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REVIEW

Efficacy and safety of low profile stents in Y-stent assisted coil embolization of wide-necked bifurcation aneurysms: a systematic review and meta-analysis

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Abstract

Low-profile stents may provide significant advantages in Y-stent-assisted coiling due to their miniaturized design and capability to be delivered through a 0.0165-inch microcatheter. We aim to investigate the safety and efficacy of using these newer versions of stents in Y-stent-assisted coiling for the treatment of wide-necked bifurcation aneurysms. We conducted a systematic review of the PubMed, Embase, Cochrane Library, and Web of Science databases up to September 2023, following the PRISMA guidelines. Eligible studies included ≥5 patients with intracranial wide-necked bifurcation aneurysms treated with Y-stent-assisted coiling using low-profile stents, providing angiographic and clinical outcomes. Two authors independently handled the search and selection. Primary outcomes were immediate and follow-up aneurysm occlusion, procedure-related complications, aneurysm recanalization, and retreatment. Secondary outcomes included technical success, procedure-related morbidity, procedure-related mortality, procedure-related stroke, and in-stent stenosis at follow-up. We analyzed the data using random-effects meta-analysis. In total, 19 studies including 507 patients with 509 aneurysms were included. 95% of the treated aneurysms were managed using the crossing Y-configuration. Technical success rate was 99%. Immediate adequate aneurysm occlusion was 90%. Follow-up angiographies were available for 443 aneurysms. The mean angiographic follow-up duration was 15.6 ± 1.9 months. The rates for follow-up adequate aneurysm occlusion and complete occlusion were 98% and 89%, respectively. After a mean clinical follow-up of 15 ± 2.4 months, a good clinical outcome was observed in 98% of patients. Overall, procedure-related morbidity and mortality rates were 1.3%, and 0.4%, respectively. Low-profile stents in Y-stent-assisted coiling outperform previous stent versions in terms of safety, efficacy, and technical success rates.

Keywords Low-profile stents · Y-stent-assisted · Y-stenting · Coiling · Aneurysm · Bifurcation · Wide-necked

Introduction

Wide-necked bifurcation aneurysms present significant challenges for endovascular treatment due to their broad neck and associated daughter branches. Various strategies, including double-balloon remodeling, dual stent-assisted coiling, flow diverters, neck bridging, and intrasaccular devices, have been developed to address these challenges [1]. Y-stent-assisted coiling (Y-SAC) was first introduced in 2004 by Chow et al. [2] ,and despite all advancements, still remains as an effective and durable treatment option for wide-necked bifurcation aneurysms.

Between 2004 and 2018, the majority of reported series on Y-SAC utilized stents that were delivered through microcatheters with an internal diameter of either 0.027 or 0.021

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inches. Catheterizing the sharply angled and narrow side branches of bifurcations and navigating these large-profile catheters through the struts of a fully deployed first stent is challenging. A high rate of periprocedural complications and technical complications, including stent dislocation or deformation, have been reported [3–6]. However, the newer version of intracranial self-expandable stents has a low-profile and they can be delivered using microcatheters specifically designed for coiling, with internal diameters of 0.0165 and 0.017 inches [7–9]. Their miniaturized design enables more straightforward catheterization of sharply angled bifurcation branches and smoother catheterization through the stent struts. Many centers have published their experiences with Y-SAC using these newer stents, reporting relatively high technical success and favorable safety and efficacy outcomes [7–13].

To our knowledge, there is no comprehensive study systematically assessing the influence of these newly introduced low-profile stents on the safety and efficacy of Y-SAC. Herein, we present a systematic review and meta-analysis that evaluates the angiographic and clinical outcomes of Y-SAC, using these low-profile stents for the treatment of wide-necked bifurcation aneurysms.

Materials & methods

Literature search

We conducted a systematic literature search using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [14] guidelines across PubMed, Embase, Cochrane Library, and Web of Science databases from inception to September 29, 2023. Our search terms included "y-stent", "y-configuration", "y-", "dual", "double", "stent", "stent-assisted", "y-stent-assisted", "low-profile", "neuroform atlas", "lvis jr", "acclino", "Lvis", "low-profile visualized intraluminal support", "leo baby", "accero", "wide-necked", "wide-neck", "wide", "neck", "bifurcation", "aneurysm", "intracranial", "brain", and "cerebral". We used "AND" and "OR" Boolean operators to maximize the search sensitivity. Our full search strategy is provided in Supplementary Table 1. We used the Zotero reference manager for de-duplication of the studies. Following this, the initial study triage was done based on titles and abstracts using the 'Rayyan' web application for systematic reviews [15].

Eligibility criteria

The low-profile self-expandable intracranial stents are compressed to a very small diameter for delivery through ultra-fine 0.0165-inch and 0.017-inch microcatheters, which are specifically used for coil delivery. A summary of low-profile stents used in the Y-SAC is provided in Table 1. Our inclusion criteria encompassed studies in the English language reporting on series of ≥ 5 patients with intracranial wide-necked bifurcation aneurysms treated with Y-SAC using low-profile stents, which included both angiographic and clinical outcomes. Exclusion criteria were stated in the supplementary material 1. Two independent authors screened articles in their entirety to determine eligibility for inclusion (A.G. and M.Y.F.).

Angiographic and neurological assessment

Aneurysms were categorized as small (≤ 10 mm), large (10–25 mm), and giant (> 25 mm). Aneurysms with a neck diameter ≥ 4 mm or a dome-to-neck ratio < 2 mm were defined as wide-necked. The Raymond-Roy occlusion classification (RR) was used to assess the degree of aneurysm occlusion [16]. RR class 1 was defined as complete occlusion, RR class 2 as neck residue, and RR class 3 as sac residue. RR classes 1 and 2 were defined as adequate occlusion. In the studies where RR or modified RR was not used, complete occlusion was identified only when the term "complete occlusion" was used. Terms such as "near complete occlusion" or "neck remnant/residue" that signify only neck filling were considered as adequate occlusion along with complete occlusion. Terms such as "sac residue" or "sac/body filling" were identified as inadequate occlusion. The immediate degree of aneurysm occlusion was determined by angiographic evaluation at the conclusion of the procedure. Follow-up occlusion degrees were assessed from either MRA or DSA follow-ups. If a study reported multiple angiographic follow-up results, those with the longest duration and DSA follow-ups were prioritized. Recanalization was identified if any deterioration in the RR class was reported (e.g., from 1 to 2/3 or 2 to 3) or if terms like "recanalization" or "aneurysm growth" were used. Significant chronic in-stent stenosis at follow-up was identified by the presence of in-stent stenosis of $\geq 50\%$ or if terms such as "significant stenosis or intimal hyperplasia" were explicitly mentioned.

Complications that occurred during the operation were classified as intraoperative, those that occurred within 1-month post-procedure were classified as early postoperative, and those that arose after 1 month were classified as delayed. Procedure-related complications encompassed intraoperative, early postoperative, and delayed complications. An acute in-stent thrombus was identified if any thrombus occurred in the newly deployed stent(s) and obstructed blood flow, either partially or totally, during the intraoperative or early postoperative period. Procedure-related stroke

Table 1 Overview of low-profile stents used in the Y-stent-assisted coiling technique

Stent Name (Company)	Structural design	Stent diameter range (mm)	Cell design	Resheathability	Visible Areas	Availability** (World Region)
Neuroform Atlas (Stryker)	Laser-cut	3.0-4.5	Hybrid	0%	Ends (Both)	North America, Europe, Asia-Pacific, Latin America, Middle East
Leo Baby (Balt)	Braided	2.0–3.0	Hybrid	95%	Full Length	Europe, Latin America, Asia-Pacific, Middle East, Canada
Lvis Jr. (Microvention)	Braided	2.5–3.5	Closed	80%	Full Length	North America, Europe, Middle East, Asia-Pacific, Latin America
Acclino (Acandis)	Laser-cut	3.0-6.5*	Closed	90%	Ends (Both)	Europe, Latin America, Asia-Pacific, Middle East
Accero (Acandis)	Braided	2.5-4.0	Closed	90%	Full Length	Europe, Latin America, Asia-Pacific, Middle East

*Up to 5.5 mm deliverable through 0.0165 or 0.017-inch microcatheters

**Availability may change due to regional regulatory approvals or company policies; please check the company's official website for the most updated information

referred to an ischemic stroke that was directly attributable to the procedure, whether it occurred as an intraoperative, early postoperative, or delayed complication. Clinical outcomes were assessed with the modified Rankin Scale (mRS); scores of 0–2, or terms like "no morbidity", "good recovery" or "asymptomatic" were indicative of good clinical outcomes (absence of any procedure-related morbidity or death). Procedure-related morbidity was defined as a clinical outcome of mRS 3–5 due to procedure-related complications. Procedure-related mortality was defined as the death of a patient from procedure-related complications. For cases presenting with rupture, any initial rupture-related morbidities or death were excluded from these pooled calculations.

Outcomes and data extraction

For each study, we extracted data on the number of patients, number of aneurysms, sex, mean age, aneurysm rupture status, mean aneurysm diameter, mean neck size, and durations of clinical and angiographic follow-up. The antiaggregation protocol for each study was noted for unruptured cases, and ruptured cases (if any). Additionally, we obtained details on technical success, type of stents used, in-stent stenosis, procedure-related complications, procedure-related stroke, procedure-related morbidity and mortality rates, and immediate and follow-up angiographic and clinical outcomes, as well as recanalization and retreatment rates.

The primary outcomes of this study included immediate and follow-up aneurysm occlusion, aneurysm recanalization, retreatment, and procedure-related complications. In addition, although classified as either intraoperative or early postoperative complication, acute in-stent thrombus was also included as a separate primary outcome. Secondary outcomes included technical success, procedure-related morbidity, procedure-related mortality, procedure-related stroke, and chronic in-stent stenosis at follow-up. Outcomes based on rupture status or size were not differentiated, as most studies did not stratify results by rupture status or mean diameter.

Study risk of bias assessment

We utilized a modified version of the Newcastle-Ottawa Scale to evaluate the risk of bias in the included studies, based on guidance from Zhao et al. [17] In line with the criteria set by Granja et al. [18], we designated studies that had satisfactory angiographic and clinical follow-ups, along with clear outcome reports, as having a "low risk of bias." Studies with unsatisfactory follow-ups were labeled as "medium risk of bias." Those lacking both satisfactory

follow-ups and clear outcome reports were categorized as "high risk of bias."

Statistical analysis

In each cohort, we determined the cumulative incidence (event rate) and its associated 95% confidence interval (CI) for every outcome. We assessed data heterogeneity across the studies using the Higgins index (I^2), noting that I^2 values of $\geq 50\%$ indicate high heterogeneity. A p-value of less than 0.05 ($p < 0.05$) was considered statistically significant. We employed the DerSimonian and Laird random-effects model. We additionally conducted subanalyses of the studies that used solely laser-cut stents and studies that used solely braided stents. A two-proportion z-test was applied to compare the percentages of these subanalyses and determine p-values. We conducted the meta-analysis and generated forest plots using the OpenMeta[Analyst] software (http://www.cebm.brown.edu/openmeta/).

Results

Study selection and characteristics

The literature search in stated databases yielded 1221 articles. After removing duplicates and assessing titles and abstracts for relevance, we excluded 1090 articles. We further reviewed 131 articles in full-text. Out of these, 112 were excluded, primarily because they pertained to single stent-assisted coiling series or did not provide adequate data on the Y-SAC subgroup (Supplementary Table 2). In the end, 19 studies [7–13, 19–30], representing 507 patients with 509 aneurysms, were included in our final analysis. Of these, 11 had a low risk of bias [7–11, 19–21, 26, 28, 30], six had a medium risk of bias [12, 13, 23, 25, 27, 29], and two had a high risk of bias [22, 24] (Supplementary Table 3). The search flow is presented in Fig. 1.

The mean age of patients was 58.6 ± 1.4 years, and the majority were female (66.2%). Among the 509 assessed aneurysms, 38 presented as ruptured, 471 as unruptured, and 53 experienced recurrence post-treatment—52 following coiling and one following clipping. The largest study consisted of 111 patients with 111 aneurysms, while the smallest had 6 patients with 6 aneurysms. The most common aneurysm locations were the middle cerebral artery (MCA) bifurcation (196, 38.5%), basilar apex (153, 30%), and anterior communicating artery (Acom) (134, 26.3%). Y-stenting in a kissing configuration was reported in only one study, [25] where all stents used were Acclino (Acandis, Pforzheim, Germany). All other aneurysms in the included studies were treated with crossing Y-configuration. In all studies, treatment was conducted in a single stage; no study reported a staged Y-SAC.

Out of the 509 cases, only three were treated with two different stents. In these cases, the first stent was a Neuroform Atlas (Stryker Neurovascular, Fremont, CA, USA), while the second stent was an LVIS (MicroVention, Tustin, California) in two cases, and an Enterprise (Codman Neurovascular, Raynham, Massachusetts, USA) in one. Despite the second stents being non-low-profile, these cases were retained in the overall analysis since individual outcomes were not reported. All other included aneurysms were treated with the same low-profile stents. Two Neuroform Atlas stents were used in 206 cases, two Leo Baby stents (Balt Extrusion, Montmorency, France) in 155 cases, and two Lvis junior (MicroVention, Aliso Viejo, CA, USA), stents in 121 cases. A summary of the included studies is provided in Table 2. All studies reported dual antiplatelet therapy, most commonly consisting of 75 mg clopidogrel and 100–300 mg aspirin, started from 2 days to 2 weeks pre-treatment. For ruptured cases treated in the acute setting, either dual antiplatelets were loaded pre-treatment, or a glycoprotein IIb/IIIa inhibitor or cangrelor infusion was administered before stent deployment. All studies reported the continuation of dual antiplatelet regimen post-treatment ranging from 3 months to 12 months. The full antiaggregation protocol for all studies is detailed in Supplementary Table 4.

Angiographic and clinical outcomes

Immediate adequate aneurysm occlusion was reported by 17 studies, with pooled rates being 90% (95% CI, 86–94.0%). Immediate complete occlusion was reported by 16 studies, with a rate of 65% (95% CI, 53–77%). Follow-up angiographies were available for 443 aneurysms. The mean angiographic follow-up duration was 15.6 ± 1.9 months (range, 4.4–43.5 months). The rates for follow-up adequate aneurysm occlusion and complete occlusion were 98% (95% CI, 97–99%) and 89% (95% CI, 85–93%), respectively. Aneurysm recanalization rates were 3% (95% CI, 2–5%), and aneurysm retreatment rates were 1.7% (95% CI, 0.7–3.1%). All reported cases of recanalization or retreatment are detailed in Supplementary Table 5.

Pooled rates for intraoperative and early postoperative complications were 6% (95% CI, 3-9%) and 3% (95% CI, 1.5-4.6%), respectively. The acute in-stent thrombus was the most common specified complication during these periods, developing in 18 cases with a pooled rate of 2% (95% CI, 0.9–3.3%). Only 6 cases of delayed complications were reported, with a pooled rate of 1% (95% CI, 0–2%). However, the majority of procedure-related complications resulted in good clinical outcomes. After a mean clinical

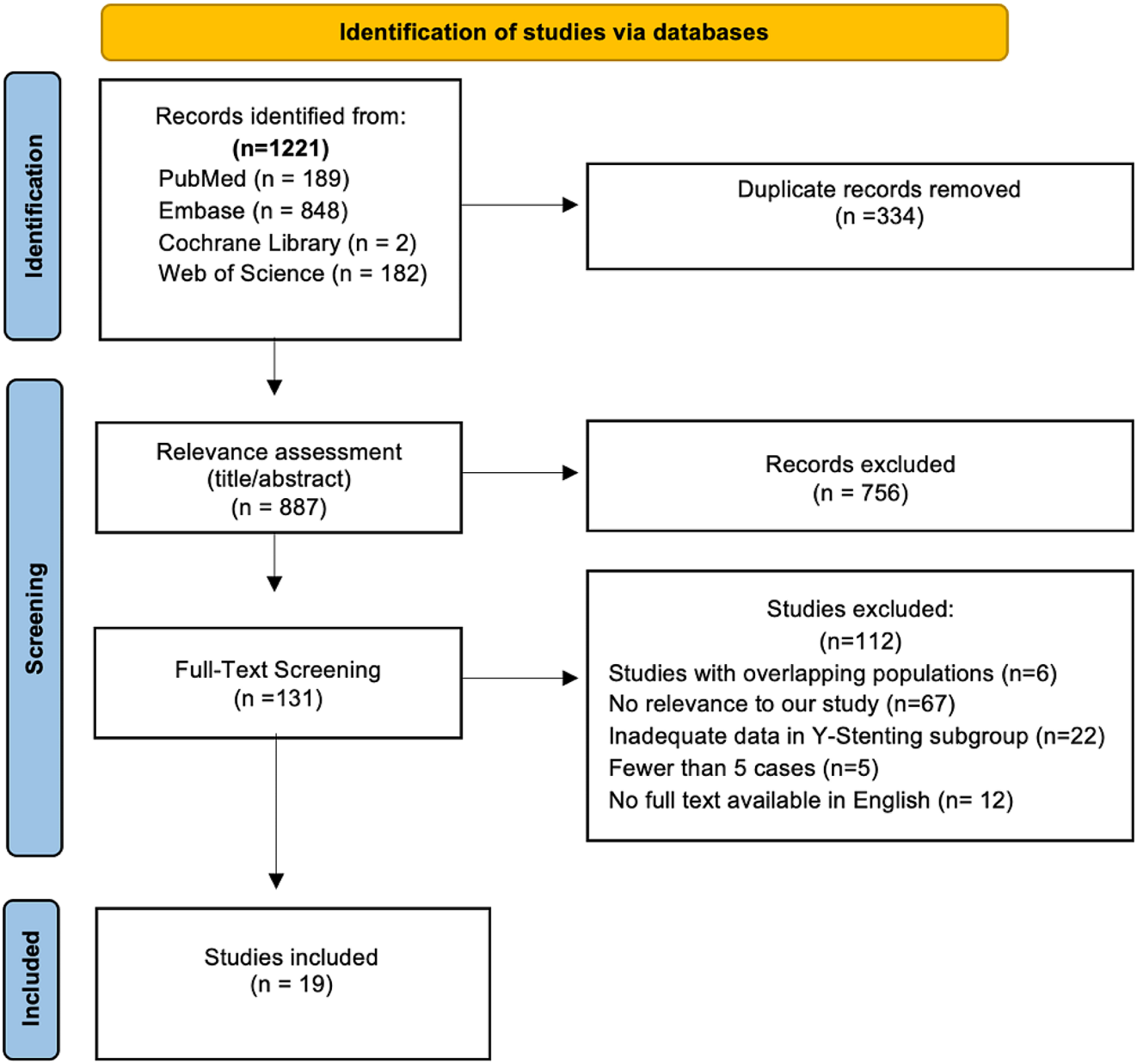

Fig. 1 PRISMA flow diagram

follow-up of 15 ± 2.4 months, the rate of good clinical outcomes was 98% (95% CI, 97–99%). All reported procedure-related complications, their management (if any), and outcomes during follow-up are detailed in Supplementary Table 6.

A high rate of technical success was reported, with pooled rates across the studies being 99% (95% CI, 98–100%) (Fig. 2). During the procedure, early postoperative, and delayed periods, a total of 27 cases of procedure-related strokes occurred. Due to procedure-related complications, mortality occurred in 2 patients and morbidity in 9 patients. Overall, procedure-related morbidity and procedure-related mortality rates were 1.3% (95% CI, 0.4–2.3%) and 0.4% (95% CI, 0–1.4%), respectively. All reported procedure-related stroke cases, mortality, and morbidity cases are also detailed in Supplementary Table 6. After a mean clinical follow-up of 15 ± 2.4 months, the rate of good clinical outcomes was 98% (95% CI, 97–99%). Follow-up DSA revealed chronic in-stent stenosis in 10 cases, with a pooled rate of 1% (95% CI, 0–2.2%). The results of primary and secondary outcomes are summarized in Table 3.

When comparing the results of studies that solely used laser-cut stents with those that solely used braided stents, follow-up adequate occlusion was reported significantly higher in the braided stent group at 99% (95% CI, 98-100%) compared to the laser-cut group at 96% (95% CI, 93–98%),

Table 2 Summary of the included studies

Study		Patients			Aneurysms					Stents used (n)
Author, yr	Y-configuration	No.	Mean age(yr)	Sex M/F	No.	R/UR	Mean sac size (mm)	Mean neck size (mm)	Location(n)	
Mohlenburg et al., 2014 [26]	Crossing	8	NA	NA	8	2/6	6.2 ± 2.5	5.4 ± 2.3	BA (4), ACOM (1), MCA (3)	Lvjs Jr-Lvjs Jr (8)
Samaniego et al., 2018 [7]	Crossing	28	62.8	10/18	28	6/22	11.5	6.01	BA (15), ACOM (4), MCA (6) Pericallosal (1) PICA (2)	Lvjs Jr-Lvjs Jr 28)
Aydin et al., 2018 [8]	Crossing	40	52 ± 11.4	15/25	40	1/39	8.4 ± 3.6	NA	MCA (22), ACOM (9), BA (7), ICA (2)	Leo Baby-Leo Baby (40),
Park et al., 2018 [13]	Crossing	21	60 ± 8.9	6/15	21	0/21	7.9 ± 2.7	5.7 ± 1.8	MCA (4), ACOM (6) BA (9), ICA (1), VBF (1)	Lvjs Jr-Lvjs Jr 21)
Mihalea et al., 2019 [12]	Crossing	6	56.8	NA	6	0/6	7.2	4.7	MCA (6)	Leo Baby-Leo Baby (4), Lvjs Jr-Lvjs Jr (2)
Boddu et al., 2019 [20]	Crossing	11	60 ± 11	1/10	11	0/11	8.2 ± 3.4	NA	BA (2), ACOM (3), MCA (3), MCA-M2 (1), ICA (1) PICA (1)	Lvjs Jr-Lvjs Jr (11)
Aydin et al., 2019 [9]	Crossing	30	52.4 ± 8.9	10/20	30	3/27	6.9 ± 2.2	NA	MCA (17), ACOM (10) BA (2), Pericallosal (1)	Neuroform A.-Neuroform A. (30)
Ciccio et al., 2019 [19]	Crossing	52	58	19/33	52	0/52	7.7	5.3	MCA (30), ACOM (19), BA (3)	Neuroform A.- Neuroform A. (52)
Son et al., 2019 [27]	Crossing	17	60 ± 13	4/13	18	2/16	5.4 ± 3.4	NA	ACOM (11) BA (7)	Lvjs Jr-Lvjs Jr (18)
Poncyljusz et al., 2020 [29]	Crossing	11	NA	NA	11	0/11	NA	NA	MCA (11)	Lvjs Jr-Lvjs Jr 11)
Sato et al., 2021 [28]	Crossing vs. Kissing*	19	67.7 ± 1.5	NA	19	5/14	10 ± 3.5	6.6 ± 2.5	BA (10) ACOM (5) MCA (3) ICA (1)	Neuroform A.- Neuroform A. (16), Neuroform A.-Lvis (2), Neuroform A.-Enterprise (1)
Chatterjee et al., 2022 [22]	Crossing	6	53.5	3/3	6	5/1	4.6	3.5	ACOM (4) MCA (2)	Neuroform A.- Neuroform A. (6)
Dongkyu et al., 2022 [23]	Crossing	15	56.4 ± 6.6	6/9	15	0/15	6.4 ± 3.1	4.7 ± 1.8	MCA (3), ACOM (8) BA (3), ICA (1)	Neuroform A.- Neuroform A. (15)
Endo et al., 2022 [30]	Crossing	21	63.9 ± 11.6	11/10	22	0/22	6 ± 2.7	4.1 ± 1.7	MCA (8), ACOM (7) BA (7),	Lvjs Jr-Lvjs Jr (22)
Melber et al., 2022 [25]	Kissing	24	NA	NA	24	0/24	NA	NA	ACOM (8), BA (6), MCA (6), ICA (2) PICA (1) ACA (1)	Acclino-Acclino (24)
Kuwajima et al., 2022 [24]	Crossing	15	68.9	5/10	15	3/12	NA	NA	MCA (7), ACOM (4) BA (4)	Neuroform A.- Neuroform A. (15)
Jadhav et al., 2023 [10]	Crossing	60	58.9 ± 10.6	17/43	60	0/60	6.7	4.3	ACA (2), ACOM (12), BA (34), BT (2), MCA (7) MCA-M1 (1), ICA (2)	Neuroform A.- Neuroform A. (60)
Borota et al., 2023 [21]	Crossing	12	53.2	4/8	12	7/5	NA	2.1	MCA (4) ACOM (2) BA (5), ICA (1)	Neuroform A.- Neuroform A. (12)
Suleyman et al., 2023 [11]	Crossing	111	56.0 ± 10.8	37/74	111	3/108	NA	NA	MCA (54) ACOM (21) BA (35), VA (1)	Leo Baby-Leo Baby (111)
TOTAL	Crossing (18) Kissing (1)	507	58.6 ± 1.4	148/291	509	38/471	7.3 ± 0.6	4.7 ± 0.3	MCA (196), BA (153), ACOM (134), ICA (11), Pericallosal (2), PICA (4), MCA-M2 (1), ACA (3), BT (2), VBF (1), VA (1), MCA-M1 (1)	Neuroform A.- Neuroform A. (206), Leo Baby-Leo Baby (155), Lvjs Jr-Lvjs Jr (121), Acclino-Acclino (24), Neuroform A -Lvis (2), Neuroform A -Enterprise (1)

*In this study, only crossing subgroup met the inclusion criteria; NA: Not available; M: Male; F: Female; ICA: Internal Carotid Artery; VA: Vertebral Artery; BA: Basilar Apex; BT: Basilar Trunk; MCA: Middle Cerebral Artery; VBF: Vertebrobasilar Fenestration; PICA: Posterior Inferior Cerebellar Artery; SCA: Superior Cerebellar Artery; ACA: Anterior Cerebral Artery; ACOM: Anterior Communicating Artery; R: Ruptured Aneurysm; UR: Unruptured Aneurysm

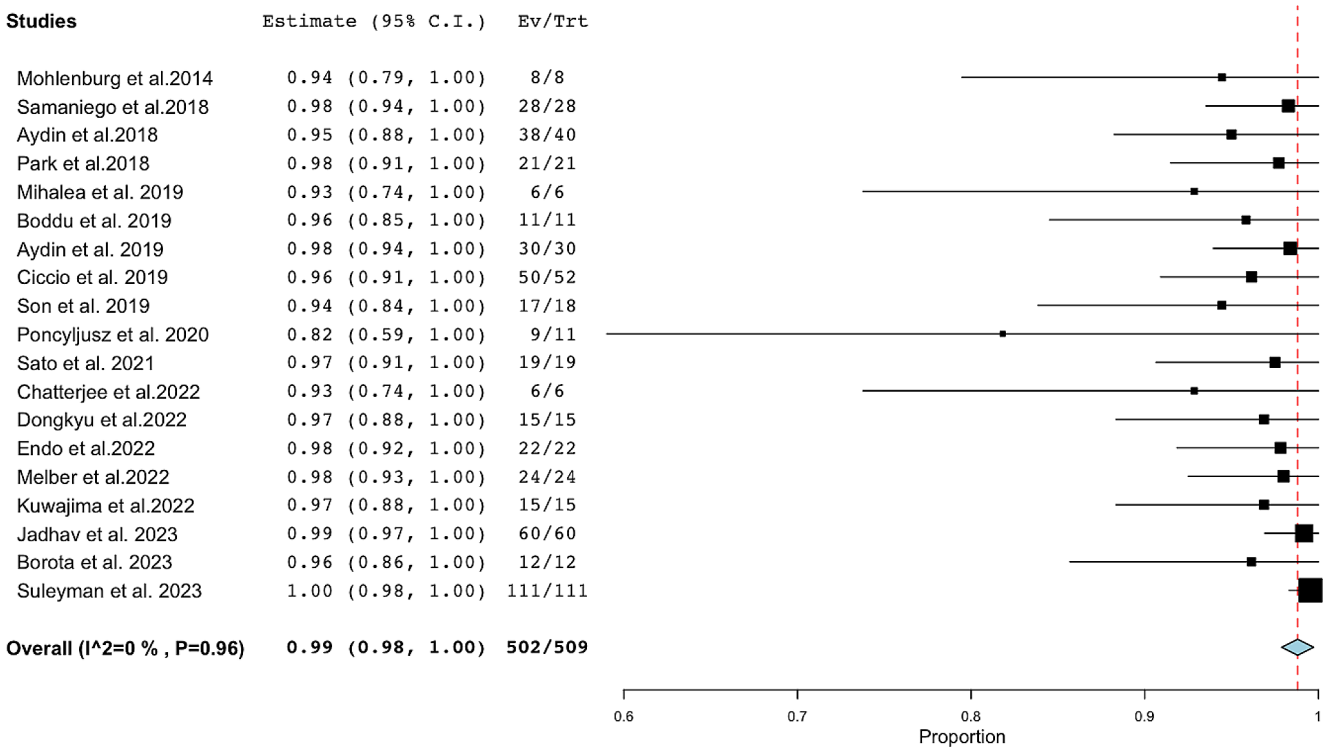

Fig. 2 Forest plot of technical success across included studies

Table 3 Results of the meta-analysis

Outcomes	Estimate (95% C.I.)	I^2(%)	No. of studies	Events/ Total
Primary outcomes				
Immediate adequate occlusion	90% (86–94.0)	79	17	429/487
Immediate complete occlusion	65% (53–77)	91	16	337/463
Follow-up adequate occlusion	98% (97–99)	0	19	425/443
Follow-up complete occlusion	89% (85–93)	41	17	356/404
Recanalization	3% (2.0–5.0)	0	18	17/448
Retreatment	1.7% (0.7–3.1)	0	19	11/463
Intraoperative complications	6% (3.1-9.0)	63	19	41/509
Early postoperative complications	3% (1.5–4.6)	9	19	26/509
Acute in-stent thrombus	2% (0.9–3.3)	0	19	18/509
Delayed complications	1% (0.0–2.0)	0	16	6/390
Secondary outcomes				
Technical success	99% (98–100)	0	19	502/509
Procedure-related stroke	2.7% (1.3–4.1)	0	19	27/509
Procedure-related morbidity	1.3% (0.4–2.3)	0	19	9/504
Procedure-related mortality	0.4% (0.0–1.4)	0	19	2/504
Chronic in-stent stenosis	1% (0.0–2.2)	0	15	10/405

with a *p*-value of 0.002. Follow-up adequate occlusion rates for the laser-cut and braided stent groups is shown in Fig. 3. Acute in-stent thrombus was reported significantly more often in the braided stent group than in the laser-cut stent group, while chronic in-stent stenosis and procedure-related morbidity were observed more frequently in the laser-cut stent group (Table 4).

Heterogeneity assessment

The majority of outcomes demonstrated low or no heterogeneity. For immediate angiographic results, considerable heterogeneity was observed, with I^2 values exceeding 50%. Intraoperative complications also showed heterogeneity, with an I^2 value of 63%. In subanalysis, heterogeneity in intraoperative complications was observed only in the laser-cut stents group.

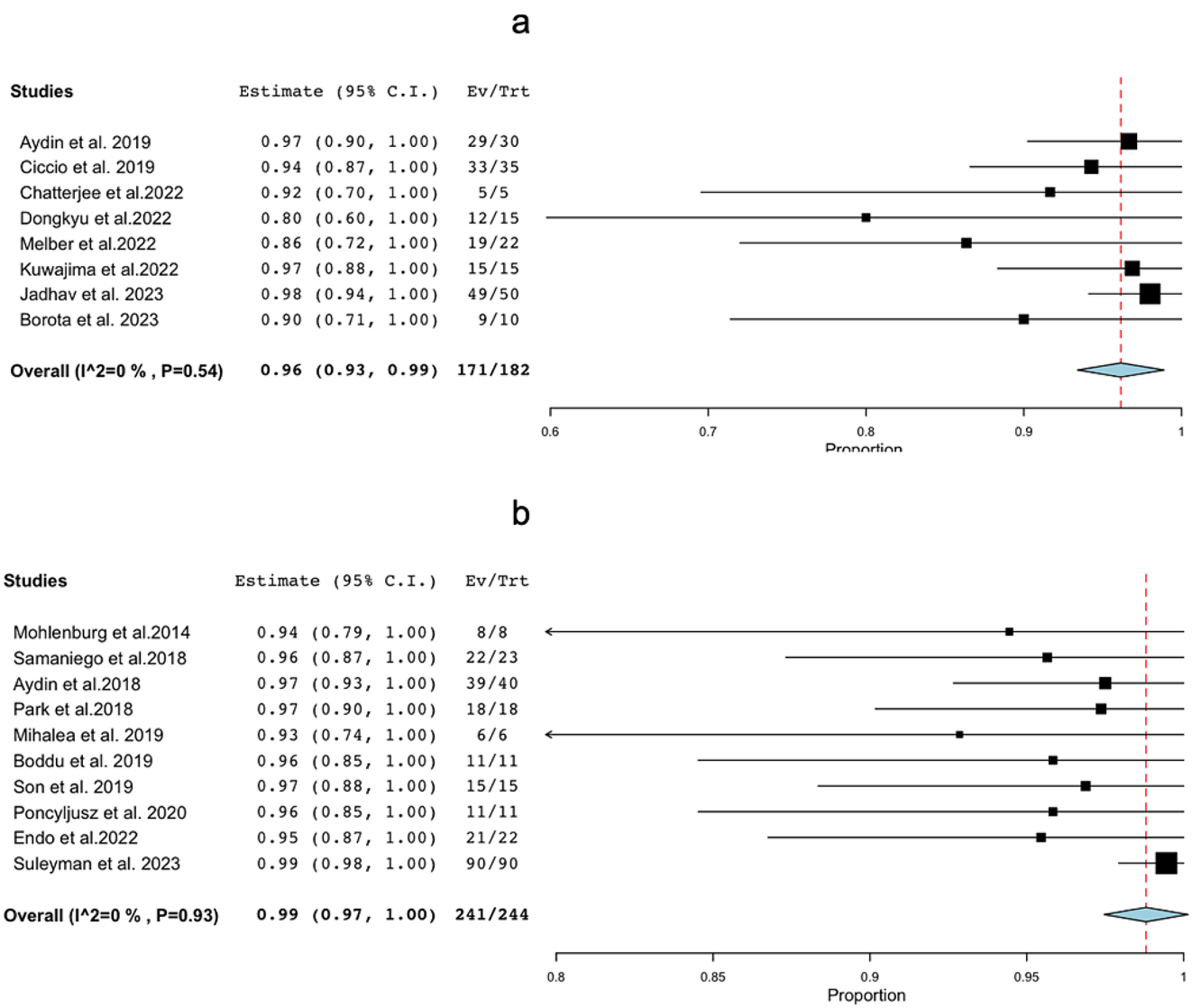

Fig. 3 Follow-up adequate occlusion rates for the laser-cut (**a**) and braided (**b**) stent groups

Discussion

Our meta-analysis, which included 509 bifurcation aneurysms treated with Y-SAC using low-profile stents, presented several important findings. Y-SAC is a technically complex procedure that necessitates catheterization of both bifurcation branches and the aneurysm sac. In our review, 95% of the treated aneurysms were managed using the crossing Y-configuration. This approach requires catheterization through the struts of the fully deployed first stent, followed by the deployment of the second stent through the struts of the first. Especially, for braided stents, concerns have arisen regarding catheterization through struts and the adequate expansion of the second stent at the intersection point [3, 8]. However, the overall technical success rate in our study was 99%, and it did not differ based on the structural or cell design of the stent (Table 4; Fig. 2). In total, approximately 90% of aneurysms achieved complete occlusion, and 98% had adequate occlusion at the last angiographic follow-up. Recanalization rates stood at 3%, and only 1.7% of the aneurysms required reintervention. Procedure-related mortality rates were below 1%. A good clinical outcome was observed in 98% of patients, and procedure-related morbidity developed in 1.3%.

In this study, we defined complete occlusion only if studies reported "complete occlusion" or "RR grade 1". This was done to better assess and compare the efficacy of this technique with other available treatment options. However, two previous Y-SAC meta-analyses by Cagnazzo et al. [31] and Granja et al. [18], which included almost 100% non-low profile stents, described angiographic outcomes as complete/near complete occlusion. In our study, this was classified as adequate occlusion (RR 1 or 2). In the study by

Table 4 Subanalysis by the structural design of stents

Outcomes	Laser-cut group				Braided group				*p*-value*
	Estimate (95% C.I.)	I^2(%)	No. of studies	Events/ Total	Estimate (95% C.I.)	I^2(%)	No. of studies	Events/ Total	
Primary outcomes									
Immediate adequate occlusion	88% (79–97)	83	6	168/193	92% (86–97)	70	10	251/275	0.070
Immediate complete occlusion	70% (53–87)	84	5	124/169	68% (53–83)	88	10	210/275	0.238
Follow-up adequate occlusion	96% (93–99)	0	8	171/182	99% (98–100)	0	10	241/244	**0.002**
Follow-up complete occlusion	90% (86–95)	0	7	141/160	88% (82–94)	55	10	215/244	0.500
Recanalization	3% (1.6–5.0)	0	7	7/167	3% (1–5)	0	10	9/264	0.418
Retreatment	2% (0–5.0)	0	8	6/182	1% (0–2.3)	0	10	4/264	0.211
Intraoperative complications	8% (2–14)	75	8	28/214	4% (0-6.4)	24	10	11/276	0.101**
Early postoperative complications	1.4% (0-2.5)	0	8	6/214	6% (3–8)	0	10	19/276	
Acute in-stent thrombus	1% (0–3)	0	8	3/214	3.5% (0–6)	17	10	13/276	**0.02**
Delayed comp.	1% (0–2.5)	0	6	3/123	1% (0–2)	0	9	3/248	0.189
Secondary outcomes									
Technical success	98% (97–100)	0	8	212/214	99% (98–100)	0	10	271/276	0.208
Procedure-related stroke	6% (3–9)	0	8	15/214	2% (0–4)	0	10	12/276	0.2
Procedure-related morbidity	2.6% (0–5)	0	8	7/214	0.5% (0–1)	0	10	2/274	**0.038**
Procedure-related mortality	0% (0-1.5)	0	8	0/214	0.6% (0–2)	0	10	2/274	0.211
Chronic in-stent stenosis	3% (0–6)	38	6	8/153	0.2% (0-0.5)	0	9	2/251	**0.002**

*The 2-proportions *z* test has been applied. ** The majority of studies reported these two complications together as periprocedural. Thus, we compared total proportions

Cagnazzo et al. [31], the immediate and follow-up adequate occlusion rates were 82% and 95%,respectiely. In the study by Granja et al. [18], the follow-up adequate occlusion rate was 91%, and the procedure-related morbidity and mortality rates were 4% and 2%, respectively. Good clinical outcomes from these studies were reported at 94% and 92% [18, 31]. When comparing our findings to these studies, our safety and efficacy outcomes seem superior. These important findings suggest that low-profile stents enhance the efficacy of Y-SAC, along with technical success rates and safety outcomes.

There may be several advantages of low-profile stents in Y-SAC, regardless of their structural or cell design: (1) Low-profile stents can be utilized with microcatheters that have an internal diameter of 0.0165 inches [7–9]. Navigating through the acutely angled, small-sized side branches of bifurcations is easier and safer than with 0.021-inch microcatheters [7, 8]. (2) Another advantage of 0.0165-inch microcatheters is the absence of a step-off with the 0.014-inch microwire, simplifying navigation through stent struts [27]. This becomes more challenging with 0.021 or 0.027-inch microcatheters due to the ledge effect between the 0.014-inch microwire and the microcatheter [13]. Easier trans-strut navigation reduces the need for exchanges with the 300 cm microwire, minimizing technical complications. (3) Additionally, low-profile stents can be safely deployed in parent vessels with diameters less than 2 mm, offering benefits, especially when bifurcation branches are notably small [7, 21].

Low-profile stents with a laser-cut structural design, primarily the Neuroform Atlas, have been recommended and prioritized due to hybrid cell design, which offers an advantage in crossing Y-SAC [9, 10, 19, 21]. The central portion of this stent features an open-cell design, facilitating the easier catheterization of the second bifurcation branch and aiding the expansion of the second stent. However, our additional subanalyses of the studies that used solely laser-cut stents, and those that used solely braided stents, showed that braided stents, Leo Baby and Lvis Jr., were not inferior to laser-cut stents in terms of technical success. Procedure-related complications were reported at similar rates. Despite their smaller cell size, these braided stents feature sliding struts that allow for cell expansion and facilitate catheterization [7, 8, 13]. Using the technique of pushing the delivery catheter with the stent wire during the deployment of the second stent ensures optimal expansion at the intersection point [8, 13]. Moreover, braided stents are visible throughout their length and are resheathable up to almost 90% of their length, enabling more controlled deployment [7, 12]. Their braided design and enhanced metal coverage contribute to a flow diversion effect [7]. In our study, for the braided stent group, follow-up adequate occlusion rates were significantly higher. On the other hand, the immediate and follow-up complete occlusion rates were higher in the laser-cut stent group. These findings suggest that irrespective of the structural or cell design of the stents, the Y-configuration creates a sufficient flow diversion effect, contributing to progressive aneurysm occlusion [32–34]. Although initial angiographic outcomes were highly heterogeneous, this heterogeneity

significantly reduced in follow-up angiographic results. In Y-SAC technique, coiling can be performed either by jailing the coil microcatheter before stent deployment or after the deployment of the stents using a coil-through approach. Some authors recommend using a single microcatheter for the entire process [27], while others suggest using two microcatheters for coiling after deploying the second stent [7]. Furthermore, many operators count on the progressive occlusion of the aneurysm by the flow-diversion effect, so they do not strive for tight coiling [33]. These approaches result in heterogenity in initial angiographic outcomes. In addition, Y-SAC can be performed without the need to cross the struts of the first stent by using a kissing Y-configuration [25, 28]. Although this provides a technically easier alternative, kissing Y-SAC has been associated with a higher risk of in-stent stenosis at follow-up [25, 35]. In our study, 10 cases of in-stent stenosis were reported, and 6 of these were associated with kissing Y-SAC. Parallel deployment of two stents in the parent artery may lead to insufficient deployment, which could subsequently result in-stent stenosis [25].

Recent prospective studies on the WEB treatment of wide-necked bifurcation aneurysms reported a complication rate of under 1% and long-term adequate aneurysm occlusion rates of 77.9% and 87.2% [36, 37]. However, aneurysms outside the 3–10 mm range or those with complex morphology, such as asymmetry between the aneurysm and bifurcation plane, poly-lobed shape, or incorporation of a bifurcation branch into the aneurysm base, may pose challenges to WEB treatment [12]. Despite a very safe profile, recanalization-related retreatment rates of 15.5% are still clinically noteworthy [36]. In our study, follow-up adequate occlusion rates were 98%, recanalization rates were 3%, and retreatment was 1.7%. Endovascular alternatives recently introduced for wide-necked bifurcation aneurysms include neck bridging devices such as PulseRider and pCONus. These devices provide scaffolding at the aneurysm neck to facilitate safe coiling. However, the lack of intrasaccular or intravascular flow diversion effects raises questions about their long-term durability. Additionally, recent meta-analyses indicate a long-term complete occlusion rate of 60% and a retreatment rate of 14% for pCONus [38], while PulseRider has a six-month complete occlusion rate of 64% [39]. Furthermore, a novel neck bridging device eCLIPs has an additional flow diversion effect; however, its application is more complex and may not be suitable for aneurysms with a neck size larger than 6 mm or those located at sites other than the basilar tip and internal carotid bifurcation [40]. In the current study, 64.4% of the included aneurysms were located at the MCA bifurcation and Acom locations, where using eCLIPS was not feasible.

Another technique for the treatment of wide-necked bifurcation aneurysms is flow diversion. However, the two main concerns are the insufficient neck coverage and the occlusion risk of covered branches [1]. In a meta-analysis, 244 MCA aneurysms underwent flow diverter treatment, with 76.3% of them located at the bifurcation. The study found an adequate occlusion rate of 78.7% after a median follow-up of 12 months. The rate of treatment-related complications was 20.7%, with nearly 10% of the covered branches occluded during follow-up [41]. While using two stents can make the procedure challenging, preserving both bifurcation branches—rather than covering one of them—is an advantage of Y-SAC. In our study, the overall rate of procedure-related complications was 10%, and there was only one case of asymptomatic branch occlusion during follow-up. Wide-necked bifurcation aneurysms, with branches frequently arising from or adjacent to the aneurysm neck, pose challenges for single-stent-assisted coiling. Complete occlusion rates for wide-necked bifurcation aneurysms treated with single stent-assisted coiling have been reported to range from 30.6 to 70.3% in follow-up studies [42, 43]. As the aneurysm size increases and the neck widens the success rate of complete occlusion with single stent-assisted coiling decreases, necessitating the Y-SAC [42].

This systematic review has several limitations. Except for one, all included studies were retrospective, and most were conducted at single institutions. Furthermore, most of the studies were small and lacked a comparison group. Angiographic outcomes were assessed by core laboratory adjudication in one study and by independent investigators in two others; the remaining studies either conducted self-adjudication or did not specify the independence of their assessments. Thus, potential observer bias and selection bias may impact the presented results. Variability in the definitions of morbidity, as well as in the categorization and definitions of complications across studies, presents a limitation; however, we have sought to mitigate this by detailing all reported complications and their outcomes. Subgroup analyses based on aneurysm size, rupture status, location, and patient comorbidities were not possible due to insufficient data. Nevertheless, this systematic review and meta-analysis could serve as valuable data for comparing the results of Y-SAC with this newer version of stents.

Conclusion

This systematic review and meta-analysis demonstrated that using low-profile stents for Y-SAC in treating wide-neck bifurcation aneurysms, under dual antiplatelet therapy, is effective and safe. The technique achieved a 99% technical success rate, a 98% rate of follow-up adequate aneurysm occlusion, and a procedure-related mortality rate of only 0.4%. Safety and efficacy outcomes are better when

compared with older versions of stents. Notably, comparable follow-up angiographic outcomes were achieved with both braided and laser-cut low-profile stents.

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Declarations

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References

1. Pierot L, Spelle L, Cognard C et al (2021) Wide neck bifurcation aneurysms: what is the optimal endovascular treatment? J Neurointerv Surg 13(5). https://doi.org/10.1136/neurintsurg-2021-017459
2. Chow MM, Woo HH, Masaryk TJ et al (2004) A Novel Endovascular Treatment of a wide-necked basilar apex aneurysm by using a Y-Configuration, Double-Stent Technique. AJNR Am J Neuroradiol 25(3):509
3. Spiotta AM, Gupta R, Fiorella D et al (2011) Mid-term results of endovascular coiling of wide-necked aneurysms using double stents in a Y configuration. Neurosurgery 69(2):421–429. https://doi.org/10.1227/NEU.0b013e318214abbd
4. Bartolini B, Blanc R, Pistocchi S et al (2014) Y and X stent-assisted coiling of complex and wide-neck intracranial bifurcation aneurysms. AJNR Am J Neuroradiol 35(11):2153–2158. https://doi.org/10.3174/ajnr.A4060
5. Akgul E, Aksungur E, Balli T et al (2011) Y-Stent-assisted Coil embolization of wide-Neck Intracranial aneurysms. A single center experience. Interv Neuroradiol 17(1):36–48. https://doi.org/10.1177/159101991101700107
6. Limbucci N, Renieri L, Nappini S et al (2016) Y-stent assisted coiling of bifurcation aneurysms with Enterprise stent: long-term follow-up. J Neurointerv Surg 8(2):158–162. https://doi.org/10.1136/neurintsurg-2014-011483
7. Samaniego EA, Mendez AA, Nguyen TN et al (2018) LVIS Jr Device for Y-Stent-assisted Coil embolization of wide-Neck Intracranial aneurysms: a Multicenter experience. Interv Neurol 7(5):271–283. https://doi.org/10.1159/000487545
8. Aydin K, Men S, Barburoglu M et al (2018) Initial and long-term outcomes of Complex Bifurcation aneurysms treated by Y-Stent-assisted coiling with Low-Profile Braided stents. AJNR Am J Neuroradiol 39(12):2284. https://doi.org/10.3174/ajnr.A5869
9. Aydin K, Balci S, Sencer S et al (2020) Y-Stent-assisted coiling with Low-Profile Neuroform Atlas stents for Endovascular treatment of wide-necked complex intracranial bifurcation aneurysms. Neurosurgery 87(4):744–753. https://doi.org/10.1093/neuros/nyz516
10. Jadhav AP, Desai SM, Jovin TG et al (2023) Y-Stent–Assisted Coiling of Wide-Necked Intracranial Aneurysms With the Neuroform Atlas Stent System. Stroke: Vascular and Interventional Neurology. ;3(1). https://doi.org/10.1161/SVIN.122.000437
11. Suleyman K, Korkmazer B, Kocer N et al (2023) Evaluation of short- and long-term results of Y-stent-assisted coiling with Leo stents in endovascular treatment of wide-necked intracranial bifurcation aneurysms. Neuroradiology 65(4):785–791. https://doi.org/10.1007/s00234-023-03116-x
12. Mihalea C, Caroff J, Ikka L et al (2020) Y-stenting with braided stents for wide-neck intracranial bifurcation aneurysms. A single-center initial experience. J Neuroradiol 47(3):227–232. https://doi.org/10.1016/j.neurad.2018.12.005
13. Park KY, Kim BM, Kim DJ et al (2019) Y-configuration stenting for coiling of wide-neck bifurcation aneurysms using low-profile visualized Intraluminal Support Junior. J Neurointerv Surg 11(4):400–404. https://doi.org/10.1136/neurintsurg-2018-014128
14. Page MJ, McKenzie JE, Bossuyt PM et al (2021) The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 372:n71. https://doi.org/10.1136/bmj.n71
15. Ouzzani M, Hammady H, Fedorowicz Z et al (2016) Rayyan-a web and mobile app for systematic reviews. Syst Rev 5(1). https://doi.org/10.1186/s13643-016-0384-4
16. Roy D, Milot G, Raymond J (2001) Endovascular Treatment of Unruptured Aneurysms. Stroke 32(9):1998–2004. https://doi.org/10.1161/hs0901.095600
17. Zhao B, Yin R, Lanzino G et al (2016) Endovascular coiling of wide-Neck and wide-Neck Bifurcation aneurysms: a systematic review and Meta-analysis. AJNR Am J Neuroradiol 37(9):1700–1705. https://doi.org/10.3174/ajnr.A4834
18. Granja MF, Cortez GM, Aguilar-Salinas P et al (2019) Stent-assisted coiling of cerebral aneurysms using the Y-stenting technique: a systematic review and meta-analysis. J Neurointerv Surg 11(7):683–689. https://doi.org/10.1136/neurintsurg-2018-014517
19. Ciccio G, Robert T, Smajda S et al (2019) Double stent assisted coiling of intracranial bifurcation aneurysms in Y and X configurations with the Neuroform ATLAS stent: immediate and mid term angiographic and clinical follow-up. J Neurointerv Surg 11(12):1239–1242. https://doi.org/10.1136/neurintsurg-2019-015175
20. Boddu SR, Link TW, Santillan A et al (2019) Double stent-assisted (Y and X) Coil Embolization of Unruptured Intracranial Saccular aneurysms using the Low-Profile visualized Intraluminal Support device-single Center experience. J Vasc Interv Neurol 10(3):1–9
21. Borota L, Nyberg C, Lenell S et al (2023) Expanded range of indications for Neuroform Atlas stent in the treatment of very small, wide-necked cerebral aneurysms. J Clin Neurosci 114:38–47. https://doi.org/10.1016/j.jocn.2023.05.023
22. Chatterjee A, Mahajan A, Banga V et al (2022) Y stenting in wide-necked bifurcation aneurysms: a single-center experience. Indian J Neurosurg 11(1):55–60. https://doi.org/10.1055/s-041-1730103
23. Kim D, Chung J et al (2022) Y-stent-assisted coiling with Neuroform Atlas stents for wide-necked intracranial bifurcation aneurysms: a preliminary report. J Cerebrovasc Endovasc Neurosurg 24(1):1–9. https://doi.org/10.7461/jcen.2021.E2021.06.010
24. Kuwajima T, Kazekawa K, Maruyama K et al (2022) Usefulness and problems of Y-Stent and T-Stent assisted coiling for Unruptured Cerebral aneurysms. J Stroke Cerebrovasc Dis 31(10). https://doi.org/10.1016/j.jstrokecerebrovasdis.2022.106668
25. Melber K, Boxberg FW, Schlunz-Hendann M et al (2022) Long-term results of wide-necked intracranial bifurcation aneurysms treated with stent-assisted coiling using low-profile acandis

acclino stents. Interv Neuroradiol 15910199221121398. https://doi.org/10.1177/15910199221121398
26. Möhlenbruch M, Herweh C, Behrens L et al (2014) The LVIS Jr. microstent to assist coil embolization of wide-neck intracranial aneurysms: clinical study to assess safety and efficacy. Neuroradiology 56(5):389–395. https://doi.org/10.1007/s00234-014-1345-z
27. Son C, Page P, Niemann D et al (2020) Cerebral aneurysms treated with low-profile visualized intraluminal support device (LVIS Jr) Y-stent constructs: technical experience with a single microcatheter technique. Interventional Neuroradiol 26(2):156–163. https://doi.org/10.1177/1591019919880420
28. Sato K, Matsumoto Y, Kanoke A et al (2021) Y-Configuration stenting for Coil Embolization of Complex Intracranial aneurysms: distinguishing between Use of Crossing-Y and Kissing-Y. World Neurosurg 146:e1054–e1062. https://doi.org/10.1016/j.wneu.2020.11.092
29. Poncyljusz W, Zwarzany Ł, Limanówka B et al (2020) Stent-assisted coiling of unruptured MCA aneurysms using the LVIS Jr. Device: a multicenter registry. J Clin Med 9(10):1–10. https://doi.org/10.3390/jcm9103168
30. Endo H, Mitome-Mishima Y, Suzuki K et al (2022) Long-term outcomes of Y-stent-assisted coil embolization using low-profile visualized Intraluminal Support Junior (LVIS Jr) for intracranial bifurcation aneurysms. Clin Neurol Neurosurg 217:107275. https://doi.org/10.1016/j.clineuro.2022.107275
31. Cagnazzo F, Limbucci N, Nappini S et al (2019) Y-Stent-assisted coiling of wide-Neck Bifurcation Intracranial aneurysms: a Meta-analysis. AJNR Am J Neuroradiol 40(1):122–128. https://doi.org/10.3174/ajnr.A5900
32. Kono K, Terada T (2013) Hemodynamics of 8 different configurations of stenting for bifurcation aneurysms. AJNR Am J Neuroradiol 34(10):1980–1986. https://doi.org/10.3174/ajnr.A3479
33. Cekirge HS, Yavuz K, Geyik S et al (2011) A novel Y stent flow diversion technique for the endovascular treatment of bifurcation aneurysms without endosaccular coiling. AJNR Am J Neuroradiol 32(7):1262–1268. https://doi.org/10.3174/ajnr.A2475
34. Babiker MH, Gonzalez LF, Ryan J et al (2012) Influence of stent configuration on cerebral aneurysm fluid dynamics. J Biomech 45(3):440–447. https://doi.org/10.1016/j.jbiomech.2011.12.016
35. Melber K, Meila D, Draheim P et al (2017) Vascular angular remodeling by kissing-Y stenting in wide necked intracranial bifurcation aneurysms. J Neurointerv Surg 9(12):1233–1237. https://doi.org/10.1136/neurintsurg-2016-012858
36. Fiorella D, Molyneux A, Coon A et al (2023) Safety and effectiveness of the Woven EndoBridge (WEB) system for the treatment of wide necked bifurcation aneurysms: final 5 year results of the pivotal WEB intra-saccular therapy study (WEB-IT). J Neurointerv Surg. https://doi.org/10.1136/jnis-2023-020611.;jnis-2023-020611
37. Pierot L, Szikora I, Barreau X et al (2023) Aneurysm treatment with the Woven EndoBridge (WEB) device in the combined population of two prospective, multicenter series: 5-year follow-up. J Neurointerv Surg 15(6):552–557. https://doi.org/10.1136/neurintsurg-2021-018414
38. Sorenson TJ, Iacobucci M, Murad MH et al (2019) The pCONUS bifurcation aneurysm implants for endovascular treatment of adults with intracranial aneurysms: a systematic review and meta-analysis. Surg Neurol Int 10(1). https://doi.org/10.4103/sni.sni_297_18
39. Pranata R, Yonas E, Vania R et al (2021) Efficacy and safety of PulseRider for treatment of wide-necked intracranial aneurysm—A systematic review and meta-analysis. Interventional Neuroradiol 27(1):60. https://doi.org/10.1177/159101992094052
40. De Vries J, Boogaarts HD, Sørensen L et al (2021) eCLIPs bifurcation remodeling system for treatment of wide neck bifurcation aneurysms with extremely low dome-to-neck and aspect ratios: a multicenter experience. J Neurointerv Surg 13(5):438–442. https://doi.org/10.1136/neurintsurg-2020-016354
41. Cagnazzo F, Mantilla D, Lefevre PH et al (2017) Treatment of Middle Cerebral Artery aneurysms with Flow-Diverter stents: a systematic review and Meta-analysis. AJNR Am J Neuroradiol 38(12):2289–2294. https://doi.org/10.3174/ajnr.A5388
42. Adeeb N, Griessenauer CJ, Patel AS et al (2018) The use of single stent-assisted coiling in treatment of bifurcation aneurysms: a multicenter cohort study with proposal of a scoring system to predict complete occlusion. Neurosurgery 82(5):710–718. https://doi.org/10.1093/neuros/nyx310
43. De Leacy RA, Fargen KM, Mascitelli JR et al (2019) Wide-neck bifurcation aneurysms of the middle cerebral artery and basilar apex treated by endovascular techniques: a multicentre, core lab adjudicated study evaluating safety and durability of occlusion (BRANCH). J Neurointerv Surg 11(1):31–36. https://doi.org/10.1136/neurintsurg-2018-013771