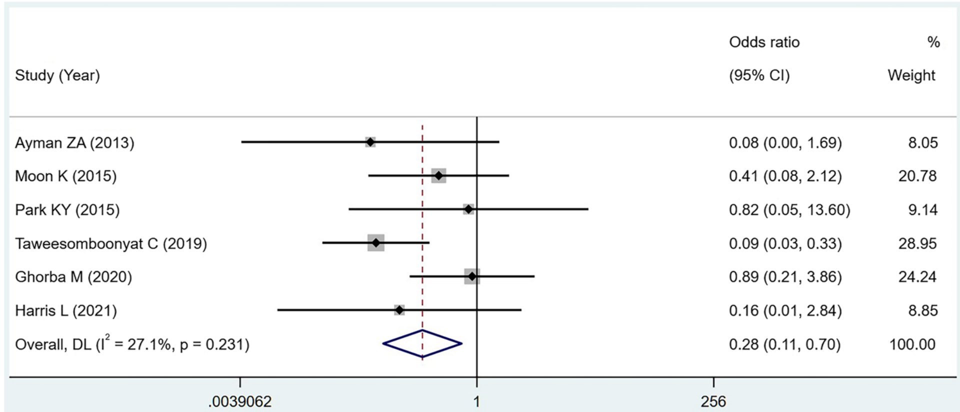


Fig. 4 Forest plot of odds ratio (OR) of retreatment with clipping versus coiling

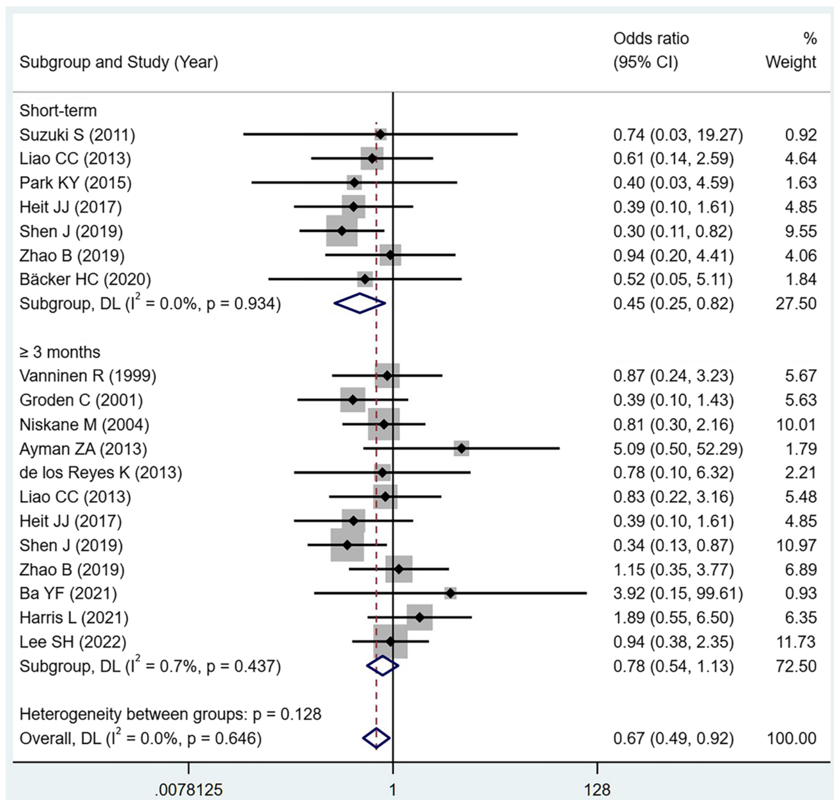


Fig. 5 Forest plot of odds ratio (OR) of mortality with clipping versus coiling

difference between the two groups in the rate of hydrocephalus (OR:0.86, 95%CI (0.40, 1.85), $P = 0.695$, Fig. 9).

Other outcomes of interest

The data on LOS were available from four studies that included 475 patients. The meta-analysis showed that clipping was associated with a longer length of stay than coiling (WMD:6.12, 95% CI (4.19, 8.04), $P < 0.001$, Fig. 10).

Publication Bias

Although there were less than 10 studies for some outcomes, we assessed publication bias for each outcome, and no significant publication bias was observed. A summary of these results is presented in Table 2.

Fig. 6 Forest plot of odds ratio (OR) of rebleeding with clipping versus coiling

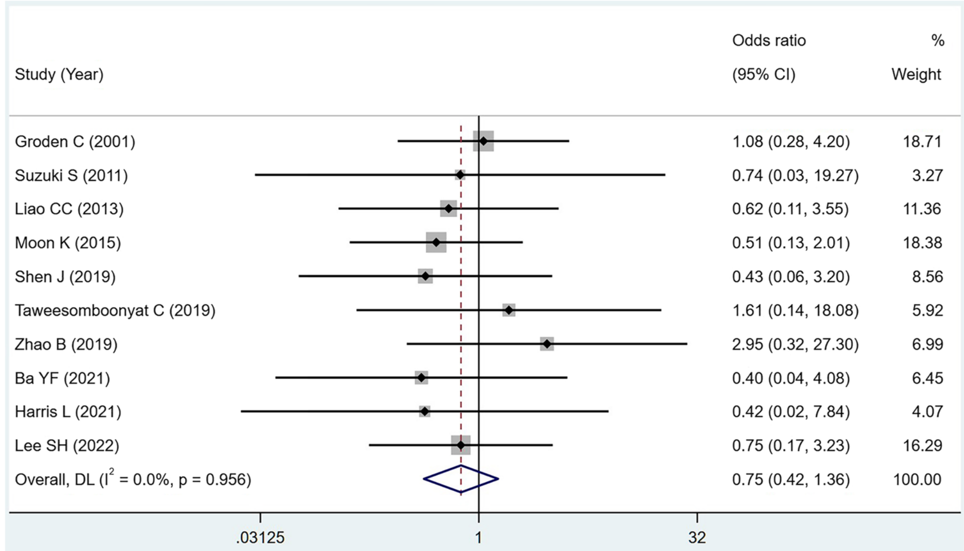


Fig. 7 Forest plot of odds ratio (OR) of vasospasm with clipping versus coiling

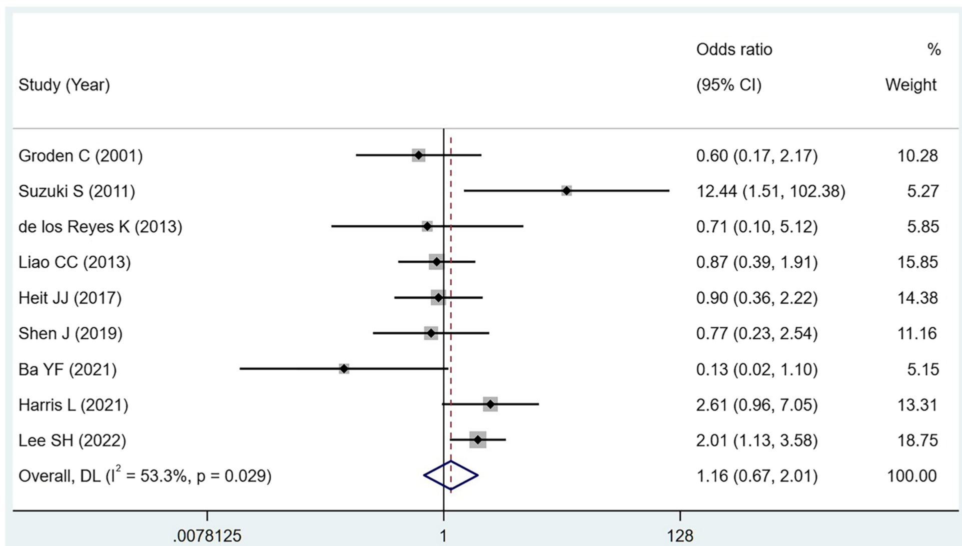
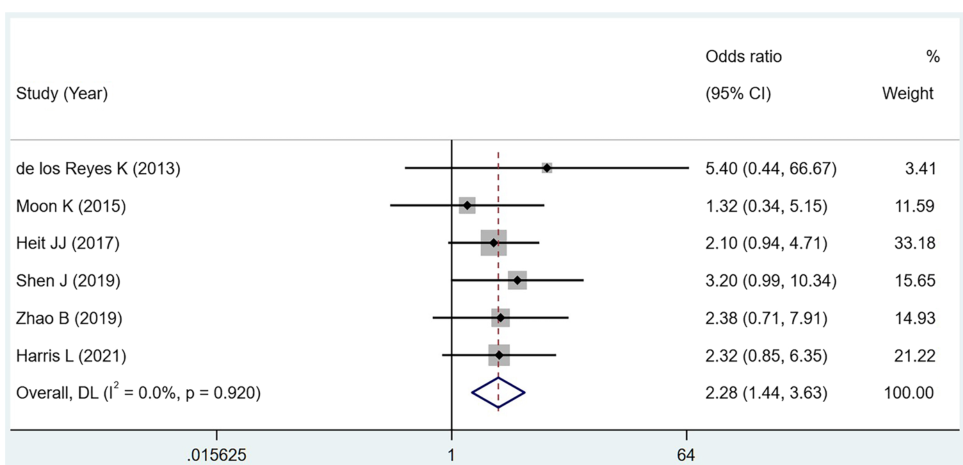


Fig. 8 Forest plot of odds ratio (OR) of ischemic infarct with clipping versus coiling



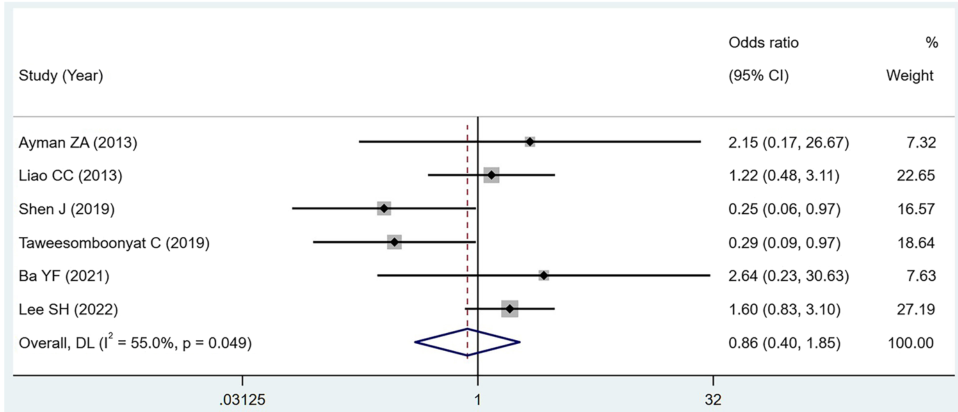


Fig. 9 Forest plot of odds ratio (OR) of hydrocephalus with clipping versus coiling

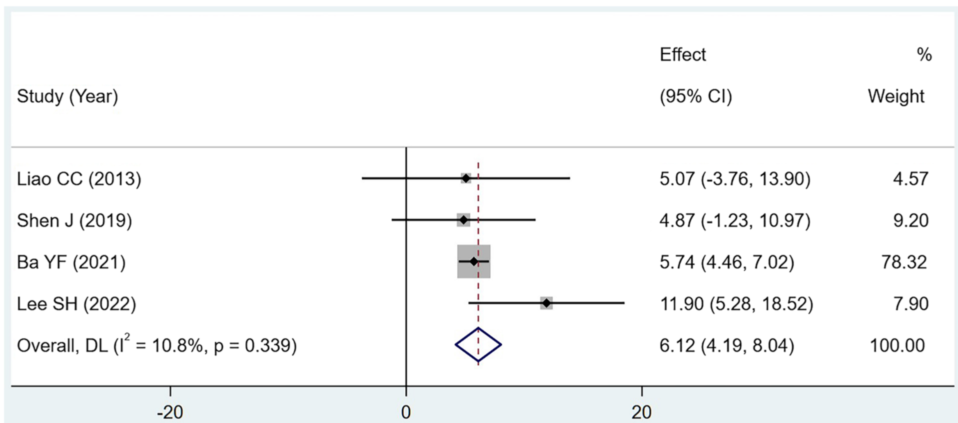


Fig. 10 Forest plot of weighted mean difference (WMD) of the length of stay with clipping versus coiling

Table 2 Results of meta-analysis comparison of coil and clip

		Groups			Over effect		Publication Bias (P value)	
Outcome	Studies	Clip	Coil	OR	95% CI	P value	Egger's test	Begg's test
Poor outcome								
Short-term	8	418	368	0.85	(0.62, 1.18)	0.343	0.080	0.174
3 m	5	269	254	1.10	(0.67, 1.81)	0.711	0.055	0.211
6 m	5	235	185	1.03	(0.67, 1.59)	0.859	0.077	0.086
≥ 1 y	6	406	437	1.20	(0.86, 1.68)	0.286	0.620	1.000
Incomplete occlusion	7	311	342	0.22	(0.11, 0.45)	**< 0.001**	0.322	0.548
Retreatment	6	318	327	0.28	(0.11, 0.70)	**0.006**	0.903	0.707
Mortality								
Short-term	7	370	303	0.45	(0.25, 0.82)	**0.009**	0.274	0.368
≥ 3 m	12	565	609	0.78	(0.54, 1.13)	0.192	0.149	0.537
Rebleeding	10	588	556	0.75	(0.42, 1.36)	0.345	0.894	0.858
Vasospasm	9	385	447	1.16	(0.67, 2.01)	0.600	0.437	0.602
ischemic infraction	7	298	287	2.28	(1.44, 3.63)	**< 0.001**	0.440	0.452
Hydrocephalus	6	353	341	0.86	(0.40, 1.85)	0.695	0.669	1.000
LOS	4	233	242	6.12*	(4.19, 8.04)	**< 0.001**	0.591	0.308

m = month, *y* = year, *LOS* = length of stay; *, The effect size of LOS is weighted mean difference (WMD)

Discussion

Appropriately managing ruptured anterior circulation aneurysms remains a major challenge for modern neurosurgeons. In previous studies, there was no certain evidence that the clinical safety and efficacy of one procedure is superior to another [8, 22, 30]. The decision to use clipping or coiling techniques for treatment is influenced by the patient's preference or the experience of the institution and the surgeon [26]. As a result, the optimal management of ruptured anterior circulation aneurysms is not easily determined. This meta-analysis evaluated the clinical benefits of endovascular coiling and surgical clipping in patients with ruptured anterior circulation aneurysms.

Compared to previous meta-analysis [36] involving patients with ruptured anterior circulation aneurysms, the present study reported inconsistent conclusions regarding the efficacy of clipping versus coiling. A limitation of the previous meta-analysis was that the pooled results were based on only eight studies, and numerous studies were not updated [36]. In our study, the pooled results of all identified studies on neurosurgical clipping versus endovascular coiling in patients with SAH from a ruptured anterior circulation aneurysm showed a reduction in retreatment and incomplete occlusion after treatment by clipping compared with coiling. Li et al. [37] reported that clipping could increase the incidence of complete occlusion (OR, 2.43; 95% CI, 1.88–3.13) compared to coiling. Zhu et al. [12] found that clipping could increase the incidence of complete aneurysmal occlusion by 33% compared to coiling. Therefore, follow-up angiography is necessary to detect incomplete occlusions after the embolization of ruptured anterior circulation aneurysms. Due to the low recurrence rate of completely occlusive aneurysms, late follow-up angiography may not be necessary for patients with complete occlusion [38, 39]. Moreover, several publications [40, 41], including ruptured anterior and posterior circulation aneurysms, have shown no significant differences in the incidence of poor outcome between neurosurgical clipping and endovascular coiling. A large and well-structured meta-analysis demonstrated that surgical clipping was associated with a higher rate of poor outcome than endovascular coiling [12]. However, subgroup analyses of this large and well-structured meta-analysis showed that clipping was not associated with a higher rate of poor outcome compared to coiling for the treatment of anterior cerebral artery, anterior communicating artery (ACA-AComA), or middle cerebral artery (MCA) aneurysms. Nevertheless, these studies included fewer RCTs in the meta-analyses, and more trials with long-term follow-up are required for further evaluation of both techniques.

The meta-analysis of ischemic infarction after treatment showed a significantly higher risk in the clipping group, but the vasospasm endpoint showed no statistical difference. Even though surgical clipping causes greater damage to brain tissue and blood vessels, our results showed no difference in vasospasm between clipping and coiling. A recent meta-analysis [42] investigated the role of antiplatelet therapy (AT) in coiling and clipping on vasospasm and found that surgically treated aSAH was associated with lower rates of symptomatic and angiographic vasospasm in the AT group. Although endovascular coiling has been associated with a higher risk of ischemic infarction in previous studies [43, 44], different results were observed in our study. Early studies suggested that ischemic infarction is caused by emboli that escape from aneurysms [45]. However, a recent high-quality meta-analysis [8] showed that the risk of ischemic infarction was lower in patients in the endovascular coiling group, which is consistent with our results. This may be due to the fact that clipping is more invasive to brain tissue. The continuous improvements in endovascular technology greatly reduce the probability of emboli escape [46]. Analysis of short-term mortality after operation showed a significantly higher risk in the coiling group; however, long-term mortality showed no statistical difference. These results are inconsistent with those of a previous meta-analysis conducted in 2017 [36], which revealed no significant difference in the risk of short-term mortality between coiling and clipping. The main difference may lie in including one study involving 94 patients with ruptured poor-grade anterior circulation aneurysms, which found a significant difference. Moreover, most studies provided only all-cause mortality data and failed to provide case fatality data, thus reducing the reliability of the results. Previous studies have shown that patients in the endovascular coiling group have a higher risk of rebleeding [8, 37, 41, 47]. However, most studies included heterogeneous subgroups (such as rupture-unruptured and anterior–posterior circulation) and were affected by ISAT. Thus, generalizing the findings of those studies to all intracranial aneurysms is inadequate. Additionally, we compared the LOS results and revealed a significantly shorter LOS in the endovascular coiling group than in the surgical clipping group because endovascular coiling is a minimally invasive treatment without craniotomy.

Owing to constant technological advancements and the introduction of new therapeutic approaches, there is a continuing impetus for less risky treatments. Nevertheless, the evolution of clinical practice tends to occur gradually rather than suddenly. Neurosurgical clipping for ruptured anterior circulation aneurysms is currently not a substitute. This study included all contemporary comparative studies and provided important information for neurosurgeons regarding treating ruptured anterior circulation aneurysms.

Limitations

There are several potential limitations to this study. Firstly, three kinds of study designs were included in the present study, of which only two randomized controlled trials and two prospective studies, mostly retrospective. Secondly, 21% of the included studies did not provide sufficient information regarding the baseline characteristics of patients. The uncertainty between the two treatment groups could have introduced a confounding bias. Moreover, we intended to conduct more subgroup analyses of patients with ruptured anterior circulation aneurysms. However, some studies lack specific information on the outcomes of this subgroup of participants.

Conclusions

According to our study, surgical clipping resulted in lower incomplete occlusion and retreatment rates and was associated with a lower incidence of short-term mortality. However, endovascular coiling was associated with a shorter LOS and a lower rate of ischemic infarction. Evidence from this systematic review illustrates that neurosurgical clipping may be superior to endovascular coiling for ruptured anterior circulation aneurysms. Large randomized controlled trials are needed to validate these outcomes and provide results based on patient status.

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Authors' contributions X.D. and L.P. conceived and planned the study. H.Q., J.L., and N.W. did the literature retrieve, extracted data, and evaluated study quality. L.P. and H.Q. analyzed and interpreted data. L.P. wrote the initial draft of the manuscript.X.D., X.W., and L.H. critically reviewed and revised the draft. All authors reviewed the manuscript.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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