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CLINICAL INVESTIGATION   STROKE/NEUROINTERVENTIONS

Stent-Assisted Coiling of Intracranial Aneurysms Using a Nitinol-Based Stent (Neuroform Atlas): A Systematic Review and Meta-analysis

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Abstract

Objective The aim of this systematic review and meta-analysis was to synthesize the latest evidence on the efficacy and safety of Neuroform Atlas-assisted coiling of intracranial aneurysms.

Methods We performed a comprehensive search for articles that assessed the efficacy and safety of Neuroform Atlas-assisted coiling of intracranial aneurysms. The outcome measurement was adequate occlusion, defined as Raymond–Roy Class I (RR1) + Raymond–Roy Class II (RR2) by previous studies.

Results A total of 557 patients (568 aneurysms) from 13 studies were included. The rate of adequate occlusion after the procedure was 88% (83–94%, I^2: 72.21%), and the rates of RR1 and RR2 were 68% (60–77%, I^2: 81.87%) and 21% (15–27%, I^2: 66.10%), respectively. The adequate occlusion rate at 6 months was 90% (81–99%, I^2: 58.04%) and 93% (91–96%, I^2: 0%) at the end of a mean of 9.03 ± 1.03 months of follow-up. Periprocedural complications occurred in 35 patients [5% (3–8%, I^2: 21.28%)]. Subgroup analysis of unruptured aneurysms showed that the rates of adequate occlusion were 85% (78–93%), 90% (79–100%) (6-month follow-up), and 93% (90–96%) (at the end of follow-up). For the wide-necked aneurysm subgroup, the rate of adequate occlusion was 86% (80–93%) and was 93% (89–97%) at the end of follow-up. Meta-regression showed that initial adequate occlusion was influenced by mean aneurysm neck size ($p = 0.034$).

Conclusion Neuroform Atlas-assisted coiling is associated with an initial adequate occlusion rate of 88% and a periprocedural complication rate of 6%. The rate of initial adequate occlusion was 85% in unruptured aneurysms and 86% in wide-necked aneurysms.

Level of Evidence Level 2, Systematic review of non-randomized and single-arm studies.

Keywords Coiling · Endovascular · Intracranial aneurysm · Neuroform Atlas · Stent-assisted coiling

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Introduction

Endovascular coil embolization of unruptured intracranial aneurysms is increasingly used [1] and has become a crucial component of treatment. This method is also reliable in patients with aneurysmal subarachnoid haemorrhage (SAH) [2]. Stent-assisted coiling (SAC) has been shown to be superior to coiling alone in both ruptured and unruptured aneurysms [3, 4]. Several stents have been introduced, with open-cell and closed-cell designs; recently, stents deliverable by microcatheters became available [5].

One of the most important uses of SAC is in patients with wide-necked aneurysm (WNA), which remains a challenge in today's medical world even with the use of coil embolizations. Several adverse effects may arise from the use of coil embolization devices, especially from conventional coiling, including protrusion or luxation into the parent vessel [6–8]. This adverse event, unfortunately, is closely related to aneurysm type (WNA has a higher risk for coil protrusion). To curtail this anticipated adverse event, SAC is performed in patients with a WNA. With the use of these devices, stents are used as a scaffolding to keep the coil components within the aneurysmal sac of a WNA [9]. One of these SAC devices is the Neuroform Atlas™ (Stryker Neurovascular, Fremont, CA, USA), which consists of a stent system that is intended to hold coil devices in place inside the aneurysmal sac of a vessel. This device received US Food and Drug Administration (FDA) approval on 16 May 2019. The Neuroform Atlas stent consists of a self-expanding nitinol stent [10]. This stent has a cellular pattern with either an open or closed design. Compared to its predecessor (Neuroform EZ Stent), the Neuroform Atlas has smaller cell sizes, and the cell pattern has also been changed from W-shaped cells into diamond-shaped cells in the new Neuroform Atlas stent. These changes are performed to achieve better coil retention inside the aneurysmal sac [11]. As with other stent-assisting devices, the Neuroform Atlas can be deployed in an X or Y manner in the aneurysmal parent vessel, and the choice of this pattern of deployment depends on anatomical variations and commonly requires multiple stents [12]. This device is intended to be used in an aneurysm in the brain with a neck size greater than 4 mm or a dome-to-neck ratio less than 2 [10]. The aim of this systematic review and meta-analysis is to synthesize the latest evidence on the efficacy and safety of Neuroform Atlas-assisted coiling of intracranial aneurysms. To the best of the authors' knowledge, this is the first meta-analysis on the Neuroform Atlas; furthermore, all of the studies were recently published (2018–2019).

Methods

Search Strategy

We performed a comprehensive search for studies that assessed the efficacy and safety of Neuroform Atlas-assisted coiling of intracranial aneurysms with a broad search strategy using keywords ("neuroform atlas") from the beginning of time until 9 December 2019 using PubMed, EuropePMC, ScienceDirect, ProQuest, and Clinicaltrials.gov. The records were then systematically evaluated using inclusion and exclusion criteria. We also performed a manual search of the references of the included studies. Two researchers independently performed an initial search, and discrepancies (different search results) that arose were resolved by discussion on whether to include the aforementioned studies. This meta-analysis follows the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, and a flowchart of the literature search strategy of studies is presented in Fig. 1.

Selection Criteria

The inclusion criteria for this study were studies that assess the adequacy of occlusion measured by Raymond–Roy Class (initial and on follow-up) and the safety (complications) of Neuroform Atlas-assisted coiling of intracranial aneurysms. We included all related clinical studies/original articles/case series and excluded case reports, review articles, and non-English language articles.

Data Extraction

Data extraction and quality assessment were performed by two independent authors using a standardized extraction form that included authors, year of publication, study design, aneurysm characteristics, mean neck diameter, dome/neck ratio, sample size, age, proportion of males, periprocedural complications (including aneurysm rupture), mean follow-up length, adequacy of occlusion, Raymond–Roy Class I (RR1), and Raymond–Roy Class II (RR2) immediately after coiling, at the 6-month follow-up, and at the end of follow-up [13]. WNA is defined by a neck size > 4 mm and/or a dome-to-neck ratio of < 1.5.

The outcome measurement of this study was adequate occlusion, defined as RR1 + RR2 upon immediate angiography, at the 6-month follow-up, and at the end of follow-up. Raymond–Roy Class III (RR3) is considered to indicate inadequate occlusion [13]. Additionally, we also measured the rate of complications, RR1, and RR2 upon immediate angiography, at the 6-month follow-up, and at

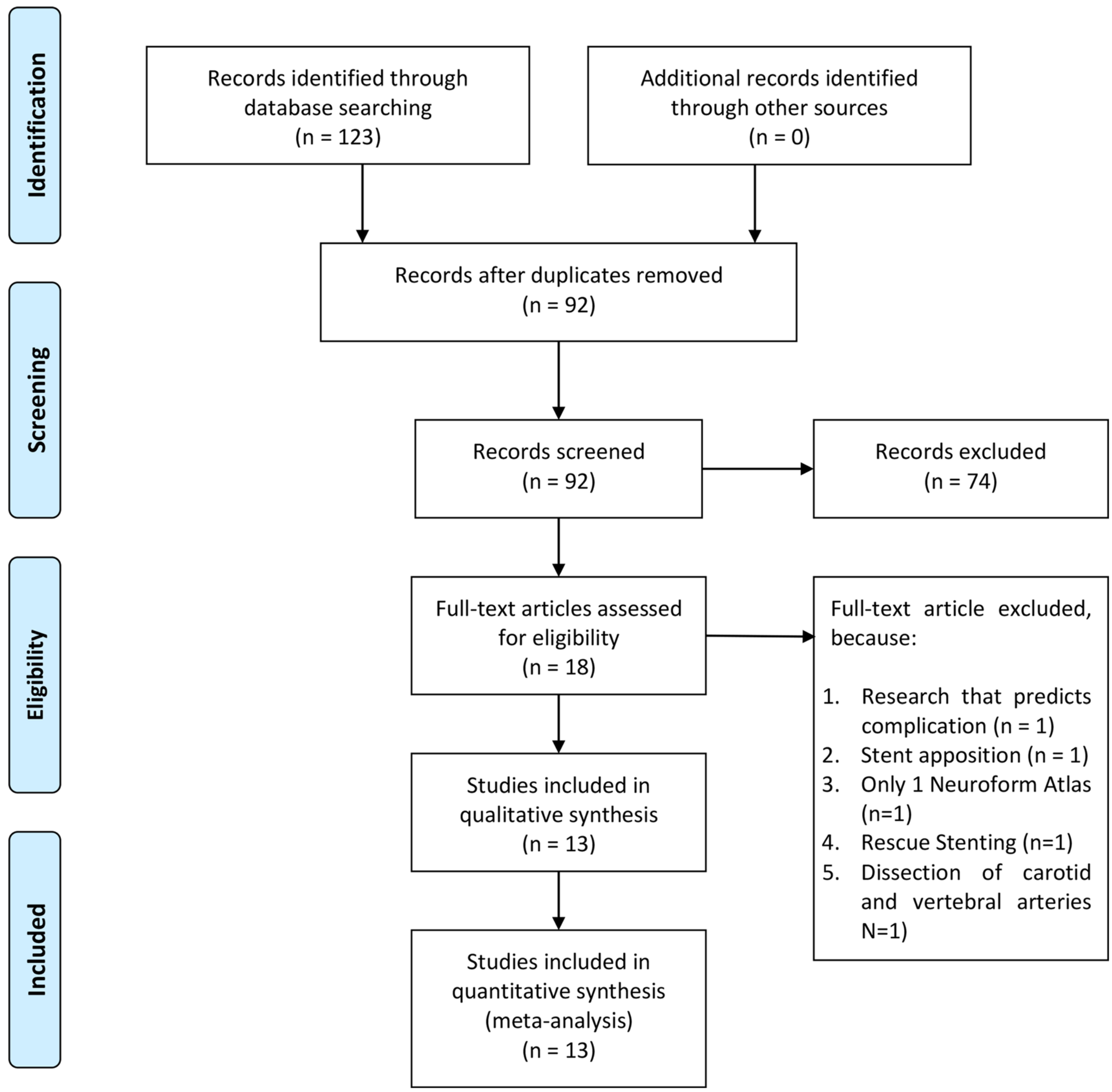


Fig. 1 Study flow diagram

the end of follow-up. These endpoints were derived from previous studies.

Statistics

To perform the meta-analysis, we used STATAMP 16.0 (StataCorp LP). We performed a meta-analysis of proportion to pool the incidence of the primary and secondary outcomes of the Neuroform Atlas-assisted coiling. The inconsistency index (I^2) test, which ranges from 0 to 100%, was used to assess heterogeneity across studies. A value above 50% or $p < 0.05$ indicates statistically significant heterogeneity. The Newcastle–Ottawa Scale (NOS) was used to assess the quality of the included cohort studies; however, since all of the included studies were single-arm studies, the NOS was modified by removing 3 components that assess comparability and the control group. Subgroup analysis was performed for unruptured aneurysms and WNA. A random-effects meta-regression model was used to explore potential confounders that cause heterogeneity in the outcomes for age, sex, mean neck size, dome-to-neck ratio, proportion of ruptured aneurysms, and proportion of WNA. All p values were two-tailed with statistical significance set at 0.05 or below.

Results

Study Selection and Characteristics

We identified a total of 123 articles. There were 92 records after the removal of duplicates. Seventy-four records were excluded after screening the title/abstracts. After assessing 18 full texts for eligibility, we excluded 5: (1) studies that predicted complications (*n* = 1); (2) evaluations of stent apposition (*n* = 1); (3) a study with only 1 use of the Neuroform Atlas (*n* = 1); (4) a study with rescue stenting (*n* = 1); and (5) a study in which dissection of carotid and vertebral arteries was performed (*n* = 1). We included 13 studies in the qualitative synthesis and meta-analysis [5, 9, 11, 12, 14–22] (Fig. 1) There were a total of 557 patients (568 aneurysms) in 13 studies. All studies were non-randomized, and most were retrospective cohorts. The subjects had unruptured and ruptured aneurysms. The patients were mostly female, and the mean/median age ranged from 51 to 63 years old. The mean follow-up duration was 9.03 ± 1.03 months (Table 1). The mean NOS score was 5.00 ± 0.23 (out of 6) (Table S1).

Rate of Adequate Occlusion

The technical success rate was 100% in 12 studies and 98% in 1 study. Immediate angiography after the procedure showed an 88% (83–94%, I^2: 72.21%) rate of adequate occlusion (Fig. 2A). The rates of RR1 and RR2 were 68% (60–77%, I^2: 81.87%) and 21% (15–27%, I^2: 66.10%), respectively. At the 6-month follow-up, adequate occlusion was found in 90% (81–99%, I^2: 58.04%) (Fig. 2B) of the aneurysms, and the rates of RR1 and RR2 were 70% (59–82%, I^2: 37.95%) and 16% (9–24%, I^2: 0%), respectively. At the end of follow-up, the rate of adequate occlusion was 93% (91–96%, I^2: 0%) (Fig. 2C), and the rates of RR1 and RR2 were 80% (73–88%, I^2: 70.84%) and 12% (8–16%, I^2: 0%), respectively. The rate of occlusion in individual studies is presented in Table 2. The mean follow-up duration was 9.03 ± 1.03 months (Table 3).

Periprocedural Complications

Periprocedural complications occurred in 35 patients [5% (3–8%, I^2: 21.48%)] (Fig. 2D). There were 13 ischaemic complications (including transient neurological deficits and transient stent-associated thrombosis), 3 temporary clots, 2 thromboembolic events, 2 stent dislodgements, 2 coil-related problems, 3 haemorrhagic events (including aneurysm rupture), 2 asymptomatic left vertebral artery dissections, 1 case of diabetic ketoacidosis-hypoxic brain damage, and 5 undefined complications (Table 1).

Unruptured Aneurysm Subgroup

A subgroup analysis of studies with unruptured aneurysms showed that the rate of adequate occlusion after the procedure was 85% (78–93%, I^2: 64.22%) (Fig. 3A), 90% (79–100%, I^2: 55.7%) (6-month follow-up), and 93% (90–96%, I^2: 0%) (at the end of follow-up; Fig. 3B). Periprocedural complications occurred in 9% (2–15%, I^2: 58.33%) of the patients. The mean follow-up duration was 8.93 ± 1.41 months (Table 3).

Wide-Necked Aneurysm Subgroup

Studies with ≥ 90% WNA were included in this subgroup analysis. The rate of adequate occlusion was 86% (80–93%, I^2: 74.26%) (Fig. 4A), 88% (75–100%, I^2: 71.99%) at the 6-month follow-up, and 93% (89–97%, I^2: 29.75%) (Fig. 4B) at the end of follow-up. The rate of periprocedural complications was 6% (3–9%, I^2: 38.09%). The mean follow-up duration was 8.61 ± 1.46 months (Table 3).

Meta-regression

The rate of adequate occlusion after the procedure was not affected by age ($p = 0.191$), sex ($p = 0.797$), proportion of ruptured aneurysms ($p = 0.163$), or proportion of WNA ($p = 0.103$). The initial adequate occlusion rate was affected by the mean aneurysm neck size ($p = 0.034$) (Fig. 5A). The RR1 rate was not affected by age ($p = 0.211$), sex ($p = 0.295$), mean aneurysm neck size (0.651), proportion of ruptured aneurysms ($p = 0.417$), or the proportion of WNA ($p = 0.480$). The rate of RR2 was not affected by sex ($p = 0.216$), mean aneurysm neck size ($p = 0.299$), proportion of ruptured aneurysms ($p = 0.116$), or the proportion of WNA ($p = 0.383$). However, it was affected by the patient's age ($p = 0.013$) (Fig. 5B).

The heterogeneity of adequate occlusion at the end of follow-up was 0%; hence, we only performed meta-regression for mean aneurysm neck size ($p = 0.899$), which was shown to affect the rate of adequate occlusion after the procedure. The rate of RR1 was not affected by age ($p = 0.486$), sex ($p = 0.447$), mean aneurysm neck size (0.839), the proportion of ruptured aneurysms ($p = 0.777$), or the proportion of WNA ($p = 0.479$).

Discussion

Neuroform Atlas-assisted coiling is associated with an 88% initial occlusion rate, which improves on follow-up to a > 90% adequate occlusion rate. However, the rate of periprocedural complications is concerning, reaching 5% of the procedure with predominantly ischaemic sequelae. The initial adequate occlusion rate was 85% in unruptured aneurysms and 86% in WNA, increasing to > 90% on follow-up. The rate of adequate occlusion was affected by the mean aneurysm neck size after the procedure but not at the end of follow-up. The aneurysm neck size has been

Table 1 Characteristics of patients included in meta-analysis

Authors	Study design	Aneurysm characteristics	Aneurysm (number)	Mean neck diameter (mm)	Mean dome-to-neck ratio	Patients (number)	Male	Age (mean ± SD)	Antiplatelet protocol	Follow-up imaging modality	Periprocedural complications
Aydin et al. [16]	PC	Bifurcation aneurysm	30	N/A	N/A	30	33.3%	52.4 ± 8.9	DAPT 5 days pre-procedure, continued for 3 months, followed by aspirin	DSA/MRA at 3–6 months And DSA 9–15 months	6.6% 1 periprocedural 1 delayed complication
Baek et al. [14]	Multicenter RC	Unruptured WNA (saccular)	54	3.82 ± 1.23	1.21	51	20%	59.29 ± 11.96	DAPT before pre-procedure until 3–6 months, followed by SAPT for ≥ 6 months	DSA & MRA	2% 1 Thromboembolism
Caragliano et al. [15]	Retrospective analysis of PC	WNA (24; 21.2% ruptured)	113	4 (2–10)	1.5	113	36.3%	58 (32–97)	DAPT 5–10 days pre-procedure, continued for 3–6 months, followed by SAPT for ≥ 1 year follow-up	DSA at 6 months and MRI at 12 months	6.2%
Ciccio et al. [12]	PC	Unruptured intracranial bifurcation aneurysms WNA (94.5%).	55	5.4 (4.6–6.6)	1.4 (1.2–1.7)	55	37.5%	58 (51–65)	DAPT pre-procedure, continued for 3 months, followed by SAPT for 3 months	MRI at 6 months and DSA at 1–3 year	12.7% 5 Ischaemic complications 3 Temporary clot 2 slight stent dislodgment
Goertz et al. [17]	Multicenter RC	Aneurysm (14; 37.8% ruptured) WNA (32; 86.5%)	37	4.3 ± 2.2	1.7 ± 0.8	37	37.8%	59.4 ± 9.7	DAPT 5–7 days pre-procedure, continued for 4 months	DSA	2.7% 1 Ischaemic complication
Jankowitz et al. [18] (ATLAS IDE trial)	Multicenter single-arm Clinical Trial	Unruptured WNA (saccular)	30	3.9 ± 1.1	1.1 ± 0.2	30	20%	59.4 ± 11.8	DAPT 5 days pre-procedure, continued for ≥ 3 months, followed by aspirin	DSA	N/A
Kim et al. [19]	RC	Intracranial aneurysm WNA (32/33; 97%) (11; 31.4% ruptured, separate analysis can be performed)	33	3.5 ± 1.0	N/A	31	22.6%	60.6 ± 13.3	DAPT ≥ 7 days pre-procedure, insufficient information for post-procedure	DSA	12% 1 coil protrusion 1 coil migration 1 rebleeding 1 diabetic ketoacidosis-hypoxic brain damage

Table 1 continued

Authors	Study design	Aneurysm characteristics	Aneurysm (number)	Mean neck diameter (mm)	Mean dome-to-neck ratio	Patients (number)	Male	Age (mean ± SD)	Antiplatelet protocol	Follow-up imaging modality	Periprocedural complications
Park et al. [20]	CS	Unruptured WNA	16	4.0 ± 0.6	N/A	16	25%	62.8 ± 6.2	DAPT 7 days pre-procedure, clopidogrel for 3 months and followed by aspirin ≥ 12 months	DSA/MRA	12.5% 2 Asymptomatic left vertebral artery dissection
Quintana et al. [21]	RC	Unruptured Aneurysm	30	3.7 (2–8)	7.9 (3–18)	30	46.7%	62.3 (46–84)	DAPT pre-procedure, continued for 4 months, followed by SAPT	DSA/MR	6.7% 1 Haemorrhagic event 1 Thromboembolic event
Tsai et al. [22]	RC	WNA (2, 3.4% ruptured)	58	3.6 (2.4–4.4)	N/A	58	22.4%	63.5 (56–71)	DAPT 5–7 days pre-procedure, continued for 3–6 months, followed by SAPT	DSA	6.9% 3 Transient stent-associated Thrombosis 1 Aneurysm rupture
Ten Brinck et al. [9]	RC	Aneurysm WNA (25; 92.6%) (10, 37% ruptured, separate analysis can be performed)	27	4.2 ± 1.67	1.25 ± 0.57	27	40.7%	55 ± 12.5	DAPT 5 days pre-procedure, continued for 3 months, followed by aspirin	Primarily MRA DSA if MRA is not available	14.8% 4 Transient neurological deficit
Cay et al. [5]	RC	Intracranial aneurysm	48	3.8 (1.5–8.7)	N/A	43	37.5%	51 (23–74)	DAPT pre-procedure, continued for 4 months, followed by aspirin	MRA at 6–12 weeks DSA at 6–12 months	0%
Ulfert et al. [11]	CS	WNA (2, 5% ruptured)	37	3.3 (1.8–9.0).	N/A	36	35%	56 (19–75)	DAPT 5–10 days pre- procedure, continued for 3-6 months, followed by SAPT for ≥ 6 months	Primarily MRA DSA was performed to determine retreatment	2.7% 1 Transient neurological deficit

CS Case series, *DAPT* dual antiplatelet therapy, *DSA* digital subtraction angiography, *MR* magnetic resonance, *MRA* magnetic resonance angiography, *N/A* not available, *PC* prospective cohort, *RC* retrospective cohort, *RR1* Raymond–Roy Class I, *RR2* Raymond–Roy Class II, *SAPT* single antiplatelet therapy, *SD* standard deviation, *WNA* wide-necked aneurysm

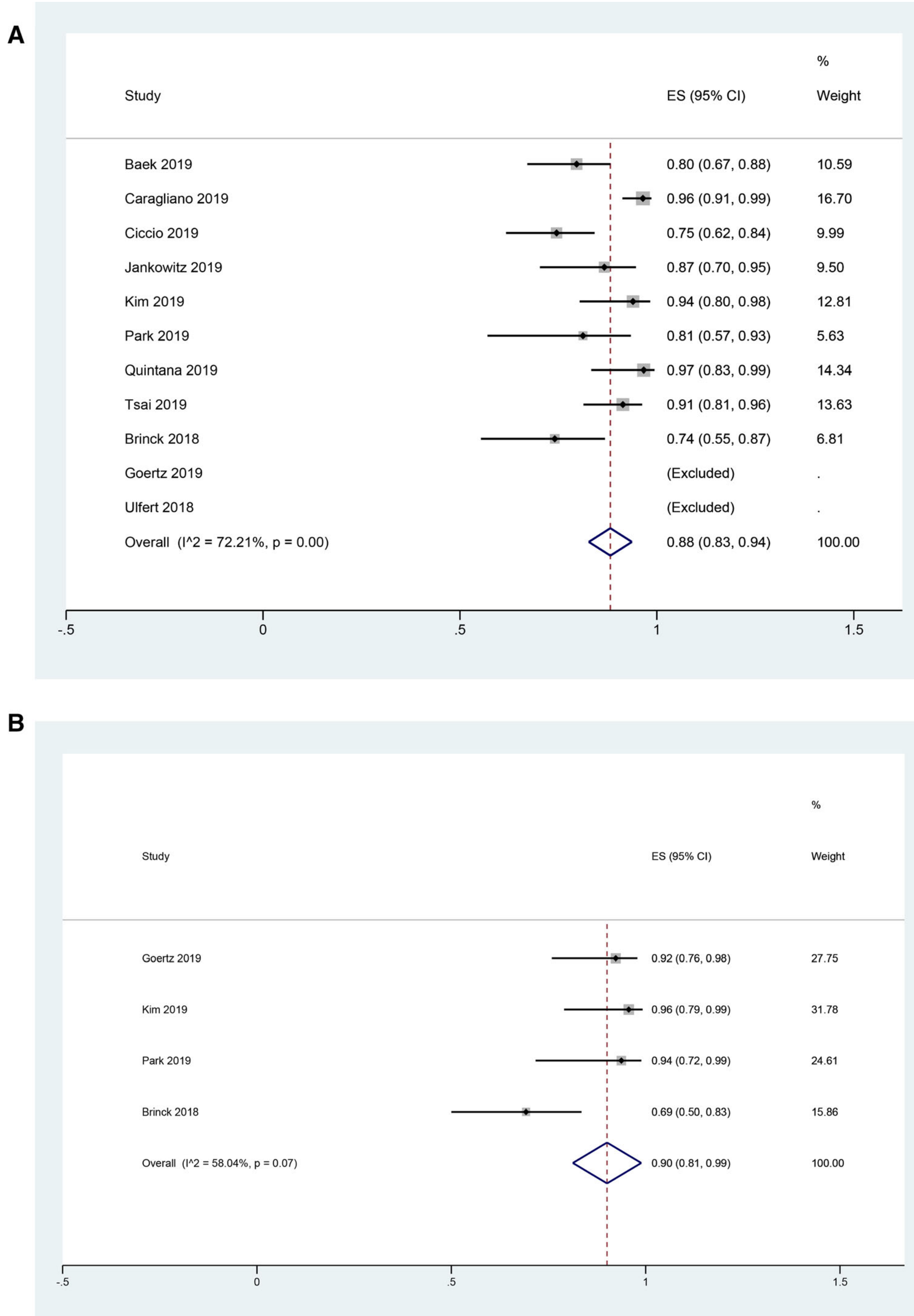
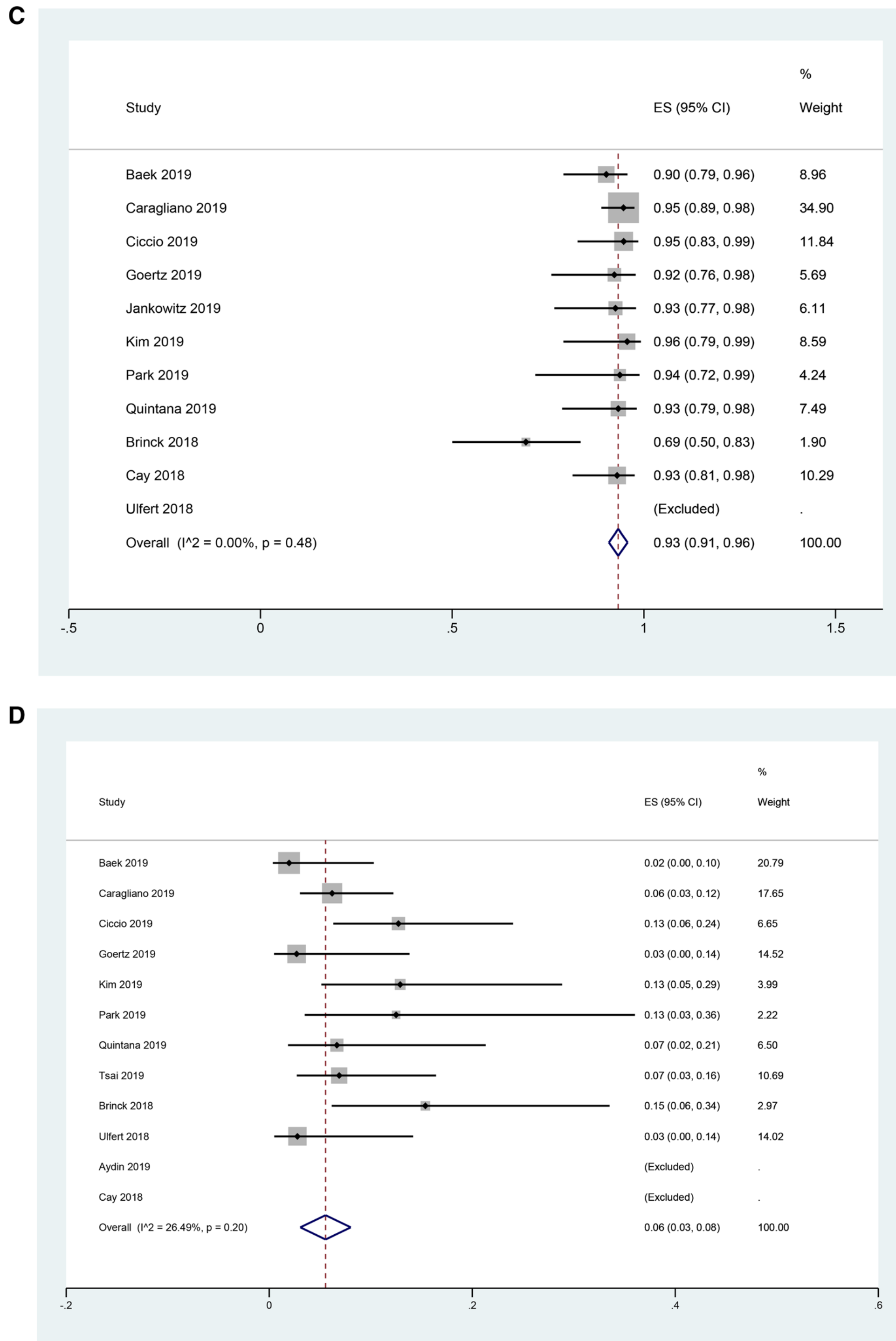


Fig. 2 Rate of occlusion and complications. Forest-plot showing the rate of adequate occlusion (RR1 + RR2) of intracranial aneurysm immediately after procedure (**A**), 6-month follow-up (**B**), and at the end of follow-up (**C**). The rate of complications was shown in **D**. *ES* effect estimate, *RR1* Raymond–Roy Class I, *RR2* Raymond–Roy Class II

identified as a predictor of complete occlusion by coil embolization [23]; however, the association was not observed at the end of follow-up.

Meta-regression analysis revealed that the aneurysm neck size affects the initial adequate occlusion. The association was previously described in an earlier study [8]. Complete coil occlusion of the WNA is difficult because the instable coil mass potentially leads to coil migration or impingement into the parent artery [24]. This problem potentially leads to a lower initial occlusion rate. The definition of WNA varies greatly [25], and the mean aneurysm neck size varies across studies; hence, meta-regression may provide more information regarding the influence of aneurysm neck size. Previously, older age was found to be an independent predictor of aneurysm recanalization in patients undergoing stent-assisted coiling, and the mechanism was hypothesized to be due to a weaker neointimal response in older patients [26]. Such

Fig. 2 continued



phenomena may explain the significance of age on the aneurysm occlusion found in the meta-regression.

Currently, there are multiple stents that are available to be used in stent-assisted coiling procedures, namely, Solitaire (Medtronic Inc, Mansfield, MA), Neuroform (Stryker Neurovascular, Fremont, CA), Enterprise (Cordis Neurovascular, Inc., Miami Lakes, FL), Leo (Balt, Montmorency, France), Leo Baby (Balt, Montmorency, France), and Low-profile Visualized intraluminal support (LVIS Jr) (MicroVention-Terumo, Inc., Tustin, CA). Compared to other stents, the Neuroform Atlas stents are available from diameters ranging from 3 to 4.5 mm and can be placed in vessels ranging from 2 to 4.5 mm with multiple stent lengths available. These wide ranges of

Table 2 Procedural outcomes of patients included in meta-analysis

Authors	Immediate adequate occlusion (%)	6-months adequate occlusion (%)	Adequate occlusion at the end of follow-up (%)	Mean/median follow-up (months)
Aydin et al. [16]	N/A	N/A	N/A	11.8
Baek et al. [14]	79.6	N/A	90.2	4.8
Caragliano et al. [15]	96.5	N/A	94.7	12
Ciccio et al. [12]	74.5	N/A	94.7	16
Goertz et al. [17]	100.0	92.3	92.3	6.9
Jankowitz et al. [18] (ATLAS IDE trial)	86.7	N/A	92.6	12
Kim et al. [19]	93.9	95.7	95.7	6
Park et al. [20]	81.3	93.8	93.8	6
Quintana et al. [21]	96.7	N/A	93.3	12
Tsai et al. [22]	91.4	N/A	N/A	N/A
Ten Brinck et al. [9]	74.1	69.2	69.2	6
Cay et al. [5]	N/A	N/A	93.02	8.7
Ulfert et al. [11]	100	N/A	100	6.1

Table 3 Result of the meta-analysis

	Effect size	Heterogeneity	Number of studies
Immediate			
Adequate occlusion	88% (83–94%)	72.21%, $p < 0.001$	9
RR1	68% (60–77%)	81.87%, $p < 0.001$	12
RR2	21% (15–27%)	66.10%, $p < 0.001$	11
Periprocedural complications	5% (3–8%)	21.28%, $p = 0.24$	11
6-months			
Adequate occlusion	90% (81–99%)	58.04%, $p = 0.07$	4
RR1	70% (59–82%)	37.95%, $p = 0.18$	4
RR2	16% (9–24%)	0%, $p = 0.61$	4
End of follow-up			
Adequate occlusion	93% (91–96%)	0%, $p = 0.48$	10
RR1	80% (73–88%)	70.84%, $p < 0.001$	11
RR2	12% (8–16%)	0%, $p = 0.47$	8
Mean follow-up	9.03 ± 1.03	–	12
Unruptured subgroup			
Adequate occlusion	85% (78–93%)	64.22%, $p = 0.01$	7
Adequate occlusion 6 months	90% (79–100%)	55.70%, $p = 0.10$	3
Adequate occlusion at end	93% (90–96%)	0%, $p = 0.63$	8
Periprocedural complications	9% (2–15%)	58.33%, $p = 0.05$	5
Mean follow-up	8.93 ± 1.41	–	8
WNA subgroup			
Adequate occlusion	86% (80–93%)	74.26%, $p < 0.001$	8
Adequate occlusion 6 months	88% (75–100%)	71.99%, $p = 0.03$	3
Adequate occlusion at end	93% (89–97%)	29.75%, $p = 0.20$	7
Periprocedural complications	6% (3–9%)	38.09%, $p = 0.13$	8
Mean follow-up	8.61 ± 1.46	–	8

RR1 Raymond–Roy Class I, *RR2* Raymond–Roy Class II, *WNA* wide-necked aneurysm

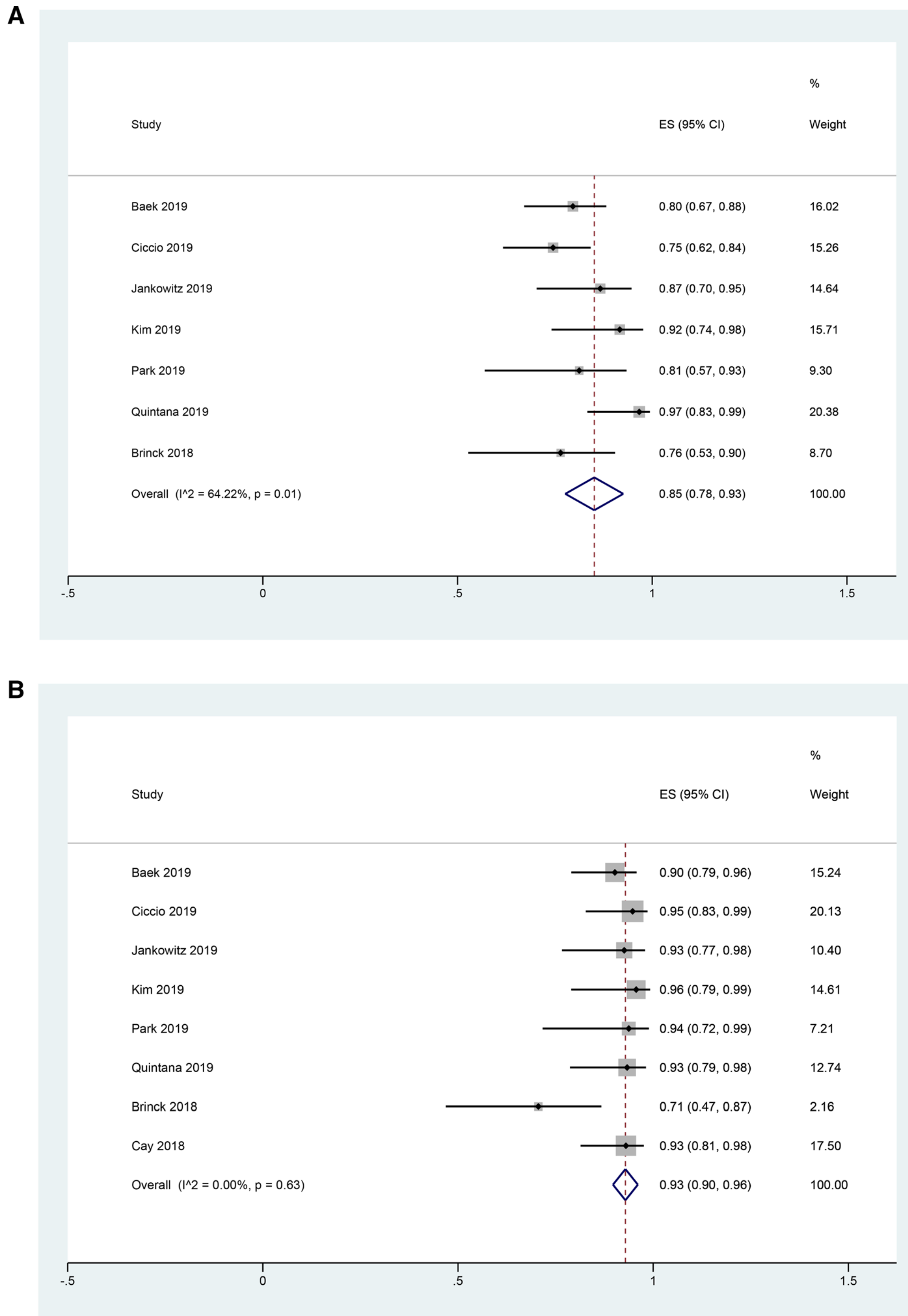


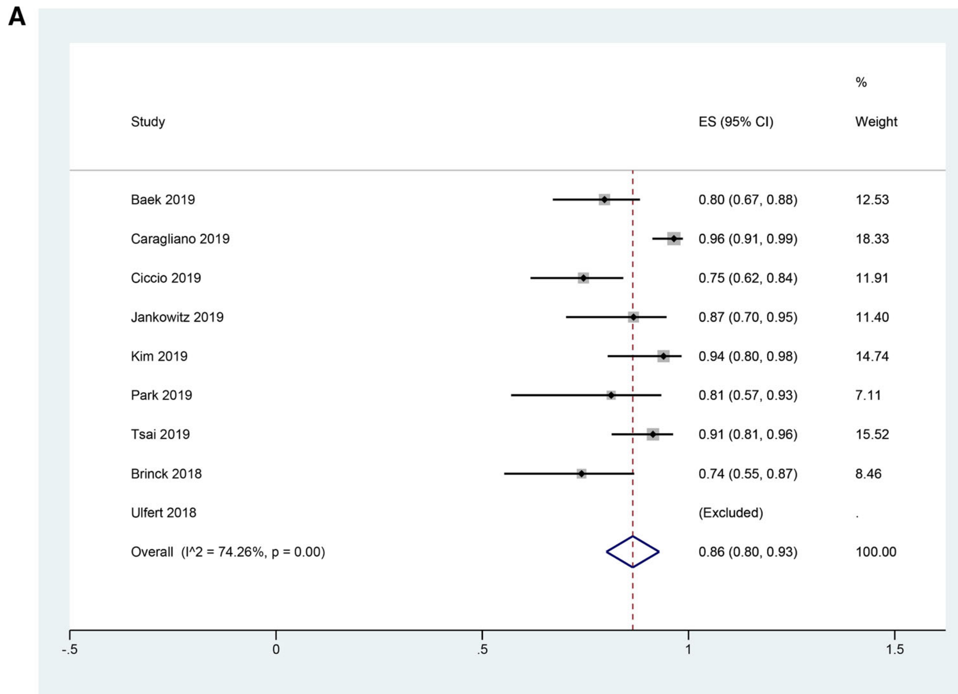
Fig. 3 Rate of occlusion in unruptured aneurysm subgroup. Forest-plot is showing the rate of adequate occlusion (RR1 + RR2) of unruptured aneurysm subgroup immediately after the procedure (**A**) and at the end of follow-up (**B**). *ES* effect estimate, *RR1* Raymond–Roy Class I, *RR2* Raymond–Roy Class II

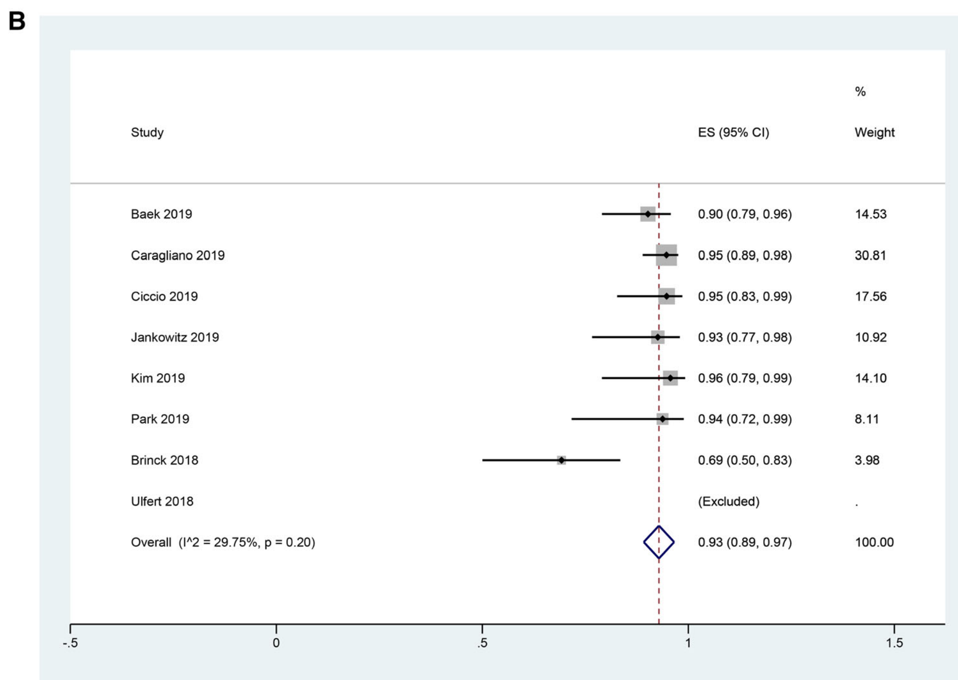
available stents are supposed to improve the accuracy and stability of stent placement within the vessel [11].

Neuroform stents (Earlier model) and Enterprise stents were the most widely used intracranial stents for stent-assisted coiling; the former was associated with 2.3% deployment failure, and the latter was associated with 0.2% deployment failure [27]. In the present meta-analysis, the rate of deployment failure was 0.17%, a significant improvement compared to the earlier model. Moreover, Neuroform Atlas stents have been shown to have good apposition even in vessels with strong curvature [28]. However, due to its partially open-cell design, resheathing of the device is not possible, and thus, accurate and reliable measurements of the target vessel must be performed prior to choosing the stent size [11].

Stent-assisted coiling has been shown to be superior to coiling alone in both ruptured and unruptured aneurysms [29, 30]. Furthermore, stent-assisted coiling seemed to be

Fig. 4 Rate of occlusion in wide-necked aneurysm subgroup. Forest-plot is showing the rate of adequate occlusion (RR1 + RR2) of wide-necked aneurysm subgroup immediately after the procedure (**A**) and at the end of follow-up (**B**). *ES* effect estimate, *RR1* Raymond–Roy Class I, *RR2* Raymond–Roy Class II





non-inferior compared to the balloon remodelling technique, or even superior, although more evidence is needed [31, 32]. Stent-assisted coiling was also shown to be more appropriate than the balloon remodelling technique in ruptured WNA [33]. This meta-analysis demonstrated that the rate of adequate occlusion for WNA using the Neuroform Atlas was 86% initially, increasing to 93% after a mean 8.61 months follow-up with a periprocedural complication rate of 6%. Other methods of assisted coiling using low-profile stents, such as the LVIS Jr stent, have an 89.6% adequate occlusion rate but a concerning periprocedural complication incidence (11.2–17.2%) [12, 34]. Woven Endobridge is another device that can be used to assist coiling; it has an 82–85% adequate occlusion rate at approximately 12 months of follow-up with a good safety profile [35, 36]. Another option that can be used is T-stent-assisted coiling, which has been shown to result in an 83% complete occlusion rate, increasing to 90% at a mean

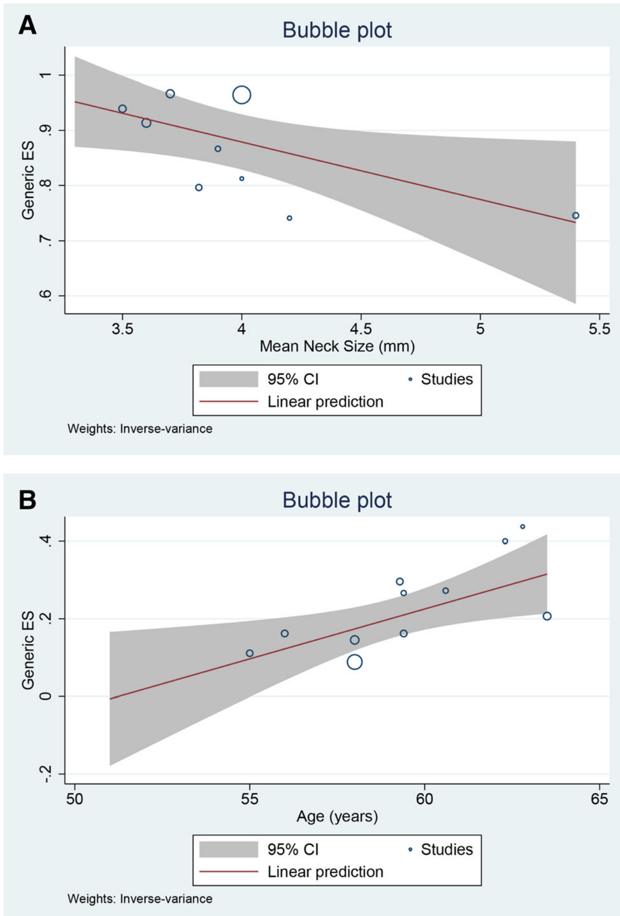


Fig. 5 Meta-regression. Bubble-plot showed that the rate of adequate occlusion after procedure was affected by mean aneurysm neck size (**A**). Meanwhile, the rate of RR2 was affected by age (**B**). *RR2* Raymond–Roy Class II

30-month follow-up along with a 13.7% rate of periprocedural complications [37].

A limitation of this systematic review was the unavailability of randomized controlled trials (RCTs); all of the studies were only single-arm studies and therefore lack direct comparison to the other devices. Furthermore, most of the studies were retrospective in design. RCTs are necessary to establish evidence on whether the Neuroform Atlas is superior to other devices. Additionally, the 6-month outcome was inadequately powered.

Conclusion

Neuroform Atlas-assisted coiling has 88% initial adequate occlusion, which increases on follow-up. The mean aneurysm neck size seemed to affect the initial adequate occlusion. Initial adequate occlusion was 85% in unruptured aneurysms and 86% in WNA. The rate of periprocedural complications was 6%. Nevertheless, RCTs are needed to provide direct comparisons with other devices.

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Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Pouratian N. Endovascular management of unruptured intracranial aneurysms. J Neurol Neurosurg Psychiatry. 2006;77(5):572–8. https://doi.org/10.1136/jnnp.2005.078469.
2. Lindgren A, DI Vergouwen M, van der Schaaf I, et al. Endovascular coiling versus neurosurgical clipping for people with aneurysmal subarachnoid haemorrhage. Cochrane Database Syst Rev. 2018. https://doi.org/10.1002/14651858.CD003085.pub3.
3. Hong Y, Wang YJ, Deng Z, Wu Q, Zhang JM. Stent-assisted coiling versus coiling in treatment of intracranial aneurysm: a systematic review and meta-analysis. PLoS ONE. 2014. https://doi.org/10.1371/journal.pone.0082311.
4. Zhang X, Zuo Q, Tang H, et al. Stent assisted coiling versus non-stent assisted coiling for the management of ruptured intracranial aneurysms: a meta-analysis and systematic review. J Neurointerv Surg. 2019;11(5):489–96. https://doi.org/10.1136/neurintsurg-2018-014388.
5. Cay F, Peker A, Arat A. Stent-assisted coiling of cerebral aneurysms with the Neuroform Atlas stent. Interv Neuroradiol. 2018;24(3):263–9. https://doi.org/10.1177/1591019917753710.
6. Ishihara H, Ishihara S, Niimi J, et al. Risk factors for coil protrusion into the parent artery and associated thrombo-embolic events following unruptured cerebral aneurysm embolization. Interv Neuroradiol. 2015;21(2):178–83. https://doi.org/10.1177/1591019915582375.
7. Shanno GB, Armonda RA, Benitez RP, Rosenwasser RH. Assessment of acutely unsuccessful attempts at detachable coiling in intracranial aneurysms. Neurosurgery. 2001;48(5):1066–74. https://doi.org/10.1097/00006123-200105000-00019.
8. Standhardt H, Boecher-Schwarz H, Gruber A, Benesch T, Knosp E, Bavinzski G. Endovascular treatment of unruptured intracranial aneurysms with guglielmi detachable coils. Stroke. 2008;39(3):899–904. https://doi.org/10.1161/STROKEAHA.107.496372.
9. Ten Brinck MFM, De Vries J, Bartels RHMA, Grotenhuis JA, Boogaarts HD. Neuro form atlas stent-assisted coiling: preliminary results. Clin Neurosurg. 2019;84(1):179–89. https://doi.org/10.1093/neuros/nyy048.
10. Administration USF and D. Summary of safety and effectiveness data; 2019. https://www.fda.gov/medical-devices/recently-approved-devices/neuroform-atlasr-stent-system-p180031.
11. Ulfert C, Pham M, Sonnberger M, et al. The Neuroform Atlas stent to assist coil embolization of intracranial aneurysms: a multicentre experience. J Neurointerv Surg. 2018;10(12):1192–6. https://doi.org/10.1136/neurintsurg-2017-013516.
12. Ciccio G, Robert T, Smajda S, et al. 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.

2019;11(12):1239–42. https://doi.org/10.1136/neurintsurg-2019-015175.
13. Roy D, Milot G, Raymond J. Endovascular treatment of unruptured aneurysms. Stroke. 2001;32(9):1998–2004. https://doi.org/10.1161/hs0901.095600.
14. Baek JW, Jin SC, Kim JH, et al. Initial multicentre experience using the neuroform atlas stent for the treatment of un-ruptured saccular cerebral aneurysms. Br J Neurosurg. 2019. https://doi.org/10.1080/02688697.2019.1680796.
15. Caragliano AA, Papa R, Pitrone A, et al. The low-profile Neuroform Atlas stent in the treatment of wide-necked intracranial aneurysms—immediate and midterm results: an Italian multicenter registry. J Neuroradiol. 2019. https://doi.org/10.1016/j.neurad.2019.03.005.
16. Aydin K, Balci S, Sencer S, Barburoglu M, Umutlu MR, Arat A. Y-stent-assisted coiling with low-profile Neuroform Atlas stents for endovascular treatment of wide-necked complex intracranial bifurcation aneurysms. Neurosurgery. 2019. https://doi.org/10.1093/neuros/nyz516.
17. Goertz L, Dorn F, Siebert E, et al. Safety and efficacy of the Neuroform Atlas for stent-assisted coiling of intracranial aneurysms: a multicenter experience. J Clin Neurosci. 2019;68:86–91. https://doi.org/10.1016/j.jocn.2019.07.030.
18. Jankowitz BT, Hanel R, Jadhav AP, et al. Neuroform Atlas stent system for the treatment of intracranial aneurysm: primary results of the atlas humanitarian device exemption cohort. J Neurointerv Surg. 2019;11(8):801–6. https://doi.org/10.1136/neurintsurg-2018-014455.
19. Kim CH, Kim YH, Sung SK, Son DW, Song GS, Lee SW. Clinical safety and effectiveness of stent-assisted coil embolization with neuroform atlas stent in intracranial aneurysm. J Korean Neurosurg Soc. 2019;63(1):80.
20. Park KY, Jang CK, Lee JW, Kim DJ, Kim BM, Chung J. Preliminary experience of stent-assisted coiling of wide-necked intracranial aneurysms with a single microcatheter. BMC Neurol. 2019;19(1):1–9. https://doi.org/10.1186/s12883-019-1470-8.
21. Quintana EM, Valdes PV, Deza EM, et al. Initial experience and one-year follow-up with Neuroform Atlas stent system for the treatment of brain aneurysms. Interv Neuroradiol. 2019. https://doi.org/10.1177/1591019918819087.
22. Tsai JP, Hardman J, Moore NZ, et al. Early post-humanitarian device exemption experience with the Neuroform Atlas stent. J Neurointerv Surg. 2019;11(11):1141–4. https://doi.org/10.1136/neurintsurg-2019-014874.
23. Johnston SC, Higashida RT, Barrow DL, et al. Recommendations for the endovascular treatment of intracranial aneurysms. Stroke. 2002;33(10):2536–44. https://doi.org/10.1161/01.STR.0000034708.66191.7D.
24. Kim J-W, Park Y-S. Endovascular treatment of wide-necked intracranial aneurysms: techniques and outcomes in 15 patients. J Korean Neurosurg Soc. 2011;49(2):97. https://doi.org/10.3340/jkns.2011.49.2.97.
25. Hendricks BK, Yoon JS, Yaeger K, et al. Wide-neck aneurysms: systematic review of the neurosurgical literature with a focus on definition and clinical implications. J Neurosurg. 2019. https://doi.org/10.3171/2019.3.jns183160.
26. Chalouhi N, Jabbour P, Singhal S, et al. Stent-assisted coiling of intracranial aneurysms. Stroke. 2013;44(5):1348–53. https://doi.org/10.1161/STROKEAHA.111.000641.
27. King B, Vaziri S, Singla A, Fargen KM, Mocco J. Clinical and angiographic outcomes after stent-assisted coiling of cerebral aneurysms with enterprise and Neuroform stents: a comparative analysis of the literature. J Neurointerv Surg. 2015;7(12):905–9. https://doi.org/10.1136/neurintsurg-2014-011457.
28. Kato N, Yuki I, Ishibashi T, et al. Visualization of stent apposition after stent-assisted coiling of intracranial aneurysms using high resolution 3D fusion images acquired by C-arm CT. J Neurointerv Surg. 2019. https://doi.org/10.1136/neurintsurg-2019-014966.
29. Yang H, Sun Y, Jiang Y, et al. Comparison of stent-Assisted coiling vs coiling alone in 563 intracranial aneurysms: safety and efficacy at a high-volume center. Neurosurgery. 2015;77(2):241–7. https://doi.org/10.1227/NEU.0000000000000765.
30. Zhao B, Tan X, Yang H, et al. Stent-assisted coiling versus coiling alone of poor-grade ruptured intracranial aneurysms: a multicenter study. J Neurointerv Surg. 2017;9(2):165–8. https://doi.org/10.1136/neurintsurg-2016-012259.
31. Chalouhi N, Starke RM, Koltz MT, et al. Stent-assisted coiling versus balloon remodeling of wide-neck aneurysms: comparison of angiographic outcomes. Am J Neuroradiol. 2013;34(10):1987–92. https://doi.org/10.3174/ajnr.A3538.
32. Consoli A, Vignoli C, Renieri L, et al. Assisted coiling of saccular wide-necked unruptured intracranial aneurysms: stent versus balloon. J Neurointerv Surg. 2016;8(1):52–7. https://doi.org/10.1136/neurintsurg-2014-011466.
33. Cai K, Zhang Y, Shen L, Ni Y, Ji Q. Comparison of stent-assisted coiling and balloon-assisted coiling in the treatment of ruptured wide-necked intracranial aneurysms in the acute period. World Neurosurg. 2016;96:316–21. https://doi.org/10.1016/j.wneu.2016.09.029.
34. Samaniego EA, Mendez AA, Nguyen TN, et al. LVIS Jr device for Y-stent-assisted coil embolization of wide-neck intracranial aneurysms: a multicenter experience. Interv Neurol. 2018;7(5):271–83. https://doi.org/10.1159/000487545.
35. Cagnazzo F, Ahmed R, Dargazanli C, et al. Treatment of wide-neck intracranial aneurysms with the woven endobridge device associated with stenting: a single-center experience. Am J Neuroradiol. 2019;40(5):820–6. https://doi.org/10.3174/ajnr.A6032.
36. Arthur AS, Molyneux A, Coon AL, et al. The safety and effectiveness of the woven endobridge (web) system for the treatment of wide-necked bifurcation aneurysms: final 12-month results of the pivotal web intrasaccular therapy (web-it) study. J Neurointerv Surg. 2019;11(9):924–30. https://doi.org/10.1136/neurintsurg-2019-014815.
37. Aydin K, Stracke CP, Barburoglu M, et al. Long-term outcomes of wide-necked intracranial bifurcation aneurysms treated with T-stent-assisted coiling. J Neurosurg. 2019. https://doi.org/10.3171/2019.9.jns191733.