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Endovascular *Versus* Microsurgical Treatment of Complex Intracranial Aneurysms: A Systematic Review of Occlusion Rates, Functional Outcomes, and Complications

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1. Abstract

1.1. Background: Complex intracranial aneurysms (giant, wide-necked, fusiform, dissecting, blood blister-like, thrombosed, and recurrent) pose substantial risks of rupture and treatment-related morbidity. Comparative evidence between endovascular and microsurgical approaches for this heterogeneous group remains limited.

1.2. Methods: A PRISMA 2020-compliant systematic review with a PROSPERO-registered protocol was conducted. PubMed and Google Scholar were searched for studies published between January 2000 and January 2026. Eligible studies included adults with complex intracranial aneurysms treated by endovascular or microsurgical methods and reporting at least one outcome of interest (angiographic occlusion, functional outcomes, complications, mortality, retreatment). Methodological quality was assessed using the Newcastle-Ottawa Scale. Findings were synthesized narratively due to heterogeneity.

1.3. Results: Forty studies involving approximately 7,231 patients from 18 countries were included. Microsurgical approaches achieved higher occlusion rates (93-94%) than endovascular techniques (72-75%). In comparative studies, microsurgery was associated with significantly greater complete occlusion and lower retreatment rates (0-3.5% *vs* 7-23%). Endovascular treatment showed fewer periprocedural complications and superior short-term functional outcomes, particularly in ruptured aneurysms. Mortality varied widely (0-24.3%) with no consistent difference between modalities.

1.4. Conclusion: Microsurgical treatment offers more durable aneurysm occlusion and lower retreatment rates, whereas endovascular therapy provides a better periprocedural safety profile and improved short-term recovery, especially in ruptured cases. Treatment should be individualized based on aneurysm characteristics, patient factors, and institutional expertise. Prospective comparative studies stratified by aneurysm subtype are needed.

2. Introduction

Intracranial aneurysms are focal dilatations of the cerebral vessels whose development is driven by hemodynamic stress and vascular wall degeneration [1]. This structural vulnerability is worsened by modifiable risk factors such as chronic hypertension and smoking, as well as genetic predispositions [2]. Most aneurysms remain asymptomatic; however, rupture results in Aneurysmal Subarachnoid Haemorrhage (SAH), a life-threatening event associated with increased morbidity and mortality [3]. Preventing rupture or securing the aneurysm after haemorrhage therefore forms the basis of cerebrovascular neurosurgical intervention [4].

Historically, treatment of these lesions has centred on two main modalities. Microsurgical clipping, introduced in the early 20th century, was long considered the standard treatment, offering very high rates of complete occlusion and long-term durability [5]. This changed in the 1990s with the introduction of endovascular coiling [6]. This minimally invasive approach was supported by multicentre trials showing favourable short-term outcomes in standard saccular aneurysms [7]. Both approaches have since evolved, and saccular aneurysms are now managed according to established guidelines [8].

Yet this standardisation applies principally to conventional saccular morphology; aneurysms that deviate from this pattern - broadly referred to as complex aneurysms - remain one of the most challenging areas in cerebrovascular neurosurgery. These lesions are characterised by combinations of traits including very large or giant dimensions, wide neck morphology, fusiform or dissecting wall configuration, blood blister-like appearance, intraluminal thrombosis, or documented recurrence following prior treatment [9,10]. Their clinical importance lies not only in the elevated rupture risk associated with untreated lesions, but in the inherent procedural risks of intervention. Both ruptured and unruptured forms present distinct obstacles: in the elective setting, the primary concern is achieving durable aneurysm exclusion while preserving the parent artery and adjacent perforating vessels; in the acute ruptured setting, these demands are further compounded by physiological compromise, vasospasm, and the time-sensitive risk of rebleeding.

Management of complex aneurysms generally falls into two main strategies. Endovascular techniques have expanded over the past two decades and now include flow diversion, stent-assisted coiling, the Woven EndoBridge (WEB) intrasaccular device, and primary coiling, each suited to different morphological and hemodynamic profiles. Flow diversion has demonstrated high rates of complete or near-complete occlusion in large multicentre studies [11], while next-generation technologies have reported promising early feasibility and favourable clinical outcomes in small single-centre cohorts [12]. In the ruptured setting, stent-assisted coiling has demonstrated procedural feasibility, though with increased periprocedural complication rates compared with the elective context [13,14]. Microsurgical techniques remain essential for lesions resistant to endovascular treatment. Direct aneurysm clipping and cerebrovascular bypass - both extracranial-to-intracranial (EC-IC) and intracranial-to-intracranial (IC-IC) - offer highly durable occlusion in carefully selected patients at experienced centres, particularly for giant fusiform aneurysms and wide-necked lesions involving branch vessels [15,16].

Despite the expansion of both endovascular and microsurgical techniques, comparative evidence for complex aneurysms remains limited. Most published studies are single-centre retrospective series focusing on individual devices or surgical techniques without direct comparison between modalities [9,10,12,15]. Where comparative data exist, they are often limited to specific aneurysm locations or morphological subtypes, reducing their applicability to the wider complex aneurysm population [17,18]. No comprehensive systematic review has yet synthesised outcomes across the full morphological spectrum - including giant, wide-necked, fusiform, dissecting, blister, thrombosed, and recurrent aneurysms - to compare endovascular and microsurgical approaches in terms of angiographic occlusion, functional recovery, complication rates, mortality, and retreatment rates. This evidence gap limits the development of a robust comparative framework to guide individualised clinical decision-making in this high-risk population.

This systematic review compares endovascular and microsurgical treatment for complex intracranial aneurysms, focusing on angiographic occlusion, functional neurological recovery, periprocedural complications, mortality, and retreatment rates.

3. Methods

3.1. Protocol and Reporting

This systematic review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement [19]. A pre-specified protocol agreed upon by the six-member team prior to data extraction defined the eligibility criteria, search strategy, outcome measures, and approach to synthesis. The review was registered on PROSPERO before data extraction commenced.

3.2. Eligibility Criteria

Eligibility criteria are summarised in Table 1.

3.3. Search Strategy

A systematic literature search was conducted across PubMed and Google Scholar for studies published between January 2000 and January 2026. Search terms were constructed around five key concepts - complex cerebral aneurysm, giant aneurysm, flow diversion, microsurgical clipping, and endovascular treatment - combined using Boolean operators (AND, OR). Where appropriate, Medical Subject Headings (MeSH) were applied. AI-assisted identification tools were used to support initial scoping, with all candidate studies independently verified against the eligibility criteria by the review team. Additional records were identified by hand-searching the reference lists of all included articles and relevant review papers.

3.5. Study Selection

Study selection was conducted in two stages. Two reviewers independently screened titles and abstracts against the eligibility criteria in the first stage, excluding records clearly not meeting inclusion criteria. Full texts of all remaining records were then retrieved and assessed for eligibility. Discrepancies were resolved through discussion and, where necessary, by referral to the supervising consultant. Only full-text publications were eligible; studies available as abstracts alone were excluded. Reasons for exclusion at the full-text stage were recorded. The PRISMA 2020 flow diagram, summarising the identification, screening, eligibility assessment, and final inclusion process, is presented in Figure 1.

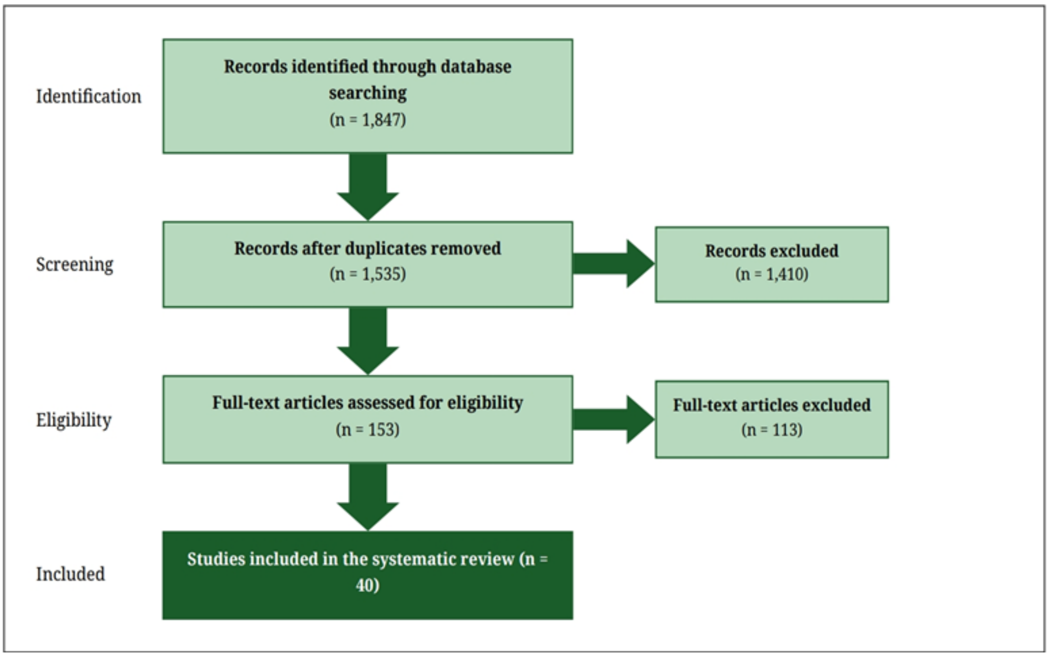

Figure 1: PRISMA flow diagram.

Table 1: Eligibility Criteria - Inclusion and Exclusion.

Inclusion Criteria	Exclusion Criteria
Study Design: Original research including case-control, prospective and retrospective cohort studies, and case series of ≥10 patients	**Aneurysm Type:** Studies reporting exclusively simple saccular or uncomplicated aneurysms without complex features
Population: Adults (≥18 years) with complex intracranial aneurysms (giant ≥25 mm, wide-necked, fusiform, dissecting, blister-like, thrombosed, or recurrent)	**Population:** Studies with exclusively paediatric participants (age <18 years)
Interventions: Studies evaluating endovascular (flow diversion, stent-assisted coiling, WEB device, primary coiling) or microsurgical (clipping, bypass, hybrid) treatment	**Sample Size:** Case series with fewer than 10 patients
Outcomes: Primary: angiographic occlusion (DSA, MRA, or CTA). Secondary: functional outcomes (mRS/GOS), complications, morbidity, or mortality	**Study Type:** Case reports, systematic reviews, meta-analyses, editorials, conference abstracts
Publication: Peer-reviewed, full-text, English-language articles; human subjects; minimum follow-up period reported	**Other:** Non-human/animal studies; non-English and non-full-text publications; studies without original patient-level data

3.6. Data Extraction

Data were extracted from all 40 included studies using a standardised extraction form developed prior to commencing the extraction process. Each reviewer was assigned a set of studies; discrepancies were resolved through independent re-review and group discussion. Where studies reported outcomes at multiple time points, data from the longest available follow-up were used. Where outcomes were stratified by treatment subgroup or rupture status, subgroup-level data were recorded alongside overall figures. Variables extracted included study design, publication year, country, sample size, patient demographics, aneurysm type and rupture status, treatment modality, follow-up duration, angiographic occlusion, functional outcome, complication rate, mortality, and retreatment or recurrence rate.

For angiographic occlusion, the grading scale used in each source study was recorded as reported: the Raymond-Roy Occlusion Classification (RROC) was most commonly applied in endovascular studies, the O'Kelly-Marotta (OKM) scale in flow diverter studies, the WEB Occlusion Scale (WOS) in WEB device studies, and the Sindou or Montreal scales in some microsurgical and comparative studies. Across all scales, complete or near-complete occlusion was treated as a favourable angiographic outcome to allow comparison. Favourable functional outcome was defined as a modified Rankin Scale (mRS) score of 0–2 or a Glasgow Outcome Scale (GOS) score of 4–5 at the last reported follow-up.

3.7. Risk of Bias Assessment

The methodological quality of each included study was assessed using the Newcastle-Ottawa Scale (NOS), which evaluates observational studies across three domains. Studies scoring 8–9 were classified as high quality, moderate quality, and low quality.

3.8. Statistical Analysis

No formal meta-analytic pooling was performed, given the substantial heterogeneity across included studies in terms of patient populations, aneurysm definitions, treatment protocols, follow-up durations, and outcome reporting conventions. Findings were synthesised narratively, structured by treatment modality and outcome category. Where individual comparative studies reported statistical measures - including p-values, Odds Ratios (ORs), and 95% Confidence Intervals (CIs) - these are reported as extracted from the source papers. Approximate descriptive mean outcomes by modality are presented in Table 3 and are not formally pooled meta-analytic estimates.

4. Results

4.1. Study Selection

The database search of PubMed and Google Scholar, supplemented by manual reference list checking, identified 1,847 records in total. After removal of 312 duplicates, 1,535 records were screened by title and abstract, with a further 28 records identified through hand-searching, giving 1,563 records for screening. Of these, 1,410 were excluded at title and abstract stage, predominantly for reporting only simple saccular aneurysms (n=512), wrong study type (n=498), non-English or no full-text available (n=311), or exclusively paediatric populations (n=89). The remaining 153 full-text articles were assessed for eligibility; 113 were excluded for sample size fewer than 10 (n=18), no quantifiable outcome data (n=24), duplicate or overlapping cohort (n=21), uncomplicated aneurysms only (n=35), and published before 2000 (n=15). Forty studies met all eligibility criteria and were included in the review.

4.2. Study Characteristics

Table 2

Table 2: Characteristics of All 40 Included Studies.

Study	Country	Design	n	Mean Age	% Female	Aneurysm Type	Rupture Status	Follow-up
Sun (2025)	China – Single Centre	Retrospective Cohort	29	Mean 57.6±9.2 yrs	55.20%	Saccular, dissecting, wide-necked; giant (mean 18.6×16.2 mm)	Unruptured 100%	12 months
Rodríguez-Fernández (2024)	Spain – Single Centre	Retrospective Cohort	50	Mean 59.5±12.7 yrs	80%	Mixed: saccular, dissecting, fusiform, wide-necked, multilobulated, thrombosed	Ruptured 30% / Unruptured 70%	Min. 12 months
Juan (2025)	China – Single Centre	Retrospective Cohort	72	Mean 54.0±9.4 yrs	61.10%	Mixed: saccular, fusiform, dissecting, blister-like, wide-necked, recurrent	Unruptured 100%	Median ~5.2 months
Aydin (2018)	Turkey – Multi-centre	Retrospective Cohort	40	Mean 52.1±11.4 yrs	62.50%	Wide-necked complex bifurcation	Ruptured 5% / Unruptured 95%	Mean 24.8 months
Aburub (2025)	Germany – Multi-centre	Retrospective Cohort	46	Mean 57.4±13.2 yrs	67.40%	Ruptured wide-neck saccular	Ruptured 100%	38 months
Sadigh (2025)	Netherlands – Single Centre	Retrospective Cohort	20	Median 59 yrs	70%	Mixed complex (bypass series)	Ruptured 50% / Unruptured 50%	Median 13 months
Hofman (2018)	Poland – Single Centre	Retrospective Cohort	354	Mean 54.1±10.8 yrs	76.00%	Complex: giant, wide-neck, unfavourable anatomy	Ruptured 17.5% / Unruptured 82.5%	Min. 6 months
Fukuda (2025)	Japan – Multi-centre	Retrospective Cohort	416	Mean 64.5±13.6 yrs	68%	Ruptured large/giant (≥10 mm) saccular	Ruptured 100%	24–60 months
Kallmes (2015)	International – 17 centres, 6 countries	Retrospective Registry	793	Mean 55.8 yrs	NR	Intracranial aneurysms treated with PED	Ruptured 8.4% / Unruptured 91.6%	Mean 19.3 months
Li (2022)	China	Retrospective Comparative	67	Mean 52±11.3 yrs (FD); 53±9.3 yrs (SAC)	36% (FD); 35.7% (SAC)	Unruptured vertebral artery dissecting	Unruptured 100%	Range 3–58 months
Guo (2022)	China	Retrospective Comparative	114	Range 34–76 yrs	56.6% (FD); 57.4% (SAC)	Wide-necked intracranial	Ruptured: FD 47.2% / SAC 34.4%	NR

Kim (2021)	South Korea	Retro-spective Com-parative	108	Mean 55.6±10.0 yrs	75.90%	Wide-necked	Ruptured 53.7% / Unruptured 46.3%	Mean 58.4±25.1 months
Oel (2013)	Neth-erlands – Single Centre	Retro-spective Case Series	13	Mean 59.7 yrs	46.20%	Dissecting, fusiform, dolichoectatic basilar trunk	Ruptured 23.1% / Unruptured 38.5%	6–72 months
Park (2025)	South Korea – Single Centre	Retro-spective Com-parative	288	WEB: 62.0±8.9 yrs; Clipping: 60.1±8.0 yrs	WEB 67.6% / Clipping 74.1%	Unruptured wide-neck bifurcation (MCA)	Unruptured 100%	12 months
Wu (2025)	China	Retro-spective Com-parative	118	Mean 54.2 yrs (range 18–80)	74.60%	Small/medium wide-neck saccular	Ruptured 16.3% / Unruptured 83.7%	Mean 11.5 months
Kranawetter (2025)	Germany – Multi-centre	Retro-spective Cohort	87	Range 29–90 yrs	60.90%	Ruptured wide-neck	Ruptured 100%	Mean 22.7 months
Goertz (2024)	Germa-ny – 3 centres	Retro-spective Cohort	319	Mean 59.2±11.5 yrs	71.20%	Wide-necked (WEB series); anterior 66%, posterior 34%	Ruptured 26.9% / Unruptured 73.1%	Mid-term mean 5.7 months; long-term mean 21.4 months
Stroh-Holly (2024)	Austria – Single Centre	Retro-spective Cohort	272	Mean 55.1±10.4 yrs	72.10%	Unruptured wide-neck MCA bifurca-tion	Unruptured 100%	Mean 11.4 months (DSA); mean 3.9 yrs (clinical)
Sitthimongkon (2026)	Thailand – Single Centre	Retro-spective Cohort	189	Range 18–81 yrs	66.10%	Ruptured wide-neck	Ruptured 100%	12 months
Yang (2024)	Northern China – 32 centres	Retro-spective Cohort	893	Range 23–81 yrs	47.40%	Ruptured AComA wide-neck	Ruptured 100%	24 months
Swiatek (2025)	Germany – Single Centre	Retro-spective Cohort	140	Mean 54.3 yrs	62.50%	AComA wide-neck (ruptured 79.2%)	Ruptured 79.2% / Unruptured 20.8%	Mean 22.5 months
Toader (2024)	Romania – Multi-centre	Retro-spective Cohort	346	Range 21–82 yrs	NR	Wide-neck mixed	Ruptured 89.3% / Unruptured 10.7%	12 months
Huang (2025)	China – Single Centre	Retro-spective Cohort	30	Mean 65 yrs	33.30%	Basilar artery (giant/ saccular)	Unruptured 100%	Mean 12.9 months
Ashouri (2026)	USA – Mul-ticentre (prospec-tive)	Pro-spective Cohort	133	Range 20–87 yrs	70.70%	Saccular 75.9%, fusi-form 8.3%, dissecting 3.8%	Ruptured 32.3% / Unruptured 67.7%	Mean 9.5 months
Lejeune (2024)	France – Single Centre	Large Case Series	60	Mean 45 yrs (range 26–65)	71%	Recurrent (post-en-dovascular)	Ruptured 8.3% / Unruptured 91.7%	1 yr; then every 3 yrs
Sughrue (2011)	USA – Single Centre	Retro-spective Cohort	140	Mean 54 yrs	64%	Giant (≥25 mm); thrombosed, fusi-form, wide-neck, recurrent	Ruptured 16% / Unruptured 84%	Mean 23±1.9 months
Grandhi (2024)	Multina-tional – 17 centres	Retro-spective Cohort	63	Median 61 yrs	68.30%	Giant (≥25 mm); sac-cular 69.8%, fusiform 30.2%	Ruptured 3.2% / Unruptured 96.8%	Median 22.4 months

Chalouhi (2013)	USA – Single Centre	Retro-spective Cohort	508	Mean 55.2±11.9 yrs	84.60%	Mixed wide-neck; recurrent; fusiform/ dissecting/blister	Ruptured 9.3% / Unruptured 90.7%	Mean 26±10.1 months
Piotin (2010)	France – Single Centre	Retro-spective Cohort	1137	SAC 51.1±12.0 yrs; non-stented 49.7±12.8 yrs	SAC 75.5% / Non-stent-ed 67.3%	All saccular (sidewall and bifurcation)	SAC rup-tured 16.2%; Non-stented ruptured 49.5%	SAC mean 14 months; non-stented mean 22 months
Wakhloo (2008)	USA – Multisite	Retro-spective Cohort	28	Mean 52.6 yrs (range 29–75)	71.40%	Fusiform: dissecting 70%, atherosclerotic 30%	Ruptured 13.3% / Unruptured 86.7%	Mean 16.2 months an-giographic
Balaji (2019)	India – Single Centre	Retro-spective Cohort	52	Mean 66.1 yrs (range 41–88)	65.40%	Large (>10 mm) and giant (>25 mm); anterior 78.8%, pos-terior 21.2%	Ruptured 5.8% / Unruptured 94.2%	3–6 months (GOS at discharge)
Acerbi (2022)	Italy – Single Centre	Retro-spective Cohort	23	Range 19–75 yrs	73.90%	Giant (≥25 mm); fu-siform; thrombosed; recurrent	Ruptured 17.4% / Unruptured 82.6%	Mean 28 months (range 3–84)
Sebök (2021)	Swit-zerland – Single Centre	Retro-spective Cohort	156	Mean 51.7±11.0 yrs	73.70%	Mixed UIAs: sac-cular, giant, para-clinoidal, fusiform, previously treated; 25% complex	Unruptured 100%	3 months (clinical)
Sevgi (2025)	USA – Single Surgeon Series	Retro-spective Cohort	127	Mean 57.9±12.9 yrs	63%	Large (10–24 mm) and giant (≥25 mm)	Ruptured 45.7% / Unruptured 54.3%	Median 19 months
Rennert (2023)	USA – Single Centre	Case Series	10	Mean 51.9±8.7 yrs	60%	Fusiform; dissecting; blister; recurrent	Ruptured 90% / Unruptured 10%	Median 14 months (range 4–72)
Kendirlioglu (2026)	USA – Single Centre	Retro-spective Cohort	313	MS 57.0±11.5 yrs; EV 57.9±12.0 yrs	MS 48.2% / EV 61.2%	Saccular AComA; predominantly small–medium sized	Ruptured 67.5% (MS 59.6%; EV 76.2%)	MS 56.6±50.7 months; EV 59.4±44.7 months
Tan (2023)	China – Single Centre	Retro-spective Cohort	72	MS 45.2±11.7 yrs; EV 44.8±11.1 yrs	59.70%	Blood blister-like (BBA)	Ruptured 100%	Follow-up not stated
Rodri-guez-Calienes (2024)	Interna-tional – 4 centres (USA, Turkey)	Retro-spective Cohort	217	Median 56 yrs (IQR 48–65)	65%	Wide-necked rup-tured	Ruptured 100%	WEB median 10 months; SAC median 14.7 months
Barbarawi (2025)	Jordan – Single Centre	Retro-spective Cohort	54	Mean 46.9 yrs (range 33–68)	52%	Giant (≥25 mm) and large (≥10 mm)	Ruptured ~3% / Unruptured ~97%	Not formally stated
Gurpinar (2026)	Turkey – Single Centre	Retro-spective Cohort	68	Mean 52.1±11.0 yrs (range 31–78)	64.70%	Residual/recurrent (post-surgical clip-ping or wrapping)	Ruptured at initial sur-gery 55.9%	Primary 12 months; mean overall ~48 months

4.3. Endovascular Treatment Outcomes

Twenty-eight studies reported outcomes for endovascular treatment, encompassing flow diversion (n=11 studies), stent-assisted coiling (n=13), and the WEB intrasaccular device (n=3 dedicated cohorts: Goertz, 2024; Rodriguez-Calienes, 2024; Park, 2025). Several studies evaluated more than one endovascular modality.

Occlusion rates varied by device and follow-up duration.

Among flow diversion studies, complete or adequate occlusion at 12 months ranged from 53.3% (Huang, 2025) to 86.2% (Sun, 2025). Rodríguez-Fernández (2024) reported OKM Grade D occlusion in 66% at 12 months using the Silk Vista Baby device, while Juan (2025) reported 71.4% OKM Grade D occlusion using the Tubridge device [9]. The largest endovascular study, Kallmes (2015), enrolled 793 PED-treated patients across 17 international centres and reported a spontaneous rupture rate of 0.6% overall and 4.5% in giant aneurysms [11]. For stent-assisted coiling, Chalouhi (2013) reported 87.5% immediate complete occlusion in 508 aneurysms with 13.2% recanalization at mean 26 months [39], while Piotin (2010) found immediate complete occlusion in 46.3% of the stent-assisted group with recanalization in 14.9% *versus* 33.3% in the coiling-alone group (p=0.008) [40]. Kim (2021) reported 61.1% complete occlusion at a mean follow-up of 58 months, with 22.8% recurrence [23]. Goertz (2024), the largest dedicated WEB cohort (n=319), reported 60.6% complete occlusion at mid-term (mean 5.7 months) and 81.9% adequate occlusion; Rodriguez-Calienes (2024) found comparable complete occlusion between stent-assisted coiling (64.5%) and WEB (60.9%) in ruptured wide-neck aneurysms (p=0.328) [49]. Across all 28 endovascular studies, the approximate mean occlusion rate was ~72% for flow diversion and ~75% for stent-assisted coiling.

Favourable functional outcome (mRS 0–2) was reported in 85.5% of patients in the Yang (2024) endovascular group at two years [31], 92.2% in the Ashouri (2026) cohort at one year [35], and 94.6% in the Tan (2023) endovascular group [48]. The Goertz (2024) WEB cohort reported 98.3% mRS 0–2 in unruptured patients, falling to 55.2% in ruptured presentations [28]. Periprocedural complication rates ranged from 3.6% in the Wu (2025) stent-assisted coiling group [26] to 30.8% in the Oel (2013) fusiform basilar trunk series [24]. Procedure-related mortality was generally low: Goertz (2024) reported 1.9% [28]; Kallmes (2015) reported 3.8% neurological mortality [11]. Aburub (2025), treating ruptured wide-neck aneurysms, reported 15.2% overall in-hospital mortality, predominantly in the stent-assisted coiling subgroup, with the flow diversion subgroup recording 0% periprocedural complications [14]. Retreatment was noted in a subset of studies: Chalouhi (2013) found 13.2% recanalization [39]; Goertz (2024) 7.1% mid-term retreatment [28]; and Ashouri (2026) 11.5% in the large-angled aneurysm subgroup [35].

4.4. Microsurgical Treatment Outcomes

Nineteen studies reported outcomes for microsurgical treatment, encompassing clipping (n=13 studies), bypass (n=4), and hybrid combined approaches (n=2). Microsurgical clipping consistently achieved high rates of complete aneurysm occlusion. Stroh-Holly (2024) reported 99.3% complete occlusion in 272 unruptured MCA aneurysms at a mean follow-up of 3.9 years [29]; Sitthimongkon (2026) reported 98.4% in 189 patients [30]; Kendirlioglu (2026) demonstrated 98.2% with microsurgery compared with 38.1% for endovascular treatment in the same cohort (p<0.001) [47]. Sevgi (2025) reported 94.5% across 127 patients with large and giant aneurysms [45]. For bypass procedures, complete occlusion or aneurysm exclusion was achieved in 100% of cases in the Sadigh (2025) and Rennert (2023) series [15,46] and in 95.6% in the Acerbi (2022) bypass series [43]. Sughrue (2011), reporting on 140 giant aneurysms using hybrid surgical approaches, found 77% complete occlusion [37]. Lejeune (2024), treating 60 recurrent aneurysms following prior endovascular failure, achieved 88% complete occlusion with 1.7% retreatment [36]. Across all 19 microsurgical studies, the approximate mean occlusion rate was 93–94%.

Favourable functional outcome varied by aneurysm complexity and rupture status. Stroh-Holly (2024) reported 99.3% mRS 0–2 in their unruptured MCA clipping series [29]; Sitthimongkon (2026) reported 74.6% in the ruptured cohort [30]; Balaji (2019) reported 98.1% GOS 4–5 at discharge in a predominantly unruptured series [42]. Yang (2024) found 75.6% favourable outcome for microsurgery *versus* 85.5% for endovascular treatment at two years (OR=1.89, p=0.005) [31]. Tan (2023) reported 28.6% mRS 0–2 for microsurgery *versus* 72.7% endovascularly in ruptured blood blister-like aneurysms (p<0.001) [48]. Complication rates reflected the heterogeneity of aneurysm complexity, technique, and rupture status. Stroh-Holly (2024) reported 2.2% permanent neurological deficit in the unruptured clipping series [29]; Swiatek (2025) found a higher ischaemic complication rate in the surgical group (54.2% *versus* 8.3%; p=0.007), though functional outcomes were comparable [32]. Sughrue (2011) reported bypass-related complications in 13% of bypass procedures [37]. Mortality ranged from 0% in elective series [42,46] to 24.3% in the high-acuity mixed cohort of Toader (2024) [33]. Retreatment rates after microsurgical treatment were low across series: Stroh-Holly (2024) 0.7% [29], Kendirlioglu (2026) 0% [47], and Lejeune (2024) 1.7% [36].

4.5. Direct Comparative Studies

Six studies directly compared endovascular and microsurgical outcomes within the same cohort and are summarised in Table 3. Kendirlioglu (2026), the largest comparative study (n=313), demonstrated significantly higher complete occlusion with microsurgery (98.2% *versus* 38.1%, p<0.001) and zero retreatment *versus* 15.6% endovascularly (p<0.001), with no significant difference in functional outcome at any time point (p>0.05) [47]. Yang (2024) used propensity score matching across 32 Chinese centres and found endovascular treatment associated with lower complication rates (OR=0.62, p=0.044), lower two-year mortality (OR=0.54, p=0.023), and better functional outcome (OR=1.89, p=0.005) [31]. Swiatek (2025) found that surgical treatment achieved higher complete occlusion (p=0.007) while functional outcomes, mortality, hydrocephalus, vasospasm, and delayed cerebral ischaemia were all comparable between groups (p>0.999 for all) [32]. Fukuda (2025), using the Japanese POST. SAH registry (n=416), found endovascular treatment associated with lower periprocedural complications (OR=0.49, p=0.045) and better functional outcomes (OR=1.56, p=0.03), but significantly higher rebleeding (6.2% *versus* 0%, p=0.008) and retreatment (13.7% *versus* 1.5%) [18]. Tan (2023) found significantly better functional outcomes and lower mortality with endovascular treatment in ruptured blood blister-like aneurysms (mRS 0–2: 72.7% *versus* 28.6%, p<0.001; mortality: 11.4% *versus* 32.1%, p=0.035) [48]. Barbarawi (2025) identified age as a significant predictor of occlusion (p=0.019) but did not report formal p-values for the surgical *versus* endovascular comparison [50].

Table 3: Direct Comparative Studies - Endovascular versus Microsurgical Treatment.

Study	Aneurysm Subtype	Occlusion (EV *vs* MS)	Functional Outcome (mRS 0–2)	Complication Rate	Mortality	Statistical Significance
Kendirlioglu (2026)	AComA saccular (n=313)	EV 38.1% *vs* MS 98.2%	MS 83.8% *vs* EV 75.0% (ruptured); no significant difference	MS: higher seizures and craniectomy; EV: higher post-treatment haemorrhage	MS 7.1% *vs* EV 11.6% (p=0.262)	Occlusion p<0.001; retreatment p<0.001; functional outcome p>0.05
Yang (2024)	Ruptured AComA (n=893)	MS 95.3% *vs* EV (NR)	EV 85.5% *vs* MS 75.6% (OR=1.89, p=0.005)	EV lower (OR=0.62, p=0.044)	EV lower (OR=0.54, p=0.023)	Functional outcome p=0.005; mortality p=0.023; complications p=0.044
Fukuda (2025)	Ruptured large/giant ≥10 mm (n=416)	NR (MS higher)	EV superior (OR=1.56, p=0.03)	EV lower (OR=0.49, p=0.045)	Not separately reported	Complications p=0.045; outcome p=0.03; rebleeding p=0.008
Swiatek (2025)	AComA wide-neck (n=140)	MS 95.8% *vs* EV – higher residual (p=0.007)	Comparable (p>0.999)	MS ischaemic 54.2% *vs* EV 8.3% (p=0.007)	No significant difference (p>0.999)	Occlusion p=0.007; all other outcomes p>0.999
Tan (2023)	Blood blister-like, ruptured (n=72)	EV recurrence 12.2% vs MS 37.0%	EV 72.7% *vs* MS 28.6% (p<0.001)	Both groups: high intraop haemorrhage and infarction	MS 32.1% *vs* EV 11.4% (p=0.035)	Functional outcome p<0.001; mortality p=0.035
Barbarawi (2025)	Giant/large ≥10 mm (n=54)	2 reoperations; rate NR	70.4% overall; posterior 33.3%	Described narratively	11.1%; posterior 28.6%	Age vs occlusion p=0.019; no formal modality comparison

4.6. Summary of Outcomes by Treatment Modality

Table 4 presents approximate mean outcomes by treatment modality across all 40 included studies. These descriptive figures are not formally pooled meta-analytic estimates and are intended to facilitate a comparative overview of the available evidence.

Table 4: Summary of Outcomes by Treatment Modality.

Treatment Modality	Studies (n)	Occlusion Rate	Complication Rate	Mortality Rate	Retreatment / Recurrence	Functional Outcome (mRS 0–2 or GOS 4–5)
Flow Diversion	11	~72% (range 53–86%)	~10% (range 0–23%)	~4% (range 0–11%)	7–17% mid-term recurrence	≥80% in unruptured; lower in ruptured
Stent-Assisted Coiling	13	~75% (range 46–88%)	~10% (range 4–25%)	~6% (range 0–22%)	13–23% recanalization	Generally favourable in unruptured
WEB Device	3 cohorts	60–76% adequate occlusion	~5–10%	~2–5%	7–17% mid-term retreatment	≥97% unruptured; ~55% ruptured
Microsurgical Clipping	13	~94% (range 88–99%)	~12% (range 2–54%)	~9% (range 0–24%)	0–3.5% retreatment	Variable by rupture status
Bypass (Surgical)	6	~94–100%	~15% (range 13–17%)	~5% (range 0–9%)	Not formally reported	87–100% at last follow-up
Hybrid Approaches	4	~85% (range 77–96%)	~15%	~9%	~3.5%	60–87%
All Endovascular (pooled)	28	~72–75%	~11%	~5%	Higher than surgical	Favourable in unruptured
All Microsurgical (pooled)	20	~93–94%	~13%	~8–9%	~0–3.5%	Variable; rupture-dependent

5. Discussion

5.1. Main Findings

This systematic review synthesised evidence from 40 observational studies enrolling approximately 7,231 patients across 18 countries to compare endovascular and microsurgical approaches for the treatment of complex intracranial aneurysms. Three interrelated findings emerge from this synthesis. First, microsurgical treatment - whether by direct clipping, cerebrovascular bypass, or hybrid combined approaches - consistently achieved higher rates of definitive angiographic occlusion than endovascular approaches, with approximate mean rates of 93–94% *versus* 72–75% respectively. Second, endovascular treatment was associated with lower periprocedural complication rates and, in comparative studies involving ruptured aneurysms, with better short-term functional outcomes. Third, the two modalities were not mutually exclusive in their optimal patient populations: endovascular approaches performed better in patients with acute subarachnoid haemorrhage and unfavourable surgical anatomy, while microsurgical techniques provided more durable occlusion in the elective setting and for morphologies not amenable to endovascular reconstruction.

The occlusion advantage of microsurgical clipping was most clearly demonstrated by Kendirlioglu (2026), who reported complete occlusion in 98.2% of surgically treated anterior communicating artery aneurysms compared with 38.1% in the endovascular group (p<0.001), with zero retreatment *versus* 15.6% endovascularly (p<0.001) [47]. This was corroborated across multiple single-arm clipping series: Stroh-Holly (2024) reported 99.3% complete occlusion at a mean follow-up of 3.9 years in 272 unruptured MCA aneurysms [29], and Sitthimongkon (2026) reported 98.4% across 189 consecutively clipped aneurysms [30]. Among bypass series, Sadigh (2025) and Rennert (2023) reported 100% bypass patency at last follow-up [15,46], and Acerbi (2022) achieved 95.6% occlusion in 23 complex anterior circulation aneurysms [43].

Nevertheless, the picture changes considerably when functional outcomes are the primary criterion. Yang (2024), in a propensity score-matched analysis of 893 patients across 32 centres, found higher rates of favourable functional outcome at two years with endovascular treatment (85.5% *versus* 75.6%; OR=1.89, p=0.005) and lower two-year all-cause mortality (OR=0.54, p=0.023) [31]. Fukuda (2025), using the Japanese POST.SAH multicentre registry, reported lower periprocedural complication rates (OR=0.49, p=0.045) and better functional outcomes (OR=1.56, p=0.03) for endovascular treatment, even in a population where surgical treatment achieved higher definitive occlusion [18]. Tan (2023) reinforced this in ruptured blood blister-like aneurysms, where endovascular treatment yielded markedly better functional outcome (72.7% *versus* 28.6%; p<0.001) and lower mortality (11.4% *versus* 32.1%; p=0.035) [48].

5.2. Comparison with Previous Studies

The findings of this review are broadly consistent with the landmark randomised controlled trials in the neurovascular field but extend them in two important directions. ISAT [7] and BRAT both demonstrated better short-term functional outcomes for endovascular coiling compared with microsurgical clipping in ruptured aneurysms, alongside higher retreatment rates following coiling. Both trials, however, enrolled predominantly patients with simple ruptured saccular aneurysms accessible to both modalities, excluding many of the morphologically complex lesions that constitute the focus of the present review. The current synthesis replicates the same directional pattern - endovascular approaches produce better early functional outcomes; microsurgical approaches produce more definitive occlusion - but within a morphologically far more challenging cohort than either landmark trial enrolled.

For flow diversion specifically, the occlusion rates observed are consistent with large device registries. The IntrePED registry (Kallmes, 2015; n=793) reported 3.8% neurological mortality and 0.6% overall spontaneous rupture rate, rising to 4.5% in giant aneurysms [11]. Grandhi (2024), drawing on IntrePED for a giant aneurysm subgroup (n=63), reported 72% complete occlusion at median 22.4-month follow-up and 22.7% procedure-related complications (38). Sun (2025) reported 86.2% complete occlusion with the Lattice flow diverter at 12 months [12], while Juan (2025) found OKM Grade D occlusion in 71.4% using Tubridge [9], illustrating the progressive improvement in flow diversion outcomes over the study period.

For stent-assisted coiling, Chalouhi (2013) - the largest single-centre study (n=508) - found 87.5% immediate complete occlusion but 13.2% recanalization, with aneurysm size greater than 10 mm as an independent predictor of recurrence (p=0.005) [39]. Piotin (2010) demonstrated that stent assistance significantly reduced recanalization compared with coiling alone (14.9% *versus* 33.3%; p=0.008) [40]. Kim (2021) further showed 61.1% complete occlusion at a mean of 58 months, with 22.8% recurrence in the stent-assisted group but lower than the 50.7% in non-stented coiling (p=0.01) [23].

The WEB device data - from Goertz (2024), Rodriguez-Calienes (2024), and Park (2025) - suggest adequate occlusion in approximately 60–76% of cases at mid-term follow-up [25,28,49]. Goertz (2024), the largest dedicated WEB cohort (n=319, 12 years), reported 60.6% complete and 81.9% adequate occlusion at midterm, with retreatment improving significantly from 13.7% in the first cohort half to 3.4% in the second (p<0.01) [28]. Park (2025) found the WEB device achieved adequate occlusion in 76.1% compared with 97.4% for clipping (OR=0.09, p<0.001), but with no significant difference in major complications (3.3% *versus* 3.1%; p=0.926) [25]. Rodriguez-Calienes (2024) found comparable complete occlusion between WEB (60.9%) and stent-assisted coiling (64.5%) in ruptured wide-neck aneurysms (p=0.328), though stent-assisted coiling was associated with significantly higher ischaemic complications (17% *versus* 6.7%; p=0.024) [49].

For microsurgical clipping, the high occlusion rates in this review likely reflect a selection effect: complex aneurysms referred for surgery in the contemporary era tend to be managed at high-volume centres by experienced surgeons. Sughrue and Lawton (2011), in a historical series of 140 giant aneurysms from UCSF, reported 77% overall occlusion and 13% overall mortality, with ruptured aneurysm mortality reaching 39% and posterior circulation as an independent risk factor for ischaemic injury (OR=2.86) [37]. The lower contemporary aggregate mortality of approximately 8–9% likely reflects improved patient selection and institutional volume effects. For bypass procedures, Sadigh (2025) reported 100% patency and 0% procedure-related mortality in 20 patients at a high-volume Dutch referral centre, with 15% permanent morbidity [15]. Acerbi (2022) achieved 95.6% occlusion with 8.7% mortality across 23 patients [43]. Lejeune (2024) reported 88% complete occlusion in 60 patients with recurrent aneurysms following prior endovascular failure, with 1.7% retreatment and 5.0% mortality [36] - underscoring the continued indispensability of surgery as a rescue pathway when endovascular approaches fail. Gurpinar (2026) reciprocally demonstrated that endovascular retreatment of surgical remnants achieved 64% complete occlusion with 1.4% mortality [51], illustrating the mutual salvage relationship between modalities.

Wakhloo (2008) demonstrated that stent-assisted reconstructive repair is feasible for fusiform and dissecting aneurysms, achieving 89% clinical improvement or stabilisation in 28 patients at mean 15.4 months, though with 50% complete immediate occlusion and 17.9% complication rate [41]. Hofman (2018), in the largest single-centre Polish series (n=354), demonstrated that complex intracranial aneurysms had significantly lower complete occlusion on the Montreal Scale compared with non-complex lesions, underscoring the morphological gradient in endovascular treatment difficulty [10]. Among hybrid series, Rennert (2023) achieved 100% immediate bypass patency in 10 highly complex aneurysms but with 30% treatment-related stroke and 20% requiring delayed additional procedures [46], illustrating both the salvage potential and residual risk of this approach in the most challenging patients. Sebök (2021), applying Clavien-Dindo grading to 156 microsurgically treated unruptured aneurysms, found that morphologically complex aneurysms carried a significantly higher risk of new neurological deficit than non-complex lesions (20.5% *versus* 1.7%; p=0.007) [44], providing granular risk stratification data relevant to pre-operative counselling.

5.3. Clinical Implications

The findings of this review carry several practical implications for the management of complex intracranial aneurysms. The evidence does not support blanket superiority of one treatment approach. Rather, it supports a modality-specific, morphology-informed decision framework in which treatment choice is individualised to the patient's aneurysm characteristics, clinical presentation, and the institutional expertise available.

For patients with unruptured complex aneurysms in whom both approaches are technically feasible, microsurgical clipping offers the advantage of definitively higher occlusion rates and lower retreatment risk, at the cost of somewhat higher complication rates. This trade-off may favour surgery in younger patients with long life expectancy, for whom the cumulative retreatment burden of incomplete endovascular occlusion would be particularly relevant over a multi-decade horizon [39,23]. For older patients or those with significant comorbidities, endovascular approaches offer a less invasive route to reasonable occlusion rates with a more favourable periprocedural safety profile [11,28].

For ruptured complex aneurysms, the available evidence - particularly from Yang (2024) and Fukuda (2025) - suggests endovascular treatment is associated with better early functional outcomes, though at the cost of higher retreatment rates [31,18]. This parallels the findings from ISAT [7] in the simple aneurysm population and suggests the general principle of favouring endovascular treatment in the acute ruptured setting extends to the complex aneurysm population. However, where morphology makes endovascular reconstruction technically inadequate - as demonstrated by Swiatek (2025), where surgery achieved higher complete occlusion despite comparable functional outcomes [32] - microsurgical clipping or hybrid approaches remain appropriate first-line options. Aburub (2025) further demonstrated that HPC-coated flow diversion under prasugrel monotherapy can be used safely in selected ruptured patients, with 0% periprocedural complications in the flow diversion subgroup [14].

For specific complex morphological subtypes, additional nuance is required. Blood blister-like aneurysms carry exceptionally high procedural risk regardless of modality, with intraoperative haemorrhage rates of 66.7% and 41.5% for microsurgery and endovascular treatment respectively [48], indicating that these lesions require management at the most experienced neurovascular centres irrespective of treatment route. Fusiform and dissecting aneurysms, as illustrated by Oel (2013) (23.1% mortality; 30.8% complication rate) [24] and Wakhloo (2008) (17.9% complication rate) [41], represent the highest-risk morphological subtype. Wide-neck bifurcation aneurysms, by contrast, can be treated safely by both the WEB device and microsurgical clipping with comparable complication rates, as demonstrated by Park (2025) [25] and Rodriguez-Calienes (2024) [49], providing genuine equipoise in device selection for this subgroup.

In all cases, the evidence supports a multidisciplinary neurovascular team discussion as the appropriate framework for treatment planning, integrating aneurysm morphology, rupture status, patient age and comorbidities, institutional volume and experience, and patient preference. The reciprocal salvage role of each modality - surgery rescuing endovascular failures (Lejeune, 2024) [36] and endovascular treatment rescuing surgical remnants (Gurpinar, 2026) [51] - argues against institutional specialisation in a single modality and in favour of centres maintaining proficiency in both approaches.

6. Conclusion

In this systematic review, we compared endovascular and microsurgical treatment across the full spectrum of complex intracranial aneurysm morphologies, drawing on evidence from 40 studies involving approximately 7,231 patients across 18 countries. Microsurgical approaches - primarily clipping and cerebrovascular bypass - consistently achieved more durable aneurysm occlusion and lower retreatament rates. In contrast, endovascular techniques were associated with a lower periprocedural burden and, particularly in the ruptured setting, better short-term functional recovery. Neither modality emerged as universally superior. The central clinical challenge remains the trade-off between immediate procedural safety and long-term durability. Treatment decisions should therefore be individualized according to aneurysm anatomy, rupture status, patient comorbidities, and institutional expertise, ideally within a structured multidisciplinary neurovascular team. Prospective comparative studies and well-designed multicentre registries, stratified by morphological subtype, remain the most pressing unmet need in this field.

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