Review Article

Stent-Assisted Coiling of Unruptured Intracranial Aneurysms with Wide Neck

Abstract

Objective: Morbidity and mortality in patients experiencing the rupture of intracranial aneurysm ruptures are high. We conducted a systematic review and meta-analysis to investigate the role of stent-assisted coiling (SAC) for unruptured intracranial aneurysms (UIAs) with wide neck. **Materials and Methods:** The current meta-analysis was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. Pooled proportions with 95% confidence intervals (CIs) of ten outcomes of interest were calculated. **Results:** We finally reviewed 13 studies, including 976 patients. The technical success of the method was 98.43% (95% CI: 95.62–99.95). Early outcomes included total periprocedural obliteration with a rate of 50.20% (95% CI: 36.09–64.30) and periprocedural rupture with zero rate. During the follow-up period, ranging from 6 months to 2 years, the total postprocedural obliteration rate was 63.83% (95% CI: 45.80–80.18) and the overall late rupture rate was 0.41% (95% CI: 0.00–2.38). The pooled in-stent stenosis rate was calculated at 1.24% (95% CI: 0.02–3.63). We also estimated a pooled rate of 0.02% (95% CI: 0.00–0.51) and 4.33% (95% CI: 2.03–7.23) for total mortality and overall neurological complications, respectively. A pooled rate of 3.94% (95% CI: 1.48–7.33) was found for stroke. Finally, the recanalization rate was recorded at 7.07% (95% CI: 4.35–10.26). **Conclusions:** SAC of UIAs with wide neck seems to be a safe and acceptable alternative to surgical clipping. Although early results concerning total periprocedural obliteration may be modest, follow-up outcomes may be indicative of adequate occlusion of treated UIAs.

Keywords: *Intracranial aneurysm, stent-assisted coiling, wide neck*

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Introduction

The incidence of cerebral aneurysms, although difficult to estimate, is reported around 0.2%–7.9% in autopsy data.[1] The ratio of ruptured to unruptured (incidental) aneurysms is 5:3–5:6, making almost 50% of these aneurysm ruptures during life.[1] Morbidity and mortality in patients experiencing significant intraoperative rupture are approximately 30%–35%,[1] thus making this pathology rather challenging to treat. Risk for rupture for incidental findings depends on many factors. Among them, aneurysm diameter is mostly important, with an estimated annual risk for aneurysms of diameter <10 mm at 0.05% and more than 1% for those with diameters >10 mm.[1]

The optimal treatment for unruptured intracranial aneurysms (UIAs) depends highly on the patient's general condition, the anatomy of the aneurysm, and the surgeon's experience and must be weighed against the natural history of the condition. Treatment options include surgical clipping across the neck of the aneurysm or vascular bypass to maintain flow distal to trapped segment.[1] At the same time, there have been considerable developments in the field of endovascular technology concerning various methods for the cure of intracranial aneurysms. What is more, the basic coil occlusion technique[2] has expanded in terms of use through the evolution of the soft and three-dimensional coil technology, along with the Guglielmi coil first use in 1991.

The introduction of balloons and stents to the endovascular armamentarium[2] has allowed better efficacy during endovascular coiling, not only on small-to-medium-sized aneurysms with narrow necks but also on wide-neck aneurysms' treatment. Stents with additional use of the coils reduce the

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possibility of dissection or vessel rupture. Implanting a stent across the neck area is used as a prop to the coil mass, thus collaborating to a change in the local hemodynamic parameters. This results in directing the flow and providing a substrate for endothelialization in that area,[2] while it is obvious that a self-expanding stent can be easily positioned in the intracranial vessel.[3] As far as wide-necked aneurysms are concerned (namely aneurysms with an aspect dome-to-neck ratio of <2 or with a neck size >4 mm), it should be noted that the latter has the possibility to be coiled with the assistance of balloon-assisted techniques or stent-assisted coiling (SAC).[2]

The aim of this systematic review and meta-analysis was to investigate the clinical outcomes of SAC limited to the UIAs with wide neck. We explored the literature in terms of case series, concerning the mortality and the morbidity, the complications, the access, and the techniques of the method.

Materials and Methods

This meta-analysis was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. Google Scholar, PubMed, and Cochrane Collaboration were systematically searched for relevant publications, while we followed a snowball process in the reference lists of the eligible articles to retrieve additional relevant articles.

We used the following terms for search purpose: stent-assisted coiling, intracranial aneurysm, and wide neck. We searched for all scientific papers, without gender or language restriction, until January 2019. We investigated studies focusing on SAC limited to the UIAs with wide neck, including aneurysms with an aspect dome-to-neck ratio of <2 or with a neck size >4 mm. Studies reporting on intracranial aneurysms without wide neck and on ruptured intracranial aneurysms with wide neck were excluded.

Data extracted from eligible studies included the first author's name, study year, country in which the study was conducted, total number of patients, number of male or female patients, follow-up (months), the mean age of patients, inclusion and exclusion criteria, vascular access (transfemoral), type of anesthesia applied, type of anticoagulation used, type of endograft used, and description of complications during follow-up.

We also extracted the number of patients with outcomes, which were thereafter described as early and late. Early outcomes were defined as outcomes during the periprocedural period and late ones as those ones occurring beyond this period. Outcomes of interest included the following: technical success, defined as stable device placement and adequate function on computed tomography angiography, total periprocedural obliteration, periprocedural rupture, total obliteration during follow-up, overall late rupture, pooled in-stent stenosis, total mortality, any neurological complication, stroke, and recanalization.

Statistical analysis

The outcome rates in patients with SAC in UIAs with wide neck were estimated for each study and reported as the proportion of patients with the corresponding outcome among all patients with SAC in UIA with wide neck. Values of the concomitant outcomes were subsequently appropriately calculated, expressed as proportions and 95% confidence intervals (CIs), and thereafter transformed into quantities according to the Freeman–Tukey variant of the arcsine square-root transformed proportion. The pooled effect estimates were calculated as the back-transformation of the weighted mean of the transformed proportions, using DerSimonian–Laird weights of a random-effects model, and expressed as percentage proportions. One meta-analysis was conducted taking into account all case series.

Formal statistical test for heterogeneity using the I^2 test was performed. Publication bias was assessed using the Egger test for small-study effects as well as visual inspection of funnel plots. We used Stata statistical software version 14 (StataCorp LP, College Station, TX, USA) for the analyses.

Results

Study characteristics

We identified 886 potentially eligible studies after a literature search [Figure 1]. We excluded a total of 82 duplicate records, as well as 17 articles which were referred to *in vitro* experiments and *in vivo* ones based on laboratory animals. Further, 76 case reports and 3 articles were referred to children and were also excluded. Review of the titles and abstracts evidenced that 201 articles were irrelevant. We also removed 323 articles because they were reviews and not original articles or they did not refer to aneurysms with wide neck. A total of 184 articles were further evaluated. Among them, 130 and 28 articles including both ruptured and unruptured aneurysms with wide neck or only ruptured ones, respectively, were excluded. Finally, 26 articles were deemed relevant to be included in the systematic review. However, 11 articles were further excluded as they were referred to endovascular treatment of UIAs with wide neck using flow diverters or temporary stent, as well as 2 articles, because of overlapping population. Eventually, 13 articles participated in the meta-analysis,[4-16] corresponding to a total of 976 patients who underwent SAC of their UIAs with wide neck [Supplemental Table 1].

The included eligible studies in the systematic review were published from 2005 to 2017. Among 976 patients included in our systemic review, 384 were females (72.6%). For another 447 patients, the gender was not specified. The access vessel was noted in 466 of 976 patients. Among them, the device delivery system was advanced

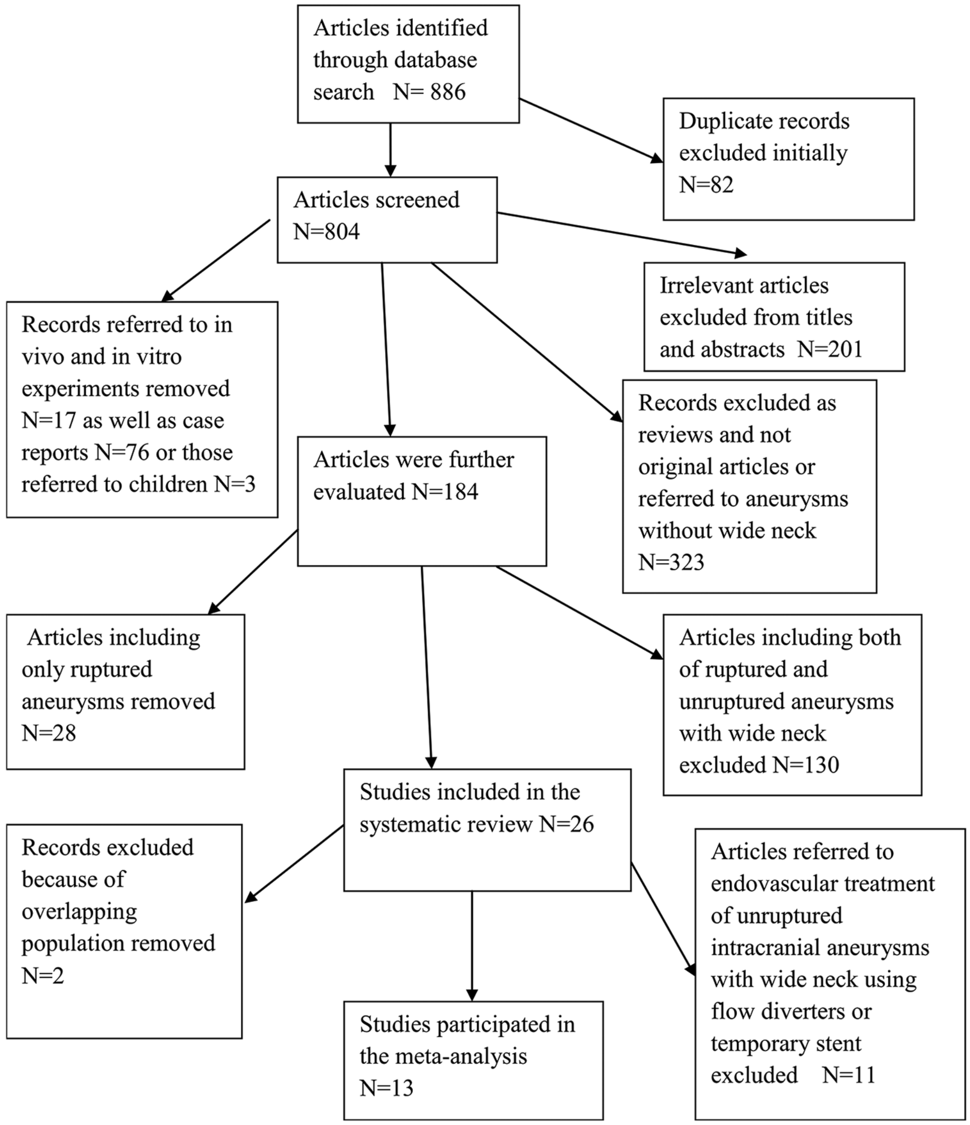

Figure 1: Flowchart of eligible studies

transfemorally. Neuroform and Enterprise devices were used in the majority of the patients. The procedure took place under general anesthesia in 460 cases (47.1%), whereas the type of anesthesia was not reported for the remaining patients. The age of the study sample ranged from 18 to 80 years, with an average age of 50 years, and the median follow-up ranged from 6 months to 2 years. The majority of the patients had also aneurysms placed in the anterior circulation. It is worth noting that the majority of the aneurysms in the posterior circulation were located on the basilar tip, while 69 patients with paraclinoid aneurysms were included in our review study. Studies on patients with blister aneurysms were excluded. Moreover, studies on fusiform (n = 500 patients), dissecting (n = 384 patients), mycotic/traumatic (n = 116 patients), or saccular (n = 116 patients) aneurysms were also excluded from our meta-analysis. Finally, antiplatelet drugs were routinely administrated during the periprocedural and postprocedural period along with intravenous heparin during procedure.

Meta-analysis

Our meta-analysis found that the technical success of the method was 98.43% [95% CI: 95.62–99.95; Figure 2]. Among the other early outcomes, total periprocedural obliteration was at 50.20% [95% CI: 36.09–64.30; Figure 3], while periprocedural rupture was zero. The pooled rate for total obliteration during follow-up was 63.83% (95% CI: 45.80–80.18), while overall late rupture was estimated at 0.41% (95% CI: 0.00–2.38). However, this figure was estimated from only four studies,[4,7,9,12] corresponding to only 4 events out of 365 patients, as these studies were the only which provided with corresponding data. Similarly, the pooled in-stent stenosis rate was 1.24% (95% CI: 0.02–3.63), and it was estimated from six studies,[5,8,10,12,14,15] with 8 events out of 261 cases during follow-up.

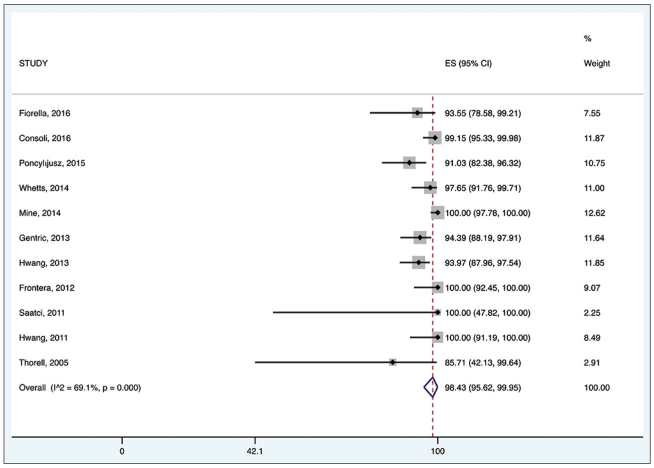

Figure 2: Forest plot presenting the meta-analysis of technical success based on event rates for the use of stent-assisted coiling of unruptured intracranial aneurysms with wide neck. Event rates in the individual studies are presented as squares with 95% confidence intervals presented as extending lines. The pooled event rate with its 95% confidence intervals is depicted as a diamond

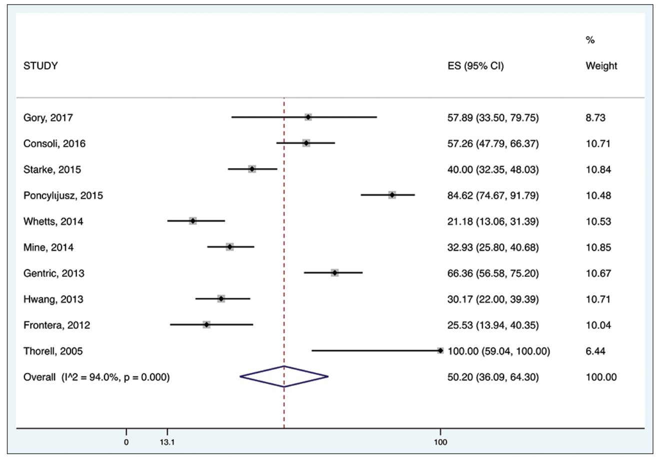

Figure 3: Forest plot presenting the meta-analysis of total periprocedural obliteration based on event rates for the use of stent-assisted coiling of unruptured intracranial aneurysms with wide neck. Event rates in the individual studies are presented as squares with 95% confidence intervals presented as extending lines. The pooled event rate with its 95% confidence intervals is depicted as a diamond

Total mortality was estimated with a pooled rate of 0.02% (95% CI: 0.00–0.51). Any neurological complication and stroke rates were found to be 4.33% [95% CI: 2.03–7.23; Figure 4] and 3.94% (95% CI: 1.48–7.33), respectively. Finally, regarding recanalization, the pooled rate was 7.07% (95% CI: 4.35–10.26).

Discussion

The meta-analysis was derived from a comprehensive review of 13 case series and provided pooled outcome rates for patients treated with SAC for intracranial aneurysms with wide neck. Although high-risk patients constituted our study cohort, a high technical success rate of 98.4% was recorded.

Concerning anatomical results, our rate of immediate complete occlusion was lower (50.20%) than in a meta-analysis for stand-alone coiling (86.1%).[17] This can be explained by the fact that coil packing after stent placement maneuverability and the use of dual antiplatelet therapy and heparin during the procedure may limit thrombosis around coil mass. The low rates of complete occlusion underline potential difficulties of SAC in relation to aneurysmal morphology, such as the size and localization. It was observed that, contrary to comparatively nonsatisfactory instant anatomical results, complete occlusion was achieved at follow-up reaching 63.83%. The thrombosis that is in progress could be further made clear through various speculations and theories. Primarily, certain computational and animal studies indicated that conventional self-expanding stents provoke a lessening of the flow velocity to the aneurysm and secondary wall shear stress.[18-21] It is also noteworthy that an arterial angular remodeling with migration and narrowing of the flow impingement zone along with a decrease in apical pressure are caused by intracranial stents. Certain alterations to the inflow to the sac that might result in thrombosis[22] could also be caused by the straightening. Finally, it should be highlighted that the stent struts that are connecting the aneurysmal neck might as well function as a bioactive scaffold for neointimal growth.[22] For the same reasons that promote progressive aneurysm occlusion, the rate of recanalization of intracranial aneurysms by SAC is low, as also confirmed by our study (7.07%). This rate is also significantly lower than in meta-analyses for a stand-alone coiling (24.4%).[17]

The mortality and neurological complication rates (0.02% and 4.33%, respectively) reported in our meta-analysis also compare favorably with those reported in the meta-analysis for stand-alone coiling (1.2% and 4.8%, respectively) and for clipping (1.7% and 6.7%, respectively),[17,23] as well as with those mentioned in the studies for balloon-assisted coiling of intracranial aneurysms using the Eclipse 2L double-lumen balloon (0% and 3.2%, respectively) and for low rates of recanalization for wide-necked aneurysms treated with stenting after balloon-assisted coiling (4.6% and 2.3%, respectively). However, we should highlight that in the aforementioned studies for balloon-assisted embolization, the initial complete occlusion rate was approximately 95% higher than this in our study (50.20%). This may have resulted from balloon-assisted technique because the technique can enable denser packing of the aneurysm fundus and neck region or help mold the coil mass to improve its interface with the parent vessel.[24,25]

Regarding the rate of stroke, this was almost 4%. Several factors may explain our low rate of stroke. Primarily, a tight antiplatelet protocol was pursued by the people in treatment. Furthermore, since a progressive thrombosis of the sac is anticipated because of a stent placement, we do not usually dare to acquire neither an immediate

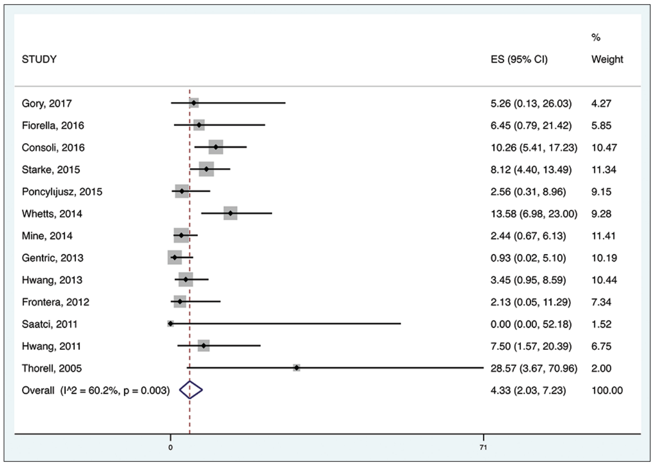

Figure 4: Forest plot presenting the meta-analysis of any neurological complications based on event rates for the use of stent-assisted coiling of unruptured intracranial aneurysms with wide neck. Event rates in the individual studies are presented as squares with 95% confidence intervals presented as extending lines. The pooled event rate with its 95% confidence intervals is depicted as a diamond

occlusion nor a very dense packing. As a third step, it should be mentioned that ruptured intracranial aneurysms with a high chance of being linked to an elevated stroke risk were not incorporated. The latter is due to the fact that ensuing subarachnoid hemorrhage induces vasospasm.[2] In addition, the interventional neuroradiologists usually make an attempt to get a denser packing with a view to succeed in obtaining complete occlusion and further reduce bleeding chances. As a result, there is an elevated chance of coil protrusion at the area of the neck or in the parent artery than in unruptured aneurysms. The coil protrusion might end up in causing thromboembolic events (TEs). Finally, it should be noted that there is a possibility that the availability of the intracranial stents assists in the reduction of the percentage of symptomatic TE complications of coiling used as a rescue therapy to treat coil protrusion or instability and clot formation at the neck.[26]

In our series, we did not observe intraprocedural aneurysmal ruptures, while this rate was 2.6% according to the meta-analyses for stand-alone coiling.[17] The zero rate of aneurysmal rupture may be partially related to the fact that, when possible, the authors of studies in our review did not place the guidewire in the sac but tried to gently advance a microcatheter through the stent. It is worth noting that the overall late rupture was only 0.41%, which could be explained partially by the fact that additional treatment with coils was decided in some cases[11] and the discontinuance of the antiplatelet therapy after some months according to the protocols.

A usual aggravation in-stent stenosis is atheromatous stenosis that is less important to endothelial and fibroelastic reaction. Despite the fact that not a major intimal damage could occur due to self-expanding stents used for stent coiling (SAC), the latter definitely takes place and most possibly causes stability or improvement of the occlusion of intracranial aneurysms with SAC. What is more, this could further cause a certain kind of intrastent stenosis, something which was not common in our series (1.25%). This could be explained by the fact that surgeons administrated routinely antiplatelet therapy including aspirin (325 mg the usual dose) and clopidogrel (75 mg the usual dose) mainly 5 days prior to surgery in combination with 5000 iu heparin intravenous bolus periprocedural which continued usually for additional 6 months for aspirin and 3 months for clopidogrel postprocedural since acute in-stent stenosis often elicits ischemic complications. However, as the premature or excessive prevention of in-stent stenosis may result in hemorrhagic complications before coil embolization, additional treatment for acute in-stent stenosis being delivered after its occurrence could be an option. It is also important to mention that in our study, even this negligible percentage for in-stent stenosis could be justified by aspirin or clopidogrel resistance. The platelet reactivity units should be measured as well as the appropriate dose of other drugs should be determined as an interaction is possible.

Among the SAC limitations are the necessity for double antiplatelet therapy, which is advisable to be kept for a period of 1 month at least. However, this might change in light of coated or absorbable stents.[15] Our findings highlight that SAC is a considerable technical progress in the management of endovascular intracranial aneurysms. It is associated with low rates of morbidity, further enabling a safer treatment of wide-necked UIAs, which is supported by the large number of 976 patients who participate in our meta-analysis

Our study has some limitations. First, in the meta-analysis, we included mainly retrospective studies that did not directly compare different techniques. Second, follow-up images were homogeneous as they were mainly magnetic resonance angiography (MRA) and digital subtraction angiography. However, MRA has been reported to be highly effective and reliable for the follow-up of SAC.[27] Third, heterogeneous aneurysm morphology and location can contribute to treatment bias since they are related to difficulties of endovascular techniques. Similarly, the modality of treatment including different choices of stents by physicians in different institutions is related to treatment bias. Other limitations of the eligible studies included in the meta-analysis were that not all patients complied with treatment during follow-up, along with the fact that some results were attributed to small number of cases, which were referred during follow-up. These two aforementioned limitations might have introduced an indirect publication bias in our study. Finally, in our series, morbidity was associated with TEs. This may have reflected the importance of adequate antiplatelet agent preparation before and even after the successful procedure. Practically, checking for antiplatelet agent resistance on a regular basis would be helpful, but it was not available in the eligible studies.

Conclusions

Our review and meta-analysis pooled together outcome rates of relevant studies and highlighted the feasibility and safety of SAC of UIAs with wide neck. SAC is a relatively new technique, and we might need more experience before sound conclusions can be drawn. In spite of the fact that it might still be premature to make a generalization of the results, it seems that this technique might assist in the treatment of UIA with wide neck and SAC represents an acceptable alternative to surgical clipping.

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Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Greenberg M. Handbook of Neurosurgery. New York: Thieme; 2006.
2. Hanel RA, Lopes DK, Wehman JC, Sauvageau E, Levy EI, Guterman LR, *et al*. Endovascular treatment of intracranial aneurysms and vasospasm after aneurysmal subarachnoid hemorrhage. Neurosurg Clin N Am 2005;16:317-53, ix.
3. Molyneux AJ. Indications for treatment of cerebral aneurysms from an endovascular perspective: The creation of an evidence base for interventional techniques. Neurosurg Clin N Am 2005;16:313-6, ix.
4. Consoli A, Vignoli C, Renieri L, Rosi A, Chiarotti I, Nappini S, *et al*. Assisted coiling of saccular wide-necked unruptured intracranial aneurysms: Stent versus balloon. J Neurointerv Surg 2016;8:52-7.
5. Fiorella D, Arthur A, Boulos A, Diaz O, Jabbour P, Pride L, *et al*. Final results of the US humanitarian device exemption study of the low-profile visualized intraluminal support (LVIS) device. J Neurointerv Surg 2016;8:894-7.
6. Frontera JA, Moatti J, de los Reyes KM, McCullough S, Moyle H, Bederson JB, *et al*. Safety and cost of stent-assisted coiling of unruptured intracranial aneurysms compared with coiling or clipping. J Neurointerv Surg 2014;6:65-71.
7. Gentric JC, Biondi A, Piotin M, Mounayer C, Lobotesis K, Bonafé A, *et al*. Safety and efficacy of neuroform for treatment of intracranial aneurysms: A prospective, consecutive, French multicentric study. AJNR Am J Neuroradiol 2013;34:1203-8.
8. Gory B, Spiotta AM, Di Paola F, Mangiafico S, Renieri L, Consoli A, *et al*. PulseRider for treatment of wide-neck bifurcation intracranial aneurysms: 6-month results. World Neurosurg 2017;99:605-9.
9. Hetts SW, Turk A, English JD, Dowd CF, Mocco J, Prestigiacomo C, *et al*. Stent-assisted coiling versus coiling alone in unruptured intracranial aneurysms in the matrix and platinum science trial: safety, efficacy, and mid-term outcomes. AJNR Am J Neuroradiol 2014;35:698-705.
10. Hwang G, Park H, Bang JS, Jin SC, Kim BC, Oh CW, *et al*. Comparison of 2-year angiographic outcomes of stent- and nonstent-assisted coil embolization in unruptured aneurysms with an unfavorable configuration for coiling. AJNR Am J Neuroradiol 2011;32:1707-10.
11. Hwang SK, Hwang G, Bang JS, Oh CW, Kwon OK. Endovascular enterprise stent-assisted coil embolization for wide-necked unruptured intracranial aneurysms. J Clin Neurosci 2013;20:1276-9.
12. Mine B, Aljishi A, D'Harcour JB, Brisbois D, Collignon L, Lubicz B. Stent-assisted coiling of unruptured intracranial aneurysms: Long-term follow-up in 164 patients with 183 aneurysms. J Neuroradiol 2014;41:322-8.
13. Poncyljusz W, Biliński P, Safranow K, Baron J, Zbroszczyk M, Jaworski M, *et al*. The LVIS/LVIS Jr. Stents in the treatment of wide-neck intracranial aneurysms: Multicentre registry. J Neurointerv Surg 2015;7:524-9.
14. Saatci I, Geyik S, Yavuz K, Cekirge S. X-configured stent-assisted coiling in the endovascular treatment of complex anterior communicating artery aneurysms: A novel reconstructive technique. AJNR Am J Neuroradiol 2011;32:E113-7.
15. Starke RM, Durst CR, Evans A, Ding D, Raper DM, Jensen ME, *et al*. Endovascular treatment of unruptured wide-necked intracranial aneurysms: Comparison of dual microcatheter technique and stent-assisted coil embolization. J Neurointerv Surg 2015;7:256-61.
16. Thorell WE, Chow MM, Woo HH, Masaryk TJ, Rasmussen PA. Y-configured dual intracranial stent-assisted coil embolization for the treatment of wide-necked basilar tip aneurysms. Neurosurgery 2005;56:1035-40.
17. Naggara ON, White PM, Guilbert F, Roy D, Weill A, Raymond J. Endovascular treatment of intracranial unruptured aneurysms: Systematic review and meta-analysis of the literature on safety and efficacy. Radiology 2010;256:887-97.
18. Canton G, Levy DI, Lasheras JC. Hemodynamic changes due to stent placement in bifurcating intracranial aneurysms. J Neurosurg 2005;103:146-55.
19. Canton G, Levy DI, Lasheras JC, Nelson PK. Flow changes caused by the sequential placement of stents across the neck of sidewall cerebral aneurysms. J Neurosurg 2005;103:891-902.
20. Tateshima S, Tanishita K, Hakata Y, Tanoue SY, Viñuela F. Alteration of intraaneurysmal hemodynamics by placement of a self-expandable stent. Laboratory investigation. J Neurosurg 2009;111:22-7.
21. Tremmel M, Xiang J, Natarajan SK, Hopkins LN, Siddiqui AH, Levy EI, *et al*. Alteration of intra-aneurysmal hemodynamics for flow diversion using enterprise and vision stents. World Neurosurg 2010;74:306-15.
22. Wanke I, Forsting M. Stents for intracranial wide-necked aneurysms: More than mechanical protection. Neuroradiology 2008;50:991-8.
23. Kotowski M, Naggara O, Darsaut TE, Nolet S, Gevry G, Kouznetsov E, *et al*. Safety and occlusion rates of surgical treatment of unruptured intracranial aneurysms: A systematic review and meta-analysis of the literature from 1990 to 2011. J Neurol Neurosurg Psychiatry 2013;84:42-8.
24. Pop R, Harsan O, Martin I, Mihoc D, Richter JS, Manisor M, *et al*. Balloon-assisted coiling of intracranial aneurysms using the Eclipse 2L double lumen balloon. Interv Neuroradiol 2020;26:291-9.
25. Velasco González A, Stracke P, Nordmeyer H, Heddier M, Saleme S, Sauerland C, *et al*. Low rates of recanalization for wide-necked aneurysms treated with stenting after balloon-assisted coiling: Combination of techniques delivers stable and improved results during follow-up. Neuroradiology 2018;60:1223-30.

26. Yoo E, Kim DJ, Kim DI, Lee JW, Suh SH. Bailout stent deployment during coil embolization of intracranial aneurysms. AJNR Am J Neuroradiol 2009;30:1028-34.
27. Takayama K, Taoka T, Nakagawa H, Myouchin K, Wada T, Sakamoto M, *et al*. Usefulness of contrast-enhanced magnetic resonance angiography for follow-up of coil embolization with the enterprise stent for cerebral aneurysms. J Comput Assist Tomogr 2011;35:568-72.

Supplemental Table 1: Characteristics of case series (n=13) included in the systematic review

Study	Study period	Country	Total number of patients	Mean age years	Genders	Device delivery	General anesthesia	Anticoagulation
1. Frontera, 2014	2003-2010 December 2003 until August 2010	USA	116 47 patients underwent SAC* 36 patients coiling 33 patients clipping	55-58	Female SAC: 89% Female coil: 55%		Yes	Aspirin 325 mg clopidogrel 75 mg 5 days prior to surgery 4000 iu heparin intraoperatively re-dose 1000/h
2. Hwang, 2013	2008-2010 November 2008 until December 2010	Korea	116 patients with SAC With 121 UIA	55.4 years	Women 87 Men 29	Femoral puncture		Dual antiplatelet agents 6 months 5 days prior to surgery: Aspirin 100 mg + clopidogrel l75 mg 3000 iubolus + 1000 iu/h during femoral puncture and discontinued after embolization clopidogrel + aspirin for 6 months after surgery
3. Hwang, 2011	2003-2008 May 2003 until January 2008	Korea	126 UIA 121 patients 40 patients with SAC	Stent group: 56.5±10.28 Nonstent group: 59.4±9.83	Stent group: Male 10 Nonstent group: Male 23		yes	3000 IU iv bolus 1000/h Antiplatelet medication 5 days prior to procedure
4. Thorell, 2005		Ohio	7 patients			Y-Configuration Dual stent-assisted technique		Aspirin and clopidogrel 5 days prior to procedure and 3 months after. Aspirin continued for additional 3 months Heparin during procedure and 24 h after
5. Onculjusz, 2015		Poland MSW Hospital	78 patients with SAC			Femoral approach	Yes	5000 IU Heparin iv bolus Salospir + clopidogrel 5 days prior to procedure Continued for 3 months followed by salospir only
6. Gory, 2017	2014-2015 June 2014-October 2015	Europe USA Hospital Hospices Civils De Lyon France	19 patients with SAC	63	10 women 9 men		Yes	Antiplatelet therapy Aspirin + clopidogrel 5 days prior to procedure clopidogrel continued for 3 months aspirin for 12 months

Contd...

Supplemental Table 1: Contd...

Study	Study period	Country	Total number of patients	Mean age years	Genders	Device delivery	General anesthesia	Anticoagulation
7. Starke, 2015	2006-2012	USA University of Virginia	100 patients DMT 160 patients SAC	57.9±1.5 DMT 56.7±1 SAC		Femoral approach		Aspirin, clopidogrel 5-7 days prior to treatment heparin bolus clopidogrel or ticlopidine for 3 months aspirin was continued
8. Mine, 2014	2004-2012 January 2004-November 2012	Belgium Erasme University	164 patients with SAC 183 UIA	46	115 women 49 men		Yes	5000 iu heparin Followed by 1500-2500/h Aspirin and clopidogrel 1 day prior to procedure clopidogrel was continued for 1 month while aspirin for 6 months
9. Consoli, 2016	2004-2012 January 2004-December 2012	Italy Careggi University	268 patients 286 UIA 117 with stent-assisted coiling	56±10				Aspirin, clopidogrel 1 days prior to procedure It was continued for 3 months or 6 months if more than one stent was used Aspirin not stopped for patients aged >50 years
10. Fiorella, 2016	Mach 2012 until November 2012	USA Stony Brook University	31 patients with SAC	18-80 average 58.6	23 women			Aspirin, clopidogrel 5 days prior to procedure antiplatelet was continued for 3 months iv heparin bolus
11. Gentric, 2013	2008-2010 January 2008-April 2010	France	107 patients with SAC 107 aneurysms	52	Men 33 Women 74	Femoral Approach	Yes	Antiplatelet therapy Clopidogrel via nasogastric tube in 29 patients IV aspirin iv 65 patients It was continued for 2 months in 90% Mean range was 13.4 weeks for clopidogrel and 32.7 weeks for aspirin
12. Saatci, 2011			5 patients with SAC	44.6	Men 2 3 women	Bilateral, femoral approach	Yes	Aspirin and clopidogrel 1 week prior to procedure clopidogrel for 6 months lifelong aspirin
13. Hetts, 2014		California San Francisco	361 patients UIA Among UIA 158 patients had wide neck >4 mm Among patients with wide neck: 85 patients received stent and coil and 73 coil	18-80				Antiplatelet use

Supplemental Table 1: Contd...

Study	Endograft used	Follow-up	Aneurysm location	Additional treatment	Excluded criteria	Included criteria
1. Frontera, 2014	2003-2006 Neuroform 2007-2010 Enterprise	6 months or 1 year	Supraclinoid ICA Basilar tip Anterior circulation: 37 SAC Posterior: 9 SAC	Pt with SAC: 7 Pt with COIL: 2 Pt with CLIP: O		UIA with wide neck SAC: 9 mm aneurysm size Coil: 6.8 mm >> Clip: 7.7 mm >>
2. Hwang, 2013	Enterprise	13.4 months with MRA	99 aneurysms anterior circulation: 81.8% 22 posterior: 18.2% Paraclinoid 69 patients 57% Basilar artery tip 12 patients 9.9% PCOM 8 patients 6.6%	recoiling 0.8%	Ruptured, fusiform, traumatic or mycotic aneurysms	Wide neck UIA Dome to neck <2 or neck >4 mm Mean D: 7.56 + or −4.59 mm
3. Hwang, 2011	Neuroform Enterprise	2 years	ICA 25 patients MCA 2 patients ACA 2 patients BA 7 patients for stent group			UIA, neck size >4 mm dome to neck <1.5 D 7.7±3.06: stent group D 7.5±2.53: nonstent group Neck size: 6.1±2.36 mm: Stent group 5.6±1.82 mm: Nonstent group
4. Thorell, 2005		DSA 6 months	Basilar tip			UIA with wide neck
5. Onculjusz, 2015	LVIS stent	6 months CTA OR DSA	59 anterior circulation 19 posterior			UIA with wide neck
6. Gory, 2017	PulseRider	6 months				UIA with wide neck Neck size: 5.8 mm Dome: 8.8 mm
7. Starke, 2015	Enterprise or Neuroform	27±18.9 months DSA CTA or MRA	SAC: ACA 4 patients ACOM 9 patients AICA 1 patients anterior choroidal 1 patients BA TIP 22 patients MCA 10 patients		Dissecting, fusiform, blister aneurysms	Dome to neck: <2 Neck d >4 mm SAC: D: 8.2+4.1 mm Neck d: 4.6±1.3

Contd...

Supplemental Table 1: Contd...

Study	Endograft used	Follow-up	Aneurysm location	Additional treatment	Excluded criteria	Included criteria
8. Mine, 2014	Enterprise, Leo, Solitaire	In 137 patients mean 26 months DSA: 6, 12 months MRA: 12 months Then MRA for 2 years	MCA 39 ICA 58 ACOM 21 BA 15 VA 9 SCA 5			UIA with wide neck Means D: 8.4 mm
9. Consoli, 2016	Enterprise or Solitaire	DSA AT 6 months in 246 patients	SAC 36 ACOM 41 MCA 11 BA 71 ICA Posterior circulation	All recurrences retreated One case two retreatment	Ruptured, dissecting, blister Fusiform and those treated with other endovascular techniques Size: <3 mm 3/286 patients EVT was suspended of difficulty with vascular access	Neck >4 mm UIA Dome to neck rate <1.5
10. Fiorella, 2016	LVIS device	6 months	5 posterior circulation the rest anterior			Neck >4 mm dome to neck ratio <2 UIA size: 7.2 mm
11. Gentric, 2013	Neuroform	12-18 months	ICA 28% MCA 26.2% PCOM 15%	Among 13 residual aneurysms 4 were retreated by additional coiling	Dissecting Fusiform Aneurysms Multiple Aneurysms associated with AVM	Only Neuroform Stent was used UIA with wide neck Dome to neck <2 mean width of aneurysm: 6.2 mm Neck d: 4.5 mm
12. Saatci, 2011	Enterprise, Solitaire	6 months 2 patients 2-year control	ACOM			UIA with wide neck 3 aneurysms were small and 2 large >10 mm
13. Hetts, 2014	137 patients were treated with Neuroform	1 year			Ruptured, those with protocol violation, lost to follow-up	UIA with wide neck Stent-coiled aneurysms had wider neck >4 mm versus coiling only and lower dome to neck ratios 1.3 versus 1.8

SAC – Stent-assisted coiling; ACOM – Anterior communication artery; UIA – Unruptured intracranial aneurysm; ICA – Internal carotid artery; BA – Basilar artery; EVT – Endovascular treatment; MCA – Middle cerebral artery; VA – Vertebral Artery; ACA – Anterior cerebral artery; SCA – Superior cerebellar artery; PCOM: Posterior communication artery; AICA – Anterior inferior cerebellar artery; DMT – Dual microcatheter technique; IV – Intravenous