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Impact of Smoking on Recurrence and Angiographic Outcomes After Endovascular Treatment of Intracranial Aneurysms: A Systematic Review and Meta-Analysis

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ABSTRACT

BACKGROUND: Cerebral aneurysm recurrence serves as a significant endpoint for assessing the efficacy of various endovascular treatment strategies. The impact of smoking on outcomes such as aneurysm occlusion, recurrence, and recanalization remains unclear due to conflicting evidence.

PURPOSE: To systematically evaluate the role of smoking in influencing angiographic outcomes following endovascular treatment of intracranial aneurysms.

DATA SOURCES: Comprehensive searches were conducted in PubMed, Embase, Scopus, and Web of Science

STUDY SELECTION: This systematic review and meta-analysis followed PRISMA guidelines to identify relevant studies assessing smoking's impact on intracranial aneurysms following endovascular treatment.

DATA ANALYSIS: Studies were screened, selected, and assessed for risk of bias using appropriate checklists. Data on complete and adequate aneurysm occlusion, and recurrence/ recanalization rates were extracted. Random-effects meta-analyses calculated risk ratios (ORs) with 95% confidence intervals (CIs). Heterogeneity was measured using the I^2 statistic.

DATA SYNTHESIS: A total of 26 studies, encompassing 6,031 patients, met the inclusion criteria. Smokers had higher rates of complete aneurysm occlusion (RR 1.12, 95% CI 1.06–1.19; p < 0.01). Subgroup analysis revealed that smokers undergoing flow diversion exhibited a higher rate of complete occlusion (RR 1.14, 95% CI 1.07–1.21; p < 0.01). However, for patients undergoing coiling, there was no significant difference in complete occlusion rates between smokers and non-smokers (RR 1.00, 95% CI 0.83–1.20; p = 0.46). Recurrence/recanalization rates were similar between smokers and non-smokers: RR 1.17, 95% CI 0.93–1.47; p = 0.20, and the rate of aneurysm retreatment did not differ between the smokers and non-smokers: RR 0.82, 95% CI 0.59–1.13; p = 0.23.

LIMITATIONS: Heterogeneity in definitions of smoking status, variations in follow-up durations, short follow up, retrospective nature of studies.

CONCLUSIONS: Smoking status does not significantly impact aneurysm recanalization or retreatment after endovascular repair. However, the impact of smoking on complete occlusion rate might differ based on the type of device used for treatment. Histological and molecular factors may contribute to varied outcomes, highlighting the necessity for further research to understand smoking's role in aneurysm healing. Clinically, patients should be advised about the risks of smoking, though current evidence suggests that smoking cessation may not consistently affect treatment efficacy.

ABBREVIATIONS: sAH =subarachnoid hemorrhage ; RROC =Raymond-Roy occlusion classification.

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INTRODUCTION

Cerebral aneurysm recurrence is the main endpoint when comparing the efficacy of different aneurysm treatment modalities[1]. Regarding unruptured aneurysms, previous meta-analyses reported an annual bleeding risk of 0.2% after endovascular therapy and recurrences occurred in up to ~24 % of aneurysms, leading to retreatment in about 10% of cases[2 3]. The significantly described rates of recurrence of intracranial aneurysms introduce complex decision-making challenges in clinical practice. This is further amplified in the less-explored scenario of unruptured intracranial aneurysms, and underscores the need for innovative and effective treatment approaches[4], as the decision to retreat recurrent aneurysms must balance procedural risks against the uncertain impact of retreatment on patient outcomes.

Several factors influence recurrence rates following endovascular aneurysm treatment, with smoking being a well-established risk factor for both aneurysm formation and rupture [5 6]. A large meta-analysis has demonstrated a 2.4% decrease in the global incidence of subarachnoid hemorrhage (sAH) for every percentage decrease in smoking prevalence[7]. However, the influence of smoking on the outcomes of endovascularly treated aneurysms remains ambiguous and has yielded contradictory results in the literature, possibly due to heterogeneity or lack of reporting of the smoking status among previous studies or heterogeneity in definition and assessment of the endpoints. Jin et al. in a meta-analysis[8] found no significant association between smoking and recurrence after coil embolization for intracranial aneurysms whereas in the same year, Pierot et al. described current smoking as a risk factor of recurrent aneurysm after repair following sAH, when both explored risk-factors of recurrence[9]. Given these inconsistencies, we conducted a dedicated systematic review and meta-analysis to elucidate the role of smoking on the recurrence and outcomes of endovascularly treated intracranial aneurysms.

MATERIALS AND METHODS

This systematic review and meta-analysis adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The supplementary materials include PRISMA checklists for both the abstract and main document. The Shiny app was utilized to generate a PRISMA 2020-compliant flow diagram and checklists. No protocol was registered for this review.

Search Strategy

A thorough literature search was performed without limitations on language, location, or time frame. We searched PubMed, Embase, Scopus, and Web of Science, on 25 Jun 2024, searching their records from inception. For PubMed, we used various Medical Subject Headings (MeSH) terms along with relevant titles and text words. The search syntax was customized for each database to fit their specific requirements. The full search syntax for all databases is available in the supplementary materials (Supplementary Table 1). Additionally, we manually performed bibliomining of included studies.

Eligibility criteria and selection process

Studies were included if they met the following criteria: (1) Design: Retrospective or prospective cohort or case-control studies (2) Population: Adult patients (≥18 years) with intracranial aneurysm who were treated with coiling, flow diversion, or a mixture of these methods (3) Exposure: smoking (4) Comparison: Patients with a history of smoking or current smoker vs never smokers (5) Outcome: Rates of aneurysm occlusion, recanalization and recurrence. The following studies were excluded: (1) Studies that did not mention the smoking status of patients, (2) Case series, conference abstracts, letters, editorials, book chapters, non-human studies, and reviews. Two authors (AH and AA) independently reviewed the titles and abstracts using eligibility criteria. If there was any disagreement, a third author (SG) was brought in to reach a consensus. The same two authors independently evaluated the full texts of all abstracts that fulfilled the inclusion criteria and performed hand searching. The included studies were reviewed to ensure institutional review board approval was obtained.

Data extraction

A standardized data collection form was designed, including the first author's name and year of publication, country and period of observation, smoking status of patients (current smoker, former smoker, non-specified smoker, non-smoker), baseline patient characteristics (age, sex, comorbidities, aneurysm location, size, and morphology), and treatments (coiling, clipping, flow diversion, other or mixed). Afterward, two authors (EN and JO) independently conducted data extraction. Any discrepancies or differences in data extraction were resolved through discussion and consensus.

Risk of Bias Assessment

Based on study design, two independent reviewers (SBJ and ASA) assessed the quality of studies using the Newcastle Ottawa Scale (NOS) for case-control and cohort studies or the JBI critical appraisal tool for case series [9 10]. Eight criteria were considered, each receiving 1 or 2 stars if the criterion was met and otherwise receiving no stars for a maximum possible score of 9. Studies scoring 8-9 were considered low risk, 6-7 indicated some concern, and scores 5 and lower were deemed high risk of bias.

Outcomes

Four endpoints were compared between smokers and non-smokers: (1) Rate of complete aneurysm (2) Rate of adequate aneurysm occlusion (3) Rate of aneurysm recurrence/recanalization, and (4) Retreatment. Complete occlusion was defined as Raymond-Roy occlusion classification[11] (RROC) grade I or 100% aneurysm occlusion in the follow up imaging. Adequate aneurysm occlusion was defined as complete or near complete aneurysm occlusion (RROC grade I and grade II or >90% occlusion in follow up imaging). Recanalization/recurrence was defined as inflow into a previously completely occluded aneurysm or growth of an incompletely occluded aneurysm.These endpoints were compared between smokers (current or former or non-specified) vs non-smokers (never-smokers). In cases where no definition for endpoints was provided, we adopted the authors' definitions of what constitutes a complete occlusion and what qualifies as recanalization/recurrence, using their reported terms as they are. Detailed definitions of study-reported endpoints are provided in supplemental materials **(Supplementary Table 7 and Supplementary Table 8)**. When multiple reports of endpoints were available from different follow-ups, we collected the results from the last follow-up.

Statistical analysis

Meta-analyses were conducted using R software version 4.3.3 (R Project for Statistical Computing) meta package version 6.5-0 and metafor package version 4.4-0. We calculated risk ratios (RRs) and their corresponding 95% confidence intervals (CI) using a random-effects model: Generalized Linear Mixed Model (GLMM). Heterogeneity was assessed using the Q statistic and I^2 test, with I2 greater than 50% or $P < 0.05$ considered significant. In the case of significant heterogeneity, a sensitivity analysis was performed with the removal of outlier studies to bring the heterogeneity to an insignificant level. Outliers were detected using "influence" and "dmetar" packages consistent with the method previously described in the literature[12]. A subgroup analysis was performed to assess the effect of different treatment methods (coiling, flow diversion or a mixture of different methods) on the specified endpoints. We did not include studies that used surgical clipping in the analysis because of low number of studies with appropriate outcome data (n=1). Publication bias was assessed using visual inspection of funnel plots for asymmetry and Egger's test with a value <0.1 considered significant. A meta-regression was performed to assess demographics on rate of aneurysm recurrence/recanalization. In our meta-regression we assessed effect of female gender, age, hypertension, aneurysm size, aneurysm location, aneurysm rupture, duration of follow up and publication year on the rate of aneurysm recurrence/recanalization. Publication bias and meta-regression analysis were not performed for aneurysm occlusion rate because of low number of studies (<10)[13].

RESULTS

Search and Screening Results

The initial search retrieved 1,171 records including 284 duplicates. After removing duplicates, the title and abstracts of 887 remaining records were screened, of which, 818 were excluded and 69 full texts underwent further checks. Finally, 26 studies met the eligibility criteria[14-37,74,75], with 6,031 included patients (Figure 1). One study 36 reported aneurysm recurrence rate in patients who use tobacco, therefore it is not included in meta-analysis but the results are mentioned qualitatively.

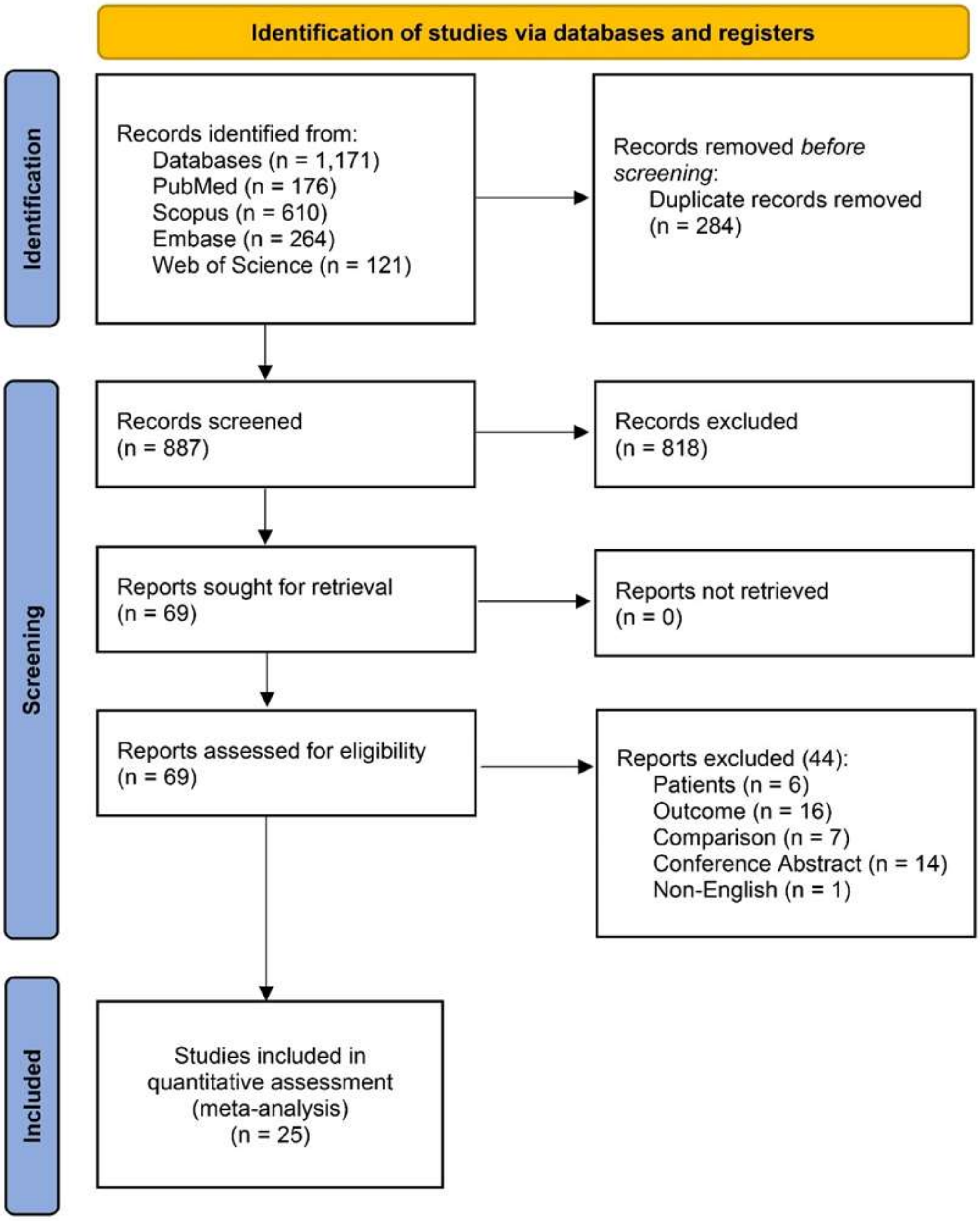


FIG 1. PRISMA checklist of study selection.

Baseline study characteristics

A summary of study characteristics is presented in Supplementary Table 2. Supplementary Table 3 and Supplementary Table 4 details the characteristics of the treated aneurysms and treatment details.

Risk of Bias

Selection criteria, encompassing representativeness of the exposed cohort and ascertainment of exposure, were well-addressed in most studies, with frequent assignment of maximum scores. However, a few studies demonstrated limitations, particularly in defining the comparison groups or failing to fully describe their selection methods, reflected in lower scores for Selection 2. In the Comparability domain, most studies appropriately adjusted for confounders, earning two stars, though some scored lower due to inadequate adjustments or a lack of explicit confounder control. Outcome assessment, including adequate follow-up length and appropriate statistical analysis, was consistently strong across studies, often achieving maximum scores. Overall, the studies ranged from moderate to high quality, with total NOS scores clustering between 6 and 9. Additionally, the single study 38 evaluated using the JBI checklist scored 8/10, suggesting it was generally well-conducted but had some areas of unclear reporting (Supplementary Table 5).

Complete aneurysm occlusion

Seven studies, with 1,402 patients, were included in meta-analysis of complete aneurysm occlusion rate between smokers and non-smokers with a median follow up of 405 days (IQR: 325-678 days). The rate of complete aneurysm occlusion was higher among smokers compared with non-smokers (RR 1.12, 95% CI 1.06–1.19; $p < 0.01$) with no heterogeneity among studies ($I^2 = 0\%$, $p = 0.59$) **(Figure 2)**. In the subgroup analysis, which considered a median follow-up duration of 535 days (IQR: 371–700 days) for coiling and 405 days (IQR: 365–492 days) for flow diversion, a significant difference in the rate of complete occlusion was observed.

The rate of complete occlusion was higher among smokers compared with non-smokers who received flow diversion, (RR 1.14, 95% CI 1.07–1.21; $p < 0.01$). However, there was no difference in complete aneurysm occlusion rate among smokers and non-smokers who underwent coiling (RR 1.00, 95% CI 0.83–1.20; $p = 0.46$) **(Figure 3)**. In three studies the status of smokers was specified as current smoker vs former smoker. We evaluated the effect of current vs past history of smoking in a separate subgroup analysis. The rate of complete aneurysm occlusion was comparable between all subgroups **(Supplementary Figure 1)**.

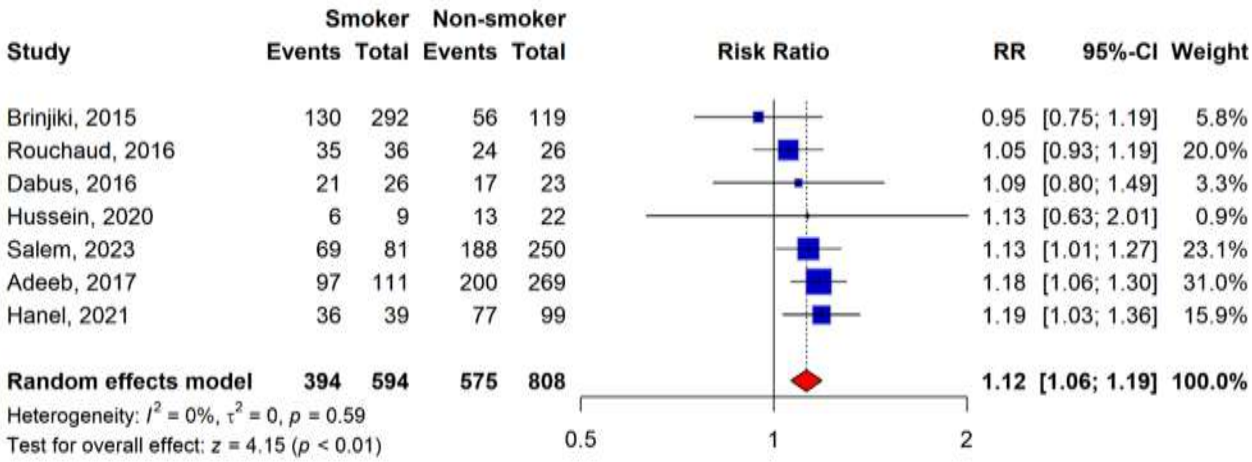
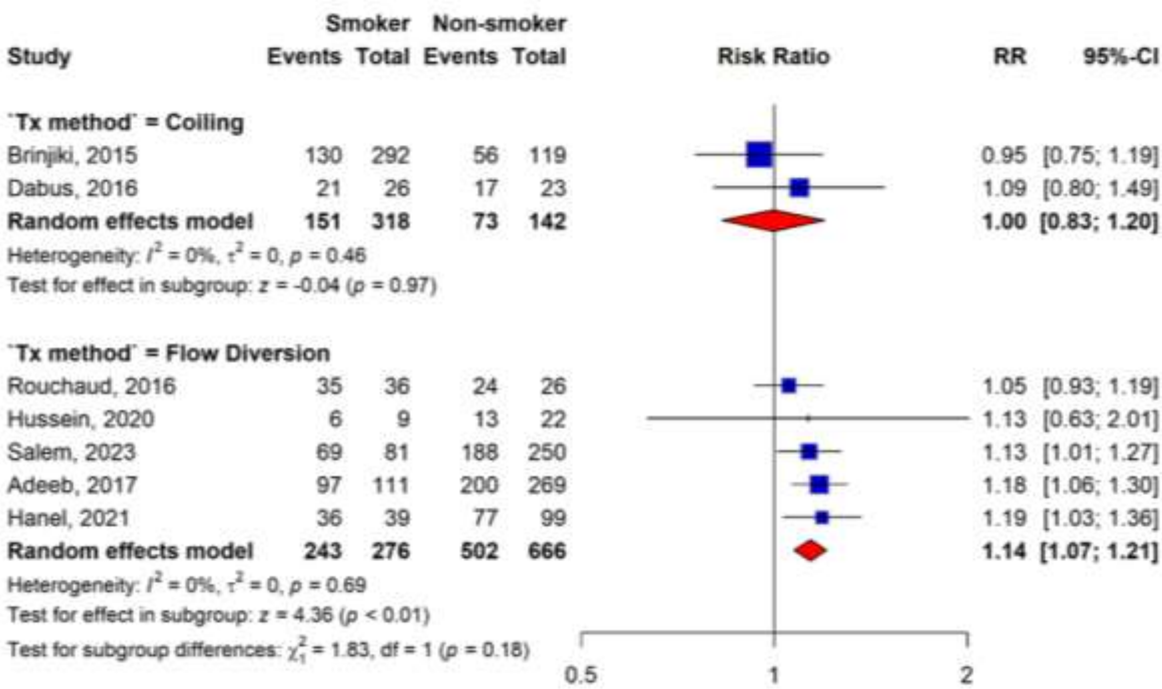


FIG 2. Forest plot of complete occlusion rate



FIG

Adequate aneurysm occlusion

Five studies, with 1,672 patients, compared adequate aneurysm occlusion rate between smokers and non- smokers with a median follow up of 193 days (IQR: 135-371 days). The rate of adequate occlusion was not different between the smokers and non-smokers (RR 0.97, 95% CI 0.93–1.01; $p = 0.17$), with no heterogeneity noted among studies ($I^2 = 0\%$, $p = 0.93$) **(Figure 4)**. Subgroup analysis showed no difference in rate of adequate occlusion between smokers and non-smokers in subgroups of coiling and flow diversion treatments **(Supplementary Figure 2)**.

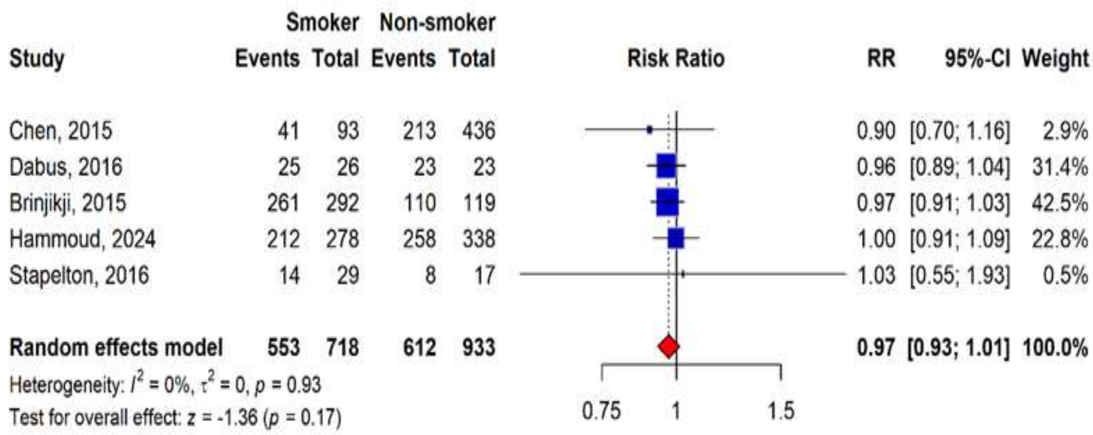


FIG 4. Forest plot of adequate occlusion rate

Aneurysm recurrence/recanalization

Seventeen studies, encompassing 3,748 patients, were included in a meta-analysis evaluating the recurrence/recanalization rates between smokers and non-smokers with a median follow-up of 649 days (IQR: 249-825 days). The rate of recurrence/recanalization was comparable between smokers and non-smokers(RR 1.17, 95% CI 0.93–1.47; p = 0.17), with high heterogeneity noted among studies (I^2 = 55%, p < 0.01) **(Figure 5)**. Due to high heterogeneity, a sensitivity analysis was performed. One study was found to be as outlier (Morga, 2020). The results of the sensitivity analysis confirmed the finding of the main analysis which showed no significant difference between smokers and non-smokers in rate of aneurysm recurrence/recanalization (RR 1.10, 95%CI 0.88–1.38). Subgroup analysis showed no difference in rate of recurrence/recanalization among smokers and non-smokers in subgroups who were treated by coiling or mixed treatments (coiling and flow diversion embolization) **(Supplementary Figure 3)**. There was no publication bias based on Egger's (intercept: -0.65, p = 0.44) and observation of the funnel plot **(Supplementary Figure 4)**. The meta-regression analysis found no significant effect for any of the assessed factors for the rate of aneurysm recurrence/recanalization among smokers vs non-smokers (Supplementary Table 6).

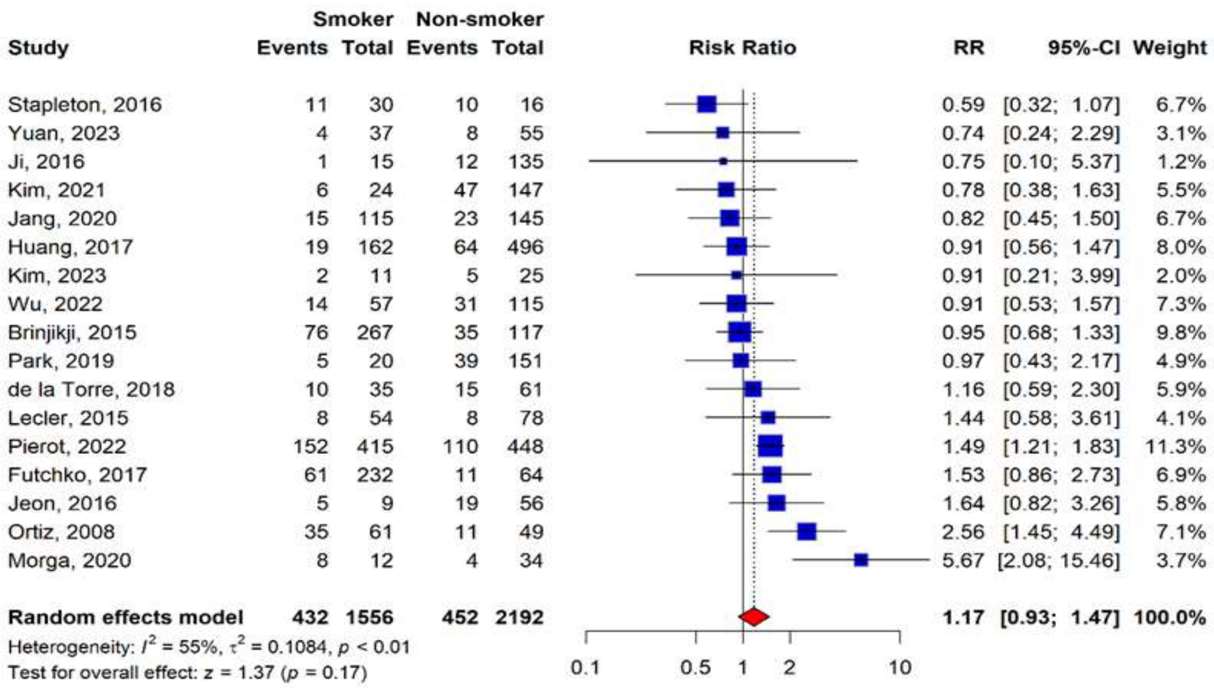


FIG 5. Forest plot of recurrence/recanalization rate

Retreatment

Five studies, encompassing 971 patients, were included in the meta-analysis evaluating the retreatment rates between smokers and non-smokers with a median follow-up of 843 days (IQR: 787-972 days). All studies used coiling as the treatment method. The rate of retreatment was not different among smokers and non-smokers (RR 0.82, 95%CI 0.59–1.13, p = 0.23) with no heterogeneity among studies (I^2=0%, p = 0.93) (Figure 6

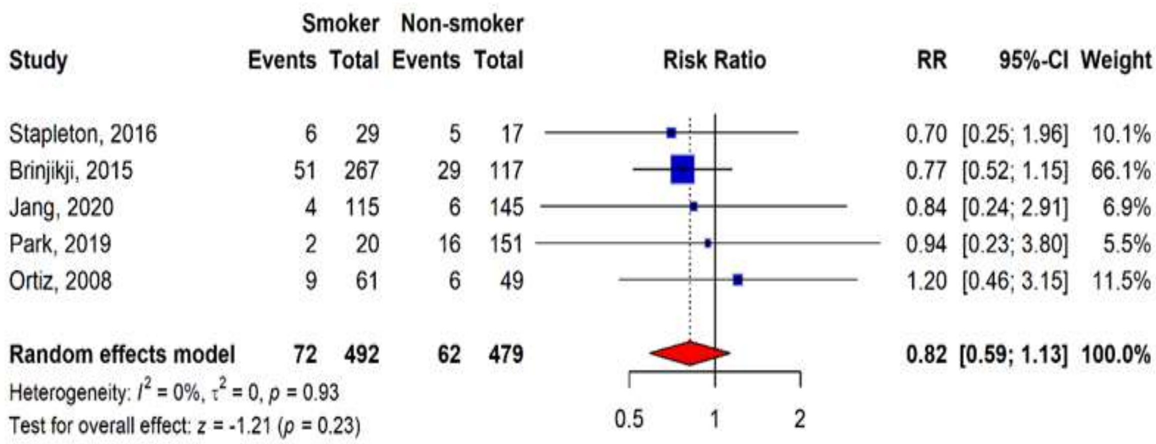


FIG 6. Forest plot of retreatment

Qualitative results

Youssef et al. (11) reported on a multicenter retrospective study of flow diversion with Woven EndoBridge (WEB) device for ruptured aneurysms, which inlcuded 45 patients with a tobacco use prevalence of 61.4%. Among baseline patient demographic factors, only tobacco use was associated with recurrent/residual aneurysm. Specifically, tobacco use was more common among patients with recurrent aneurysm compared with those without recurrence at a median follow up of 5.5 months (88.9% vs 35.7%; p=0.012).

DISCUSSION

Our findings indicate that smoking status does not significantly influence recurrence/recanalization or need to retreatment following endovascular procedures. However, smoking was associated with higher probability of complete aneurysm occlusion. following endovascular procedures. Variability in outcomes across previous studies may stem from differences in endovascular devices used. Notably, our study found that smokers who underwent flow diversion treatment had a significantly higher rate of complete aneurysm occlusion compared to non-smokers. This may be attributed to the complex interplay between smoking-induced physiological changes and the mechanisms of healing related to flow diverters. While our study found that smokers treated with flow diversion had a significantly higher rate of complete aneurysm occlusion compared to non-smokers, this finding warrants further examination. The inherent higher occlusion rates associated with flow diverters relative to coiling may confound this result, potentially overshadowing the impact of smoking status. To better delineate the influence of treatment modality, future studies should consider comparative analyses that explicitly account for device-specific occlusion dynamics while controlling for confounding factors such as aneurysm size, location, and follow-up duration .

The initial event following flow diversion treatment is adherence of clusters of inflammatory cells across the aneurysm neck. Endothelialization is relatively delayed and derived from cells in the adjacent parent artery [39]. Smoking-induced oxidative stress damages endothelial cells and this oxidative imbalance is compounded by increased levels of pro-inflammatory cytokines leading to chronic inflammation and disrupted vascular remodeling [40]. That's why the pro-thrombotic and inflammatory effects of smoking would have theoretically a more pronounced impact on the (negative) outcomes of flow diversion treatments compared to coiling [41]. Unchanged outcomes associated with coiling procedures are also surprising, but the overall process may be potentially mitigated because the long-term impact of smoking on the vessel wall, particularly given the role of chronic inflammation in smoking-induced atherosclerosis is not fully assessed in our short term event collection [42].

The risk of rebleeding after endovascular treatment of ruptured aneurysms is 2.5% in the first year, but becomes negligible after six years [43 44]This decline correlates with the early mechanisms underlying late aneurysm recanalization, including poor thrombus organization or degradation[45]. Nicotine has shown to increase plasminogen activator inhibitor-1 levels in brain endothelial cells, promoting a pro-thrombotic state by inhibiting fibrinolysis[46 47]. Smoking also upregulates tissue factor, a key initiator of the coagulation cascade, while downregulating tissue factor pathway inhibitor-1, further predisposing individuals to thrombogenesis[48]. The presence of an organizing luminal thrombus in cerebral aneurysm may favor the healing process[45 49] by recruiting macrophages and neutrophils through chemotactic factors[49]. Smoke particles have shown to activate mitogen-activated protein kinases (MAPK) and nuclear factor-κB (NF-κB) pathways[50-53], which affect vascular stress responses, wall shear stress, blood viscosity and pro-inflammatory cytokine release[54 55]. These processes can impair aneurysm wall integrity and upregulates the expression of matrix metalloproteinases, potentially promoting recanalization[56 57].

Favorable outcomes in smokers have been noted in other contexts, such as a reduction in the hospital stays and complications in patients with arteriovenous malformations with a documented smoking usage or better clinical outcomes and recanalization rates after intravenous thrombolysis for stroke[58 59]. Similarly, potential confounding factors, including aneurysm size, shape, location, genetic predisposition and demographic influences, may play a significant role in recurrence risk after treatment. Further, genetic factors linked to smoking behavior may affect aneurysm morphology and recurrence, while polymorphisms in vascular integrity and nitric oxide production genes could amplify smoking-induced damage. Further, inconsistencies in defining smoking status, follow-up durations, imaging modalities, and treatment comparisons complicates the interpretation of results, emphasizing the need for standardized methods and consideration of confounders in future studies[60-63].

The "smoker's paradox" phenomena, reported in some cardiovascular and neurovascular settings, post potential short-term benefits for smokers post-intervention [63-65] due to the anti-inflammatory and neurogenic vasodilatory effects that are mediated by nicotinic acetylcholine receptors [66] on intracranial vessels. For instance, nicotine replacement therapy has been linked to reduced clinical vasospasm and better discharge scores [67] and enhanced clopidogrel response in smokers may benefit certain interventions[68]. However, smoking remains independently associated with higher all-cause mortality after percutaneous coronary intervention[69] and negatively impacts long-term outcomes after endovascular treatments, as demonstrated by Ahmad's analysis showing a 35% lower recovery rate among smokers[70].

Smoking is a well-established risk factor for aneurysm growth and rupture, yet the impact of smoking cessation or reduction on this risk remains underexplored[5]. While smoking is well-established to impair endothelial function, quitting does not consistently lead to improvement[71].

Interestingly, our meta-regression analysis revealed that aneurysm rupture did not affect recanalization or recurrence rates. This is particularly notable given the common assumption that ruptured aneurysms might behave differently compared to unruptured ones during the healing process[72]. However, our finding aligns with the study by Cao et al., which demonstrated that, despite different endovascular approaches, ruptured and unruptured intracranial aneurysms exhibited comparable occlusion and recanalization rates[73]. It is important to emphasize that our paper exclusively focuses on endovascular treatment and does not address surgical methods such as surgical clipping.

Smoking cessation should remain a cornerstone of preventive health strategies due to its well-documented benefits in reducing aneurysm rupture and systemic vascular risks. However, the lack of significant differences in angiographic outcomes between smokers and non-smokers suggests that cessation efforts should be framed around overall health benefits rather than specific improvements in aneurysm repair outcomes. This distinction may aid clinicians in setting appropriate patient expectations during counseling. Future studies should focus on unraveling the molecular pathways through which smoking modulates aneurysm healing processes, particularly in the context of endovascular device use. A deeper understanding of these mechanisms may pave the way for the development of targeted therapies or innovative coating materials for endovascular devices. These advancements could enhance healing, reduce recurrence rates, and improve overall treatment efficacy, particularly in high-risk populations, including smokers.

Limitations:

This study has several limitations. The heterogeneity in definitions of smoking status and recurrence outcomes across studies may have introduced variability, with inconsistent categorization of smokers complicating direct comparisons. Variations in follow-up durations, ranging from months to years, may have influenced the detection of late-occurring aneurysm recurrence or recanalization. The median follow-up time of 649 days for recurrence/recanalization is relatively short for evaluating aneurysm outcomes. Although a follow-up period of ~22 months offers some preliminary insights, it may not be adequate to fully assess the long-term efficacy and durability of the treatment[74,75]. Additionally, reliance on retrospective studies, prone to selection bias, limited the control of confounders such as aneurysm characteristics, comorbidities, medications (e.g. antiplatelets) and genetic predispositions. Differences in imaging modalities and reporting standards further affected the comparability of outcomes. Due to the scarcity of data, we were unable to quantitatively assess the impact of smoking, such as in pack years. This study exclusively provides insights into endovascular treatment outcomes and does not extend to surgical aneurysm treatment methods, such as surgical clipping. The primary objective of this manuscript was to investigate the efficacy of the treatment rather than to assess periprocedural complications. Consequently, it does not provide data on periprocedural neurologic and non-neurologic complications.

CONCLUSIONS

Smoking status does not appear to significantly influence aneurysm recanalization or recurrence rates after endovascular treatment. However, our findings suggest that variations in angiographic outcomes may be partially attributed to differences in device types and the mechanisms of healing they promote. The observed heterogeneity across studies highlights the need for further research to elucidate the complex interplay between smoking-induced physiological changes, device-specific healing mechanisms, and patient outcomes. While smoking cessation remains critical for reducing the overall vascular risks and preventing aneurysm formation or rupture, the evidence suggests that cessation may not universally enhance the efficacy of endovascular treatments. These results emphasize the importance of systematic reporting of smoking status and treatment outcomes in future research to better understand the role of smoking in aneurysm healing. Clinicians should continue to counsel patients on the comprehensive health benefits of smoking cessation while managing expectations regarding its impact on aneurysm treatment efficacy.

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SUPPLEMENTAL FILES

Supplementary Table 1. Search strategy

PubMed: 176
("Intracranial Aneurysm"[Mesh] OR (Cerebrovascular) OR (Intracranial) OR (Cerebral) OR (Brain) OR (Basilar) OR (Communicating) OR

(Berry) OR (cerebellar)) AND (aneurysm) AND ("Smoking"[Mesh] OR (smoking) OR (cigarette) OR (cigar) OR (tobacco)) AND ("Thrombosis"[Mesh] OR (thrombosis) OR (Occlusion) OR (recurrence))
Scopus: 610
(TITLE-ABS-KEY(Cerebrovascular) OR TITLE-ABS-KEY(Intracranial) OR TITLE-ABS-KEY(Cerebral) OR TITLE-ABS-KEY(Brain) OR TITLE-ABS-KEY(Basilar) OR TITLE-ABS-KEY(Communicating) OR TITLE-ABS-KEY(Berry) OR TITLE-ABS-KEY(cerebellar)) AND TITLE-ABS-KEY(aneurysm) AND (TITLE-ABS-KEY(smoking) OR TITLE-ABS-KEY(cigarette) OR TITLE-ABS-KEY(cigar) OR TITLE-ABS-KEY (tobacco)) AND (TITLE-ABS-KEY(thrombosis) OR TITLE-ABS-KEY(Occlusion) OR TITLE-ABS-KEY(recurrence))
Embase: 264
(cerebrovascular OR intracranial OR cerebral OR 'brain'/exp OR brain OR basilar OR communicating OR 'berry'/exp OR berry OR cerebellar) AND aneurysm:ti,ab,kw AND (smoking:ti,ab,kw OR cigarette:ti,ab,kw OR cigar:ti,ab,kw OR tobacco:ti,ab,kw) AND (thrombosis OR occlusion OR recurrence)
Web of Science: 121
ALL=(Cerebrovascular OR Intracranial OR Cerebral OR Brain OR Basilar OR Communicating OR Berry OR cerebellar) AND ALL=(aneurysm) AND ALL=(smoking OR cigarette OR cigar OR tobacco) AND ALL=(thrombosis OR Occlusion OR recurrence)

Supplementary Table 2. Summary of the included studies and baseline characteristics

Study	Year	Group	Patients	Smoking (n)	Female (n)	Age		HTN (n)	DM (n)	Atherosclerosis (n)	Dyslipidemia (n)
						Mean/Median	**SD/IQR**				
Occlusion											
Chen	2015	Adequate Occlusion	254	41	165	49.6	1.4	32	34	33	-
		Incomplete Occlusion	275	52	173	49.8	1.6	45	28	25	-
Hussein	2020	Complete Occlusion	19	6	3	53.4	42-69	10	-	-	4
		Incomplete Occlusion	12	3	3	65.5	41-79	8	-	-	7
Brinjikji	2015	Complete Occlusion	371	261	-	-	-	-	-	-	-
		Incomplete Occlusion	40	31	-	-	-	-	-	-	-
Hanel	2021	Complete Occlusion	113	36	101	53.6	11.2	-	-	-	-
		Incomplete Occlusion	25	3	20	59.9	10.4	-	-	-	-
Stapleton	2016	Adequate Occlusion	22	14	17	54	-	14	-	-	-
		Incomplete Occlusion	24	15	22	55.3	-	13	-	-	-
Salem	2023	Complete Occlusion	257	69	206	57	47-65	80	-	-	-
		Incomplete Occlusion	74	12	62	66	56-72	26	-	-	-
Rouchaud	2016	Complete Occlusion	109	58	-	-	-	-	-	-	-
		Incomplete Occlusion	36	20	-	-	-	-	-	-	-
Adeeb	2017	Complete Occlusion	297*		255	-	-	-	-	-	-
		Incomplete Occlusion	83*		66	-	-	-	-	-	-
Hammoud	2024	Complete Occlusion	470		400	55	48–64	208	-	-	-
		Incomplete Occlusion	146		113	58	50–71	89	-	-	-
Dabus	2016	Complete Occlusion	41	21	-	-	-		-	-	-
		Incomplete Occlusion	14	5	-	-	-		-	-	-
Recurrence/recanalization											
Futchko	2017	Non-Recurrent/no recanalization	72	61	53	-	-	40	8	-	-
		Recurrent/Recanalization	224	171	179	-	-	125	25	-	-
Kim	2023	Non-Recurrent/no recanalization	29	9	15	55.8	11	18	2	8	11
		Recurrent/Recanalization	7	2	2	55.3	15.7	2	1	1	1
Jang	2020	Non-Recurrent/no recanalization	222	100	112	58.3	10.84	132	-	-	-

		Recurrent/Recanalization	38	15	14	53.58	11.7	25	-	-	-
Huang	2017	Non-Recurrent/no recanalization	575	143	363	-	-	495	180	-	-
		Recurrent/Recanalization	83	19	52	-	-	77	26	-	-
Yousef	2020	Non-Recurrent/no recanalization	15	35.70%	9	61.3	16.9	66.70%	-	-	66.70%
		Recurrent/Recanalization	10	88.90%	8	55.2	8.9	57.10%	-	-	14.30%
Yuan	2023	Non-Recurrent/no recanalization	80	33	7	58.83	6.56	7	3	3	2
		Recurrent/Recanalization	12	4	54	55.11	10.21	29	10	13	19
Wu	2022	Non-Recurrent/no recanalization	127	43	76	-	-	41	31	-	-
		Recurrent/Recanalization	45	14	29	-	-	18	17	-	-
Kim	2021	Non-Recurrent/no recanalization	118	18	101	62.3	10.6	57	15	-	49
		Recurrent/Recanalization	53	6	50	61.2	11.8	28	5	-	17
Ji	2016	Non-Recurrent/no recanalization	137	14	112	52.7	8.6	44	6	-	13
		Recurrent/Recanalization	13	1	10	52.3	7.2	6	1	-	1
de la Torre	2018	Non-Recurrent/no recanalization	71	25	47	52	11	19	-	-	-
		Recurrent/Recanalization	25	10	17	53	10	14	-	-	-
Jeon	2016	Non-Recurrent/no recanalization	41	4	30	58.1	12	27	3	-	4
		Recurrent/Recanalization	24	5	18	57.6	9.2	12	0	-	2
Stapleton	2016	Non-Recurrent/no recanalization	25	19	20	52.8	-	16	-	-	-
		Recurrent/Recanalization	21	11	19	54.7	-	11	-	-	-
Morga	2020	Non-Recurrent/no recanalization	34	4	28	58	15.26	14	-	6	4
		Recurrent/Recanalization	12	8	8	55.83	7.07	6	-	0	2
Ortiz	2008	Non-Recurrent/no recanalization	64	26	55	-	-	-	-	-	-
		Recurrent/Recanalization	46	35	32	-	-	-	-	-	-
Pierot	2022	Non-Recurrent/no recanalization	666	263	-	53.5	12.5	-	-	-	-
		Recurrent/Recanalization	279	152	-	51.7	12.1	-	-	-	-
Park	2019	Non-Recurrent/no recanalization	127	15	104	58.0	51.0-65.0	63	13	-	-
		Recurrent/Recanalization	44	5	32	65.0	55.5-71.0	25	5	-	-
Lecler	2015	Non-Recurrent/no recanalization	60	-	-	-	-	-	-	-	-

		Recurrent/Recanalization	132	54	-	-	-	-	-	-	-	-

HTN= Hypertension; DM= Diabetes Mellitus; * Number of aneurysms

Supplementary Table 3. Summary characteristics of the treated aneurysms

Study	Year	Group	Ruptured	Location							Size				Neck		Morphology	
				ACA	**Acom**	**ICA**	**MCA**	**VB**	**Pcom**	**Other**	**Micro-Miniature**	**Miniature**	**Large**	**Other**	**Wide**	**Narrow**	**Regular**	**Irregular**
Occlusion																		
Chen	2015	Adequate Occlusion	179	105		82	35	32		-	41	181	32	-	25	229	212	70
		Incomplete Occlusion	225	117		86	42	30		-	15	208	52	-	53	222	205	42
Hussein	2020	Complete Occlusion	-	-	-	-	-	-	-	Cavernous: 3; Clinoid: 4; Ophthalmic: 8; SHA: 2; Others: 2	-	-	-	Mean: 6.29			S: 16; F: 1	2
		Incomplete Occlusion	-	-	-	-	-	-	-	Cavernous: 3; Clinoid: 4; Ophthalmic: 4; SHA: 0; Others: 1	-	-	-	Mean: 10.83			S:10; F: 1	1
Brinjiki	2015	Complete Occlusion	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Incomplete Occlusion	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hanel	2021	Complete Occlusion	0	-	-	-	-	-	-	Petrous: 1; Cavernous: 3; Clinoid: 10; Ophthalmic: 86; Communicating: 11; V4: 2	-	-	-	≤ 12mm	≥ 4 mm	-	S: 111; F: 2	-
		Incomplete Occlusion	0	-	-	-	-	-	-	Petrous: 0; Cavernous: 0; Clinoid: 1; Ophthalmic: 12;	-	-	-	≤ 12mm	≥ 4 mm	-	S: 23; F: 2	-

										Communicating: 8; V4: 4								
Stapelton	2016	Complete Occlusion	6	-	-	-	-	All Basilar	-	-	19		3	small: <10; large: >10	-	-	S: 5; E: 14	Bi: 3
		Incomplete Occlusion	8	-	-	-	-	All Basilar	-	-	15		9	small: <10; large: >10	-	-	S: 11; E: 12	Bi: 1
Salem	2023	Complete Occlusion	-	-	-	-	-	-	-	Post. Cir.: 22	-	-	-	6 [3.9-10]	-	-	S: 234; F: 23	-
		Incomplete Occlusion	-	-	-	-	-	-	-	Post. Cir.: 12	-	-	-	7 [5-11.9]	-	-	S: 67; F:7	-
Rouchaud	2016	Complete Occlusion	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Incomplete Occlusion	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Adeeb	2017	Complete Occlusion	-	-	-	-	-	-	-	Ant: 240, Post: 57	-	-	-	1–20 mm: 269, ≥ 21 mm: 21	-	-	S: 201, Blister: 11, F: 76, Dissecting: 9	-
		Incomplete Occlusion	-	-	-	-	-	-	-	Ant: 56, Post: 27	-	-	-	1–20 mm: 21, ≥ 21 mm: 12	-	-	S: 56, F: 26, Dissecting: 1	-
Hammoud	2024	Complete Occlusion	-	6	1	443	18	-	11	Post: 32	-	-	-	-	-	-	S: 447, Blister: 5, F: 31, Dissecting: 28	-
		Incomplete Occlusion	-	3	0	237	7	-	2	Post: 18	-	-	-	-	-	-	S: 122, Blister: 1, F: 21, Dissecting: 1	-
Dabus	2016	Complete Occlusion	41	-	15	5	-	-	13	8	-	-	-	-	-	-	-	-
		Incomplete Occlusion	14	-	8	-	1	-	1	4	-	-	-	-	-	-	-	-

Recurrence/recanalization																		
Futchko	2017	Non-Recurrent/no recanalization	20	-	-	-	-	-	-	High Risk (Acom, A2/Pericallosal, Pcom, Basilar): 38	-	-	-	≥7: 51	-	-	-	-
		Recurrent/Recanalization	42	-	-	-	-	-	-	High Risk (Acom, A2/Pericallosal, Pcom, Basilar): 114	-	-	-	≥7: 69	-	-	-	-
Kim	2023	Non-Recurrent/no recanalization	0		-	-	-	All VB	-	-	-	-	-	7.76 (2.35)	-	-	F: 24; D: 4; T: 1	-
		Recurrent/Recanalization	0		-	-	-	All VB	-	-	-	-	-	12.41 (6.61)	-	-	F:3; T: 4	-
Jang	2020	Non-Recurrent/no recanalization	56		All Acom	-	-	-	-	-	-	-	-	5.17 (2.1)	-	-	-	-
		Recurrent/Recanalization	21		All Acom	-	-	-	-	-	-	-	-	6.3 (3.0)	-	-	-	-
Huang	2017	Non-Recurrent/no recanalization	479	41	122	-	75	-	160	Posterior Circulation: 37	236	292	47	<5; 5-10; 10<	> 4: 171	404	S: all	-
		Recurrent/Recanalization	77	2	35	-	17	-	15	Posterior Circulation: 2	28	39	16	<5; 5-10; 10<	> 4: 57	26	S: all	-
Yousef		Non-Recurrent/no recanalization	All	-	-	-	-	-	-	-	-	-	-	6.6 (2.6)	-	-	-	-
		Recurrent/Recanalization	All	-	-	-	-	-	-	-	-	-	-	5.9 (2.5)	-	-	-	-
Yuan	2023	Non-Recurrent/no recanalization	-	-	-	-	80	-	-	-	-	-	-	5.23 (1.88)	-	-	S: 80	-
		Recurrent/Recanalization	-	-	-	-	12	-	-	-	-	-	-	5.75 (2.13)	-	-	S: 12	-
Wu	2022	Non-Recurrent/no	95	-	-	-	-	-	127	-	-	-	-	≥7: 31	29	98	S: 25	-

		recanalization																
		Recurrent/Recanalization	35	-	-	-	-	-	45	-	-	-	-	≥7: 19	19	26	S: 18	-
Kim	2021	Non-Recurrent/no recanalization	31	-	-	-	-	-	ALL Pcom		-	-	-	-	-	-	-	-
		Recurrent/Recanalization	23	-	-	-	-	-	ALL Pcom		-	-	-	-	-	-	-	-
Ji	2016	Non-Recurrent/no recanalization	0	-	-	-	-	-	-	All Paraclinoid		-	-	6 (3.6)	12	1	-	-
		Recurrent/Recanalization	0	-	-	-	-	-	-	All Paraclinoid		-	-	9.9 (6.9)	102	35	-	-
de la Torre	2018	Non-Recurrent/no recanalization	38	-	-	-	-	-	-	-	-	-	-	8.9 (3.5)	-	-	-	-
		Recurrent/Recanalization	18	-	-	-	-	-	-	-	-	-	-	6.2 (2.2)	-	-	-	-
Jeon	2016	Non-Recurrent/no recanalization	-	-	-	-	-	-	-	-	-	-	-	6.3 (2.7)	-	-	-	-
		Recurrent/Recanalization	-	-	-	-	-	-	-	-	-	-	-	6.2 (4.1)	-	-	-	-
Stapelton	2016	Non-Recurrent/no recanalization	7	-	-	-	-	All Basilar	-	-	22	-	3	small: <10; large: >10	-	-	S: 5; E: 17	Bi: 3
		Recurrent/Recanalization	7	-	-	-	-	All Basilar	-	-	12	-	9	small: <10; large: >10	-	-	S: 11; E: 9	Bi: 1
Morga	2020	Non-Recurrent/no recanalization	0	-	17	14	2	5	-	-	-	-	-	5.82 (3.09)	-	-	27	11
		Recurrent/Recanalization	0	-	5	4	1	2	-	-	-	-	-	6.11 (2.84)	-	-	10	2
Ortiz	2008	Non-Recurrent/no recanalization	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

		n																
		Recurrent/Recanalization	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pierot	2022	Non-Recurrent/no recanalization	418	-	-	-	130	-	-	536	-	-	-	<10: 600, ≥10: 66	378	288	204	462
		Recurrent/Recanalization	196	-	-	-	68	-	-	211	-	-	-	<10: 216, ≥10: 63	179	100	65	214
Park	2019	Non-Recurrent/no recanalization	14	-	18	85	8	6	-	10	-	-	-	Mean: 9.5 [8.7; 11.2]	-	-	-	-
		Recurrent/Recanalization	15	-	5	25	5	3	-	6	-	-	-	Mean: 13.1 [10.1 ;16.7]	-	-	-	-
Lecler	2015	Non-Recurrent/no recanalization	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Recurrent/Recanalization	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

ACA = Anterior Cerebral Artery; Acom = Anterior Communicating Artery; ICA = Internal Carotid Artery; MCA = Middle Cerebral Artery; VB = Vertebrobasilar; Pcom = Posterior Communicating Artery; NR = Not Reported; Post. Cir. = Posterior Circulation; Ant = Anterior; S = Saccular; F = Fusiform; E = Embolization; Bi = Bifurcation; T = Thrombosis; SHA = Superior Hypophyseal Artery; V4 = Fourth Segment of Vertebral Artery; Blister = Blister aneurysm; Dissecting = Dissecting aneurysm; Paraclinoid = Region adjacent to the clinoid process.

Supplementary Table 4. Treatment details

Study	Year	Group	Angiographic Follow up duration	Treatment				Raymond-Roy		
				Coil	**Stent-assisted**	**Baloon-assisted**	**Other**	**1**	**2**	**3**
Occlusion										
Chen	2015	Adequate Occlusion	Immediately after EVT	189	52	13	-	254		-
		Incomplete Occlusion		226	37	12	-	-		275
Hussein	2020	Complete Occlusion	6 months	-	Flow diversion stent	-	-	Complete occlusion: 19		
		Incomplete Occlusion		-	Flow diversion stent	-	-	Incomplete occlusion: 12		
Brinjiki	2015	Complete Occlusion	2.4 ± 2.3 years.	371	-	-	-	186	185	-
		Incomplete Occlusion		40	-	-	-	-	-	40
Hanel	2021	Complete Occlusion	12 months	-	-	-	PED	113	-	-
		Incomplete Occlusion		-	-	-	PED	-	25	
Stapelton	2016	Adequate Occlusion	Not specified	18	4	3	-	22		-

		Incomplete Occlusion		20	0	1	-	-	-	24
Salem	2023	Complete Occlusion	16.4 months	-	-	-	PED	Complete occlusion: 257		
		Incomplete Occlusion		-	-	-	PED	Incomplete occlusion: 74		
Rouchaud	2016	Complete Occlusion	28.9 ± 23.7 months	-	-	-	PED	Complete occlusion: 109		
		Incomplete Occlusion		-	-	-	PED	Incomplete occlusion: 36		
Adeeb	2017	Complete Occlusion	19.2 months	-	-	-	PED	Complete occlusion: 297		
		Incomplete Occlusion		-	-	-	PED	Incomplete occlusion: 83		
Hammoud	2024	Complete Occlusion	6 months	57	21	-	clipping: 13, stenting: 2, Wraping: 2	Complete occlusion: 470		
		Incomplete Occlusion		25	11	-	clipping: 3, stenting: 1, Wraping: 1	Incomplete occlusion: 146		
Dabus	2016	Complete Occlusion	6.8 months	28	2	12	-	41	-	-
		Incomplete Occlusion		8	-	5	-	-	11	1
Recurrence/recanalization										
Futchko	2017	Non-Recurrent/no recanalization	Smokers: 1.62 years	60	12	0	-	178	34	12
		Recurrent/recanalization	Non-smokers: 1.72 years	168	54	2	-	36	26	9
Kim	2023	Non-Recurrent/no recanalization	30.5± 29.2 months (range 2–127.8 months	-	21		Sole Stenting: 2; Parent Occlusion: 1; FDS: 5	24	4	
		Recurrent/recanalization		-	3		Sole Stenting: 3; Parent Occlusion: 1; FDS: 0			
Jang	2020	Non-Recurrent/no recanalization	27 months (range 1–110)	all	47		-	147	75	
		Recurrent/recanalization		all	5		-	20	18	
Huang	2017	Non-Recurrent/no recanalization	Follow-up: at least 6 months	all	212		-	-	-	-
		Recurrent/recanalization		all	15		-	-	-	-
Yousef	2020	Non-Recurrent/no recanalization	5.5 months	-	-	-	WEB	-	-	-
		Recurrent/recanalization		-	-	-	WEB	-	-	-
Yuan	2023	Non-Recurrent/no recanalization	6 (4, 7) months	all	-	-	-	80	-	-
		Recurrent/recanalization	6 (4, 10.75) months	all	-	-	-	12	-	-
Wu	2022	Non-Recurrent/no recanalization	11.4 ± 3.9 months	73	54	-	-	101	24	2
		Recurrent/recanalization		34	11	-	-	19	16	10
Kim	2021	Non-Recurrent/no recanalization	27.7 months (range: 3.5–78.6)	all	54		-	76	42	
		Recurrent/recanalization		all	15		-	24	29	
Ji	2016	Non-Recurrent/no recanalization	7.4±2.8 months	all	117		FD: 5	93	42	2

		Recurrent/recanalization		all	11		FD: 0	1	9	3
de la Torre	2018	Non-Recurrent/no recanalization	30 months	69	1		WEB: 1; WEB+Stent: 1	32	36	3
		Recurrent/recanalization		22	0		WEB: 3	7	13	5
Jeon	2016	Non-Recurrent/no recanalization	24.8 ± 8.2 months	bioactive coil (>50%): 13	16	4	-	33		8
		Recurrent/recanalization		bioactive coil (>50%): 7	3	4	-	21		3
Stapelton	2016	Non-Recurrent/no recanalization	Not reported	19	5	1		13	4	8
		Recurrent/recanalization		19	2	0		1	4	16
Morga	2020	Non-Recurrent/no recanalization	6 months	all	-	-	-	-	-	-
		Recurrent/recanalization		all	-	-	-	-	-	-
Ortiz	2008	Non-Recurrent/no recanalization	24 months (range 18–30 months)	all	-	-	-	-	-	-
		Recurrent/recanalization		all	-	-	-	-	-	-
Pierot	2022	Non-Recurrent/no recanalization	12.6±3.9 months.	367	-	299	-	368	298	
		Recurrent/recanalization		149	-	130	-	179	100	
Park	2019	Non-Recurrent/no recanalization	48.0 months [24.0-51.5]	85	42			92	35	
		Recurrent/recanalization	32.0 months[18.5-48.0]	34	10	-	-	19	25	
Lecler	2015	Non-Recurrent/no recanalization	more than 10 years	201	-	8	-	-	-	-
		Recurrent/recanalization			-		-	-	-	-

PED = Pipeline Embolization Device; FDS = Flow Diversion Stent; WEB = Woven EndoBridge; NR = Not

Supplementary Table 5a. The Newcastle-Ottawa Scale for assessing the quality of the included studies

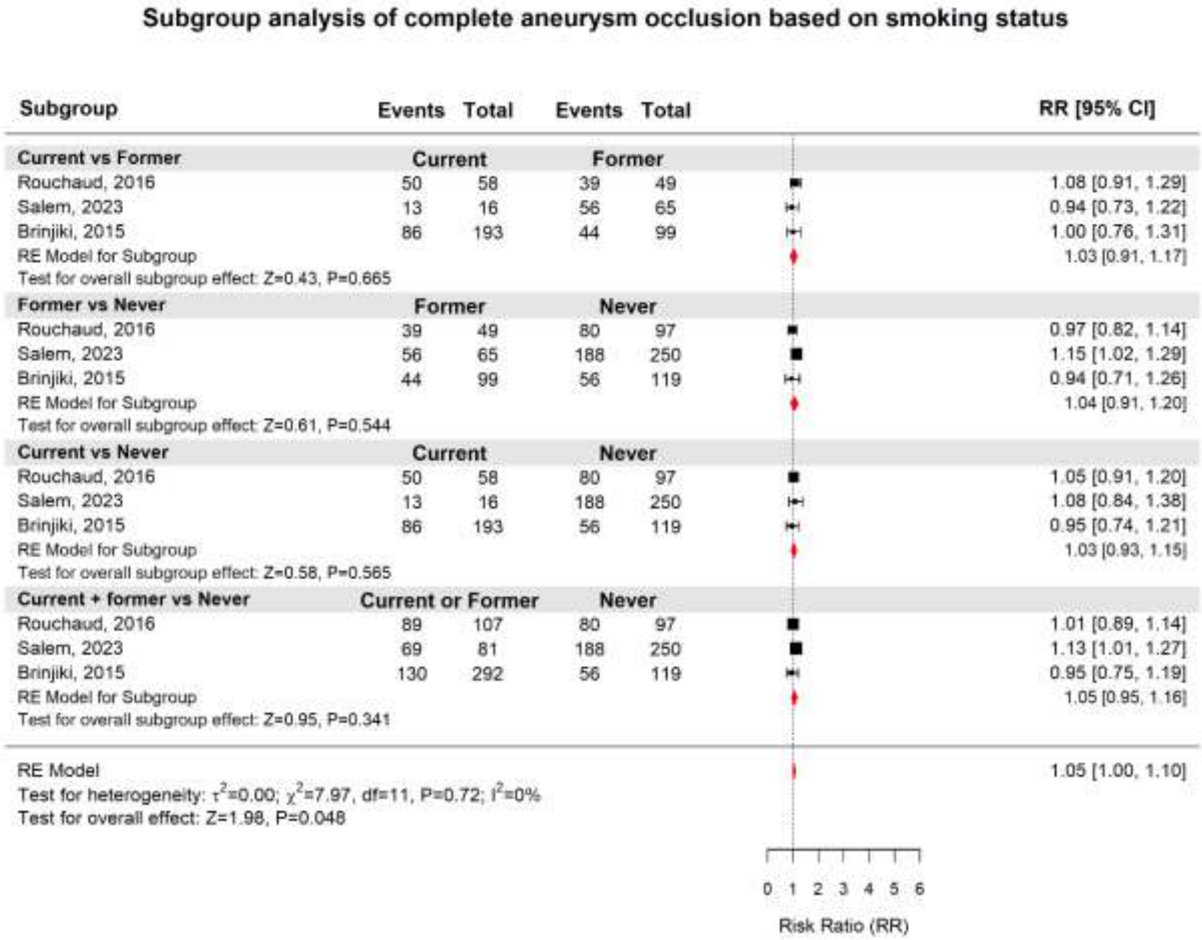
Study	Selection 1	Selection 2	Selection 3	Selection 4	Comparability	Outcome 1	Outcome 2	Outcome 3	Total
Adeeb	*	*	*	*	**	*	*	*	9
Brinjikji	*	-	*	*	**	*	*	*	8
Chen	*	-	*	*	**	*	*	*	8
de la Torre	*	-	*	*	**	*	*	*	8
Futchko	*	-	*	*	**	*	*	*	8
Hammoud	*	*	*	*	-	*	*	*	7
Hanel	-	-	*	*	**	*	*	*	7
Huang	*	-	*	*	**	*	*	*	8
Hussein	*	-	*	*	-	*	*	*	6
Jang	*	*	*	*	**	*	*	*	9
Jeon	*	-	*	*	**	*	*	*	8
Ji	*	-	*	*	**	*	*	*	8
Kim 2021	*	-	*	*	**	*	*	*	8
Kim 2023	*	-	*	*	-	*	*	*	6
Morga	*	-	*	*	-	*	*	*	6
Ortiz	*	-	*	*	**	*	*	*	8
Pierot	*	*	*	*	**	*	*	*	9
Rouchaud	*	*	*	*	**	*	*	*	9

Salem	*	-	*	*	**	*	*	*	8
Stapelton	*	-	*	*	**	*	*	*	8
Wu	*	*	*	*	**	*	*	*	9
Yousef	*	*	*	*	-	*	-	*	6
Yuan	*	-	*	*	-	*	*	*	6
Park	*	*	*	*	**	*	*	*	9
Lecler	*	-	*	*	**	*	*	*	8

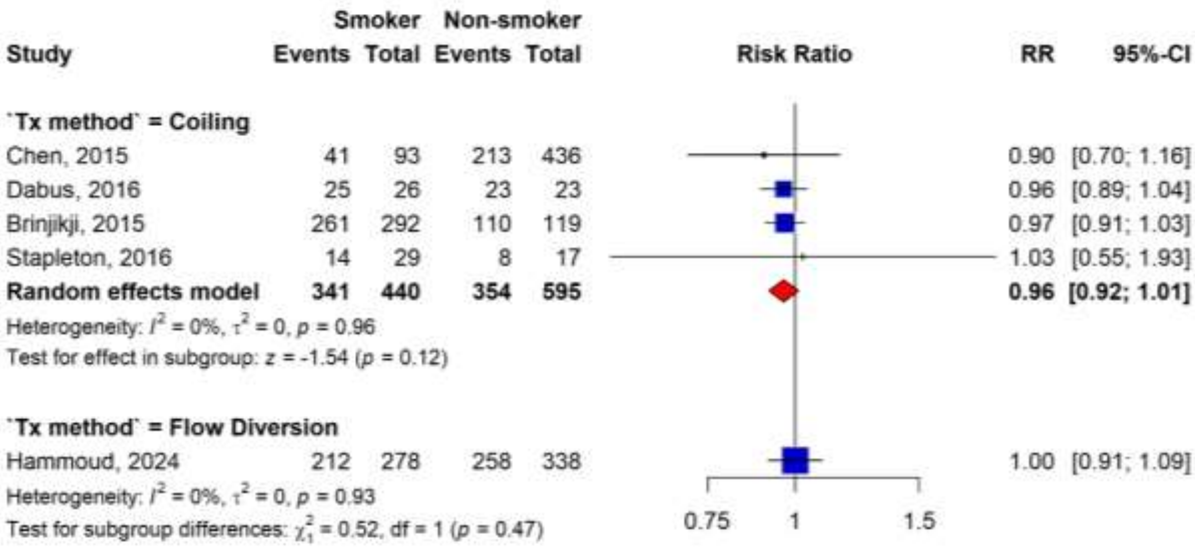
Supplementary Table 5b. JBI Critical Appraisal Checklist for Case Series

Study	1	2	3	4	5	6	7	8	9	10	Total
Dabus	Yes	Unclear	Unclear	Yes	Yes	Yes	Yes	Yes	Yes	Yes	8

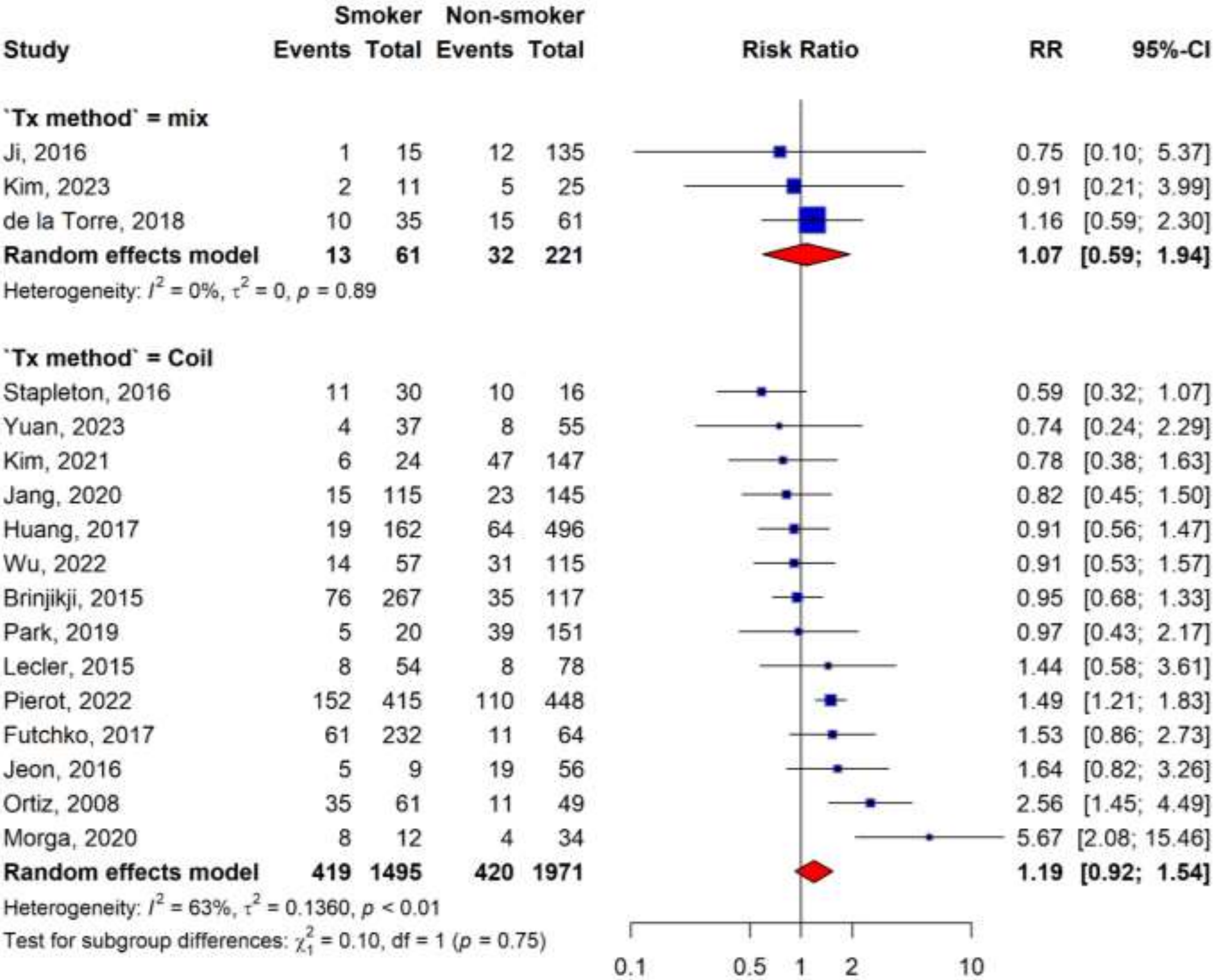
Supplementary Figure 1. Subgroup analysis of complete occlusion rate based on smoking status



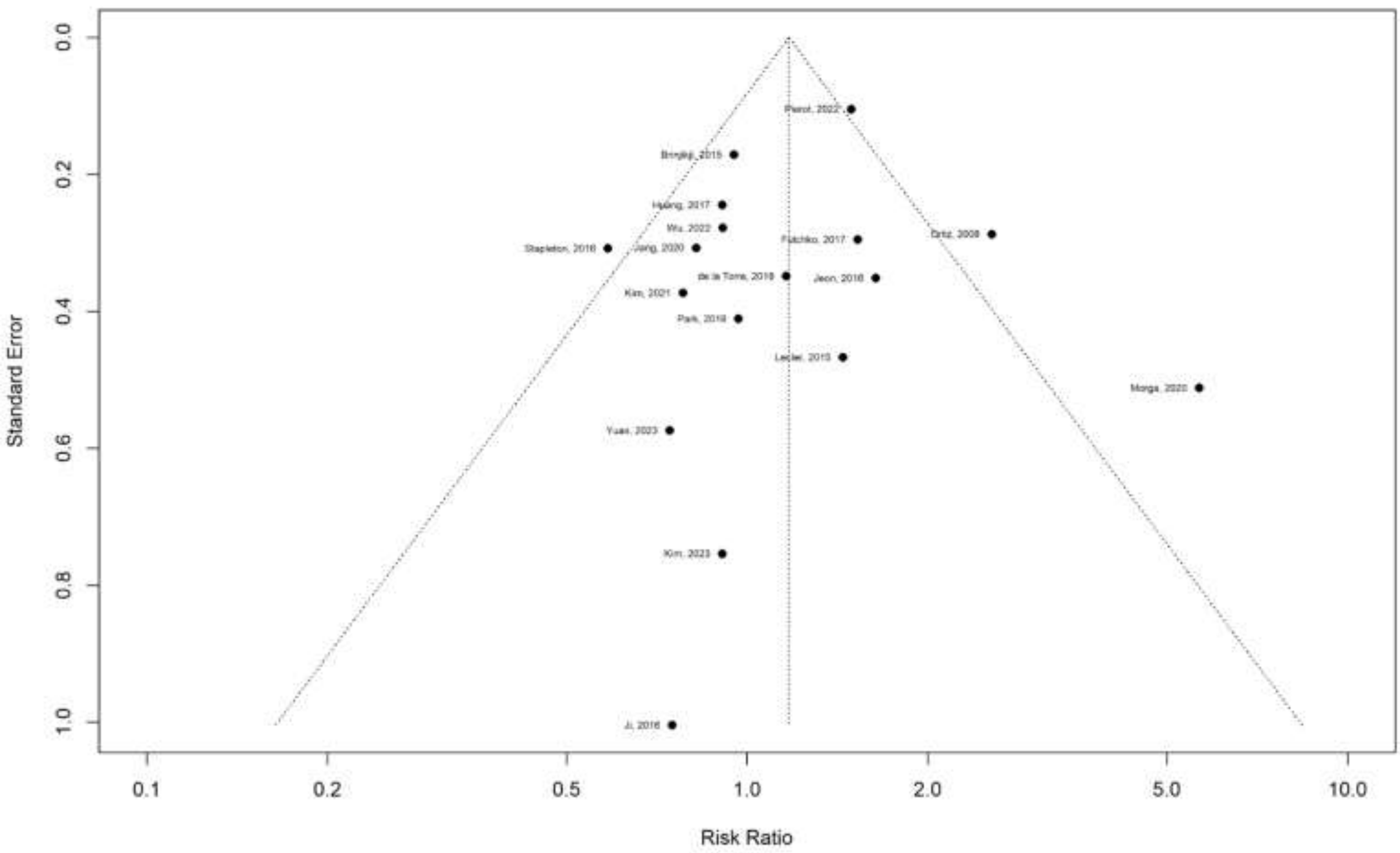
Supplementary Figure 2. Subgroup analysis of adequate occlusion rate based on treatment method



Supplementary Figure 3. Subgroup analysis of aneurysm recurrence/recanalization rate based on treatment



Supplementary Figure 4. Funnel plot of aneurysm recurrence/recanalization rate



Supplementary Table 6. Meta-regression of the effect of different factors on aneurysm recanalization/recurrence among studies. None of the evaluated factors was significant.

Recanalization/Recurrence rate	Tau^2	I^2	H^2	P value for moderator
Ruptured,%	0.1	60.1	2.5	0.3
Female,%	0.1	67.3	3.0	0.6
Age, mean	0.2	64.3	2.7	0.7
Mean follow up time, days	0.7	75.9	4.1	0.9
Aneurysm diameter, mm	0.2	60.7	2.5	0.5
Posterior circulation,%	0.07	43.1	1.7	0.1
Publication year	0.1	60.4	4.8	0.2
Hypertension,%	0.1	43.0	1.76	0.2

Supplementary Table 7. Definition of Recanalization or Recurrence by Studies

Study	**Recanalization or Recurrence definition**
Kim, 2021	Recanalization was defined as new or increased contrast filling of an aneurysm with or without aneurysm growth.
Ji, 2016	Recanalization was defined as any aneurysm remnant that had increased in size or contrast filling.
Wu, 2021	Those aneurysms appeared again while complete occlusion after 3month and/or residual aneurysm size had increased after incomplete occlusion were regard as recurrent aneurysm
Brinjikji, 2015	Aneurysm recurrence was defined as coil compaction, recanalization, or both.
Jeon, 2016	Recanalization was defined as contrast filling the aneurysm neck (minor recanalization) or dome (major recanalization) at follow-up imaging
Stapleton, 2016	Recanalization, or recurrence, was defined as an increase in opacification of the neck or dome of the aneurysm at the time of first and/or last angiographic follow-up as compared with the initial post-treatment cerebral angiogram
Morga, 2020	Each enlargement of the inflow of the aneurysm to the embolized aneurysm described by the radiologist was considered a recanalization
Ortiz, 2008	Aneurysm recanalization or regrowth was defined as an increase in inflow to the aneurysm in comparison with baseline
Pierot, 2022	Recanalization was defined as any increase of aneurysm contrast filling as depicted by the data coordinating center when directly comparing postoperative DSA and follow–up vascular imaging.
Futchko, 2017	Aneurysm recurrence was defined as inflow into a previously completely occluded aneurysm or growth of an incompletely occluded aneurysm (aneurysm recanalization)
Kim, 2023	Recurrence was defined as an increase in aneurysm contrast filling or shortened stasis, stabilization, unchanged volume of aneurysm filling
Jang, 2020	Recurrence was defined as any progression of Raymond-Roy class or increasing of aneurysmal flow.
Huang, 2017	Recurrence was defined as: Loosened or compressed spring coil, or contrast materials filling in the body or neck of the intracranial saccular aneurysm, which was not observed on the immediate postoperative angiogram, when compared with the immediate postoperative angiographic results.
Lecler, 2015	Increase in Raymond Ray Occlusion classification at long-term follow up.
Park, 2019	Recurrence was defined as coil compaction, recanalization through the coil mesh, aneurysm regrowth or neck enlargement.
Yousef, 2020	No definition is provided
Yuan, 2023	No definition is provided

de la Torre, 2018	No definition is provided

Supplementary Table 8. Definition of aneurysm occlusion by studies

Study	**Complete occlusion**	**Incomplete occlusion**
Dabus, 2016	Complete occlusion (RR I)	Residual neck or residual aneurysm (RR>1)
Brinjikji, 2015	Complete occlusion (RR I)	Residual neck or residual aneurysm (RR>1)
Hanel, 2021	Complete occlusion (RR I)	Residual neck or residual aneurysm (RR>1)
Stapleton, 2016*	Complete occlusion or neck remnant (RR I or RR II)	Residual neck and partial remnant (RR III)
Chen, 2015*	Complete occlusion or neck remnant (RR I or RR II)	Residual neck and partial remnant (RR III)
Salem, 2023	Aneurysmal occlusion was classified into 3 categories: complete occlusion (100%), near complete occlusion (90–100%)	Both near-complete and partial occlusion were collectively defined as incomplete occlusion.
Adeeb, 2017	Occlusion was categorized as complete occlusion (100%), near-complete occlusion (90%–100%), and partial occlusion (<90%).	Both near-complete and partial occlusion were collectively defined as incomplete occlusion.
Rouchaud, 2016	Clinical assessment of follow up angiography	Clinical assessment of follow up angiography
Hammoud, 2024	Clinical assessment of follow up angiography	Clinical assessment of follow up angiography
Hussein, 2020	Clinical assessment of follow up angiography	Clinical assessment of follow up angiography
* These studies only provided details for adequate occlusion (not complete occlusion). RR: Raymond Roy Occlusion Classification		