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Meta-Analysis**

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# Y-Stent-Assisted Coiling of Wide-Neck Bifurcation Intracranial Aneurysms: A Meta-Analysis

F. Cagnazzo, N. Limbucci, S. Nappini, L. Renieri, A. Rosi, A. Laio, D. Tiziano di Carlo, P. Perrini, and S. Mangiafico



## ABSTRACT

**BACKGROUND:** Y-stent-assisted coiling for wide-neck intracranial aneurysms required further investigation.

**PURPOSE:** Our aim was to analyze outcomes after Y-stent placement in wide-neck aneurysms.

**DATA SOURCES:** We performed a systematic search of 3 data bases for studies published from 2000 to 2018.

**STUDY SELECTION:** According to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines, we included studies reporting Y-stent-assisted coiling of wide-neck aneurysms.

**DATA ANALYSIS:** Random-effects meta-analysis was used to pool the following: aneurysm occlusion rate, complications, and factors influencing the studied outcomes.

**DATA SYNTHESIS:** We included 27 studies and 750 aneurysms treated with Y-stent placement. The immediate complete/near-complete occlusion rate was 82.2% (352/468; 95% CI, 71.4%–93%;  $I^2 = 92\%$ ), whereas the long-term complete/near-complete occlusion rate was 95.4% (564/598; 95% CI, 93.7%–97%;  $I^2 = 0\%$ ) (mean radiologic follow-up of 14 months). The aneurysm recanalization rate was 3% (20/496; 95% CI, 1.5%–4.5%;  $I^2 = 0\%$ ), and half of the recanalized aneurysms required retreatment. The treatment-related complication rate was 8.9% (63/614; 95% CI, 5.8%–12.1%;  $I^2 = 44\%$ ). Morbidity and mortality after treatment were 2.4% (18/540; 95% CI, 1.2%–3.7%;  $I^2 = 0\%$ ) and 1.1% (5/668; 95% CI, 0.3%–1.9%;  $I^2 = 0\%$ ), respectively. Crossing Y-stent placement was associated with a slightly lower complication rate compared with the kissing configuration (56/572 = 8.4%; 95% CI, 5%–11%;  $I^2 = 46\%$  versus 4/30 = 12.7%; 95% CI, 3%–24%;  $I^2 = 0\%$ ). Occlusion rates were quite comparable among Enterprise, Neuroform, and LVIS stents, whereas the Enterprise stent was associated with lower rates of complications (8/89 = 6.5%; 95% CI, 1.6%–11%;  $I^2 = 0\%$ ) compared with the others (20/131 = 14%; 95% CI, 5%–26%;  $I^2 = 69\%$  and 9/64 = 11%; 95% CI, 3%–20%;  $I^2 = 18\%$ ).

**LIMITATIONS:** This was a small, retrospective series.

**CONCLUSIONS:** Y-stent-assisted coiling yields high rates of long-term angiographic occlusion, with a relatively low rate of treatment-related complications. Y-stent placement with a crossing configuration appears to be associated with better outcomes. Although Y-configuration can be obtained using many types of stents with comparable occlusion rates, the Enterprise stent is associated with lower complication rates.

**ABBREVIATIONS:** IQR = interquartile range; PRISMA = Preferred Reporting Items for Systematic Reviews and Meta-Analyses; SAC = stent-assisted coiling; Y-SAC = Y-stent-assisted coiling


With the improvement of angiographic imaging, operator experience, and widespread use of more complex techniques, an increased number of intracranial aneurysms can be


effectively treated with endovascular techniques. However, aneurysms with wide necks, unfavorable anatomic configurations, and partial incorporation of bifurcation branches are still challenging lesions for endovascular treatment, and each technique presents specific limitations. Balloon-assisted coiling may not be suitable in case of very wide-neck aneurysms with complex anatomy.<sup>1</sup>

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Flow diversion appears to be a straightforward treatment, but the fate of the covered side branches in case of bifurcation aneurysms may be a concern.<sup>2,3</sup> Intrasaccular flow disruption seems to be an effective tool for wide-neck aneurysms, and treatment-related outcomes continue to improve due to better case selection, technology, and technical improvement, despite long-term angiographic occlusion rates that are still lower than those of stent-assisted coiling (SAC).<sup>4</sup> Finally, PulseRider (Cerenovus, New Brunswick, New Jersey) and pCONus aneurysm implant (phenox, Bochum, Germany) devices appear to be promising new strategies to treat wide-neck lesions, though long-term studies are needed to confirm the efficacy of these devices.<sup>5,6</sup>

Y-stent-assisted coiling (Y-SAC), first proposed by Chow et al,<sup>7</sup> in 2004, is performed by placing 2 stents from the parent artery into each of the bifurcation vessels, creating a new bifurcation point that provides a mechanical scaffold, preventing coil protrusion.<sup>8</sup> To date, the feasibility of this procedure has been confirmed by small retrospective series, but there has not been sufficient evaluation of the safety and efficacy of this technique. Improved understanding of treatment-related outcomes after Y-SAC can help practitioners in the selection of lesions that can be effectively treated with this strategy. Our meta-analysis examined occlusion rates and procedure-related complications, focusing on the influence of aneurysm and patient features and treatment characteristics on the studied outcomes.

## MATERIALS AND METHODS

### Literature Search

A comprehensive literature search of PubMed, Ovid MEDLINE, and Ovid EMBASE was conducted for studies published from January 2000 to August 2018. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)<sup>9</sup> guidelines were followed. The key words and detailed search strategy are reported in On-line Table 1, and the studies included in our review are reported in On-line Table 2. The inclusion criteria were the following: studies reporting series with >5 patients with bifurcation intracranial aneurysms treated with Y-SAC. Exclusion criteria were the following: 1) case reports, 2) review articles, 3) studies published in languages other than English, 4) in vitro/animal studies, and 5) series reporting aneurysms treated with X-stent placement. In cases of overlapping patient populations, only the series with the largest number of patients or the most detailed data were included. Two independent readers screened articles in their entirety to determine eligibility for inclusion. A third author solved discrepancies.

### Data Collection

We extracted the following data: 1) technical success rate, 2) occlusion rate, 3) treatment-related complications, and 4) clinical outcome. Occlusion and complication rates were analyzed on the basis of the influence of the following: 1) aneurysm location; 2) ruptured-versus-unruptured aneurysms; 3) aneurysm size: small saccular (<5 mm) and medium-sized aneurysms (between 5.0 and 9.9 mm) versus large (between 10 and 20 mm) and very large and giant aneurysms (>20 mm); 4) patient age (younger than 60 years versus older than 60 years); 5) crossing-versus-kissing Y-configuration; 6) type of stent used; and 7) hybrid-versus-nonhy-

brid configuration. In the hybrid configuration, an open-cell stent (Neuroform; Stryker Neurovascular, Kalamazoo, Michigan) was used with a closed-cell stent (usually Enterprise self-expanding stent; Codman & Shurtleff, Raynham, Massachusetts).

Complete/near-complete aneurysm occlusion was defined on the basis of the following: Raymond-Roy classification<sup>10</sup> (class 1–2), or when “complete occlusion” and “neck remnant” were used in the study. Treatment-related complications were divided into the following: 1) periprocedural/early events (within 30 days) and delayed events (after 30 days); 2) transient (asymptomatic events or complete neurologic recovery) and permanent complications (symptomatic events with permanent deficits); and 3) ischemic and hemorrhagic complications. Finally, good outcome was defined as a modified Rankin Scale score of 0–2 or a Glasgow Outcome Score of 4–5, or it was assumed if the study used terms “no morbidity,” “good recovery,” or “no symptoms.”

### Outcomes

The primary objectives of this study were to define the safety (treatment-related complications, mortality rate, and neurologic outcomes) and efficacy (technical success rate, immediate and long-term occlusion) of Y-SAC. The secondary objectives were to define the influence of aneurysm, patient, and treatment characteristics on the analyzed outcomes.

### Quality Scoring

The Newcastle-Ottawa Scale<sup>11</sup> was used for the quality assessment of the included studies (details in On-line Table 3). The quality assessment was performed by 2 authors independently, and a third author solved discrepancies.

### Statistical Analysis

We estimated, from each cohort, the cumulative prevalence (percentage) and 95% confidence interval for each outcome. Heterogeneity of the data was assessed by the Higgins index ( $I^2$ ), and subsequently, the DerSimonian and Laird random-effects model was applied. The graphic representation was shown by a forest plot. To evaluate the heterogeneity and bias, the meta-regression and funnel plot followed by the Egger linear regression test were analyzed, respectively. To compare the percentages and to calculate the  $P$  values, a  $Z$ -test for 2 proportions was used. Differences were considered significant at  $P < .05$ . Meta-analysis was performed with ProMeta-2 (Internovi; Cesena, Italy) and OpenMeta[Analyst] (<http://www.cbm.brown.edu/openmeta/>).

## RESULTS

### Literature Review

Studies included in our meta-analysis are summarized in On-line Table 2. The search flow diagram is shown in On-line Fig 1.

Twenty-seven studies and 750 aneurysms treated with Y-SAC were included in our review.

### Quality of Studies

Studies included in our review were retrospective series: Two studies were retrospective multicentric series, whereas 25 articles were single-center retrospective series. Details of the rating of the included studies are reported in On-line Table 3.

## Treatment-related outcomes after Y-stent-assisted coiling of bifurcation aneurysms

Variables	Results of Systematic Review and Meta-Analysis	No. of Articles	Statistic (95% CI) (I <sup>2</sup> )
Angiographic outcomes			
Rate of successful stent deployment	550/569 = 97%	20	(96–99) (I <sup>2</sup> = 0%)
Immediate aneurysm occlusion rate (RR 1–2)	352/468 = 82.2%	15	(71.4–93) (I <sup>2</sup> = 92%)
Long-term aneurysm occlusion rate (RR 1–2)	564/598 = 95.4%	24	(93.7–97) (I <sup>2</sup> = 0%)
Aneurysm recanalization	20/496 = 3%	19	(1.5–4.5) (I <sup>2</sup> = 0%)
Recanalization among anterior circulation	2/89 = 2%	9	(0.9–9) (I <sup>2</sup> = 0%)
Recanalization among posterior circulation	11/130 = 4%	12	(2–9) (I <sup>2</sup> = 0%)
Mean size of recanalized vs nonrecanalized aneurysms (mm)	11 ± 2.4 vs 7 ± 1.18	7	
Rate of retreatment of recanalized aneurysms	10/20 = 50%	19	(29–70)
Treatment-related complications and clinical outcomes			
Overall treatment-related complications	63/614 = 8.9%	23	(5.8–12.1) (I <sup>2</sup> = 44%)
Periprocedural/early complications (within 30 days)	46/574 = 6.7%	21	(4–9) (I <sup>2</sup> = 35%)
Delayed complications (after 30 days)	9/574 = 2.1%	21	(1–3) (I <sup>2</sup> = 0%)
Transient complications	33/540 = 6.5%	20	(2.2–6) (I <sup>2</sup> = 21%)
Symptomatic complications without permanent deficits	22/540 = 3%	20	(1.3–4) (I <sup>2</sup> = 35%)
Permanent complications	18/540 = 2.4%	20	(1.2–3.7) (I <sup>2</sup> = 0%)
Treatment-related mortality	5/668 = 1.1%	23	(0.3–1.9) (I <sup>2</sup> = 0%)
Overall rate of good neurologic outcome	291/317 = 94.5%	15	(92–97) (I <sup>2</sup> = 7%)
Type of complications			
Thromboembolic complications	44/594 = 6.5%	22	(3–7.6) (I <sup>2</sup> = 29%)
Hemorrhagic complications	11/594 = 2%	22	(0.7–3) (I <sup>2</sup> = 0%)
Acute in-stent thrombosis	20/577 = 2.1%	22	(1.6–6) (I <sup>2</sup> = 0%)
Aneurysm rupture after treatment	0/650 = 0%	22	
Chronic in-stent stenosis	10/295 = 2.3%	11	(0.6–4) (I <sup>2</sup> = 0%)

Note:—RR indicates Raymond-Roy grade.

### Patient Population and Aneurysm Characteristics

Overall, 744 patients and 750 aneurysms were treated with Y-SAC (On-line Table 4). The mean age of patients was 56.6 years (range, 22–80 years), and the proportion of male patients was 36% (95% CI, 32%–40%). Aneurysms included in our study were wide-neck saccular bifurcation aneurysms. Overall, 61% (366/601; 95% CI, 56%–64%) were anterior circulation aneurysms, whereas 39% (235/601; 95% CI, 35%–43%) were posterior circulation lesions. Most of the aneurysms were located at the basilar tip (235/601 = 39%; 95% CI, 35%–43%), middle cerebral artery bifurcation (206/601 = 34.4%; 95% CI, 30%–38%), and anterior communicating artery (120/601 = 20%; 95% CI, 16%–23%). Mean aneurysm size was 9.6 mm (median, 9.9 mm; interquartile range [IQR] = 8–10.5 mm; range, 3–25 mm). The proportion of acutely ruptured aneurysms treated with Y-stent placement was 11% (66/592; 95% CI, 8.5%–14%).

### Treatment Characteristics

The most common stent used was the Enterprise (476/1060 = 45%; 95% CI, 42%–47%), followed by the Neuroform (332/1060 = 31.3%; 95% CI, 28%–40%), LVIS stents (MicroVention, Tustin, California) (132/1060 = 12.5%; 95% CI, 10%–14%), Solitaire (Covidien, Irvine, California) (66/1060 = 6.2%; 95% CI, 4.9%–7.8%), and Acclino flex Stent (Acandis, Pforzheim, Germany) (54/1060 = 5%; 95% CI, 3.9%–6.6%). Nonhybrid (closed/closed-cell and open/open-cell stents) and hybrid (closed/open-cell stents) techniques were used in 87.5% (512/585; 95% CI, 84%–98%) and 12.5% (73/585; 95% CI, 10%–15%) of aneurysms, respectively. Y-stent placement with a crossing configuration was the most common technique (688/750 = 92%; 95% CI, 89%–93%), followed by kissing stent placement (60/750 = 8%; 95% CI, 6%–10%). The mean radiologic (digital subtraction angiography) follow-up was 14 months (range, 6–24

months; median, 12 months; IQR = 10–18 months), and the mean clinical follow-up was 17 months (range, 3–30 months; median, 16.5 months; IQR = 7.8–21 months).

### Angiographic Outcomes

The technical success rate was 97% (550/569; 95% CI, 96%–99%; I<sup>2</sup> = 0%) (Table). Immediate angiographic occlusion after treatment was obtained in 82.2% (352/468; 95% CI, 71.4%–93%; I<sup>2</sup> = 92%) of aneurysms. The rate of long-term complete/near-complete occlusion was 95.4% (564/598; 95% CI, 93.7%–97%; I<sup>2</sup> = 0%). Meta-regression showed a nonsignificant variation of the effect size ( $P = .056$ ), and the funnel plot, followed by the Egger linear regression test, excluded publication bias ( $P = .358$ ) (On-line Fig 2).

Aneurysm recanalization occurred in 3% (20/496; 95% CI, 1.5%–4.5%; I<sup>2</sup> = 0%) of cases, and half of the recanalized aneurysms required retreatment. The mean size of recanalized and nonrecanalized aneurysms was 11 ± 2.4 versus 7 ± 1.18 mm ( $P = .0001$ ). The aneurysm recanalization rate was 2% (2/89; 95% CI, 0.9%–9%; I<sup>2</sup> = 0%) and 4% (11/130; 95% CI, 2%–9%; I<sup>2</sup> = 0%) among the anterior and posterior circulation, respectively ( $P = .4$ ).

### Treatment-Related Complications

The overall complication rate was 8.9% (63/614; 95% CI, 5.8%–12.1%; I<sup>2</sup> = 44%) (Table). Meta-regression showed a nonsignificant variation of the effect size ( $P = .443$ ), and the funnel plot, followed by the Egger linear regression test, excluded publication bias ( $P = .574$ ) (On-line Fig 3). Periprocedural/early complications were 6.7% (46/574; 95% CI, 4%–9%; I<sup>2</sup> = 35%). Delayed complications were 2.1% (9/574; 95% CI, 1%–3%; I<sup>2</sup> = 0%) (3 cases of in-stent occlusion, 5 ischemic events, 1 thromboembolism after discontinuation of the antiplatelet therapy). Transient

(with and without related symptoms) and permanent complications were 6.5% (33/540; 95% CI, 2.2%–6%;  $I^2 = 21\%$ ) and 2.4% (18/540; 95% CI, 1.2%–3.7%;  $I^2 = 0\%$ ), respectively. The rate of symptomatic complications without permanent deficits (transient events with related symptoms) was 3% (22/540; 95% CI, 1.3%–4%;  $I^2 = 35\%$ ).

Overall, ischemic/thromboembolic, and hemorrhagic events were 6.5% (44/594; 95% CI, 3.7%–6%;  $I^2 = 29\%$ ) and 2% (11/594; 95% CI, 0.7%–3%;  $I^2 = 0\%$ ), respectively. The rate of acute in-stent thrombosis was 2.1% (20/577; 95% CI, 1.6%–6%;  $I^2 = 0\%$ ) and chronic in-stent stenosis ( $>50\%$ ) was 2.3% (10/295; 95% CI, 0.6%–4%;  $I^2 = 0\%$ ). There were no cases of aneurysm rupture after treatment during follow-up.

Treatment-related mortality was 1.1% (5/668; 95% CI, 0.3%–1.9%;  $I^2 = 0\%$ ), and the rate of good neurologic outcome was 94.5% (291/317; 95% CI, 92%–97%;  $I^2 = 7\%$ ).

### **Factors Related to Aneurysm Occlusion**

Overall, the occlusion rate was comparable among ruptured-versus-unruptured aneurysms ( $P = .2$ ), anterior-versus-posterior circulation ( $P = .27$ ), patients younger-versus-older than 60 years ( $P = .5$ ), crossing-versus-kissing techniques ( $P = .2$ ), and hybrid-versus-nonhybrid techniques ( $P = .2$ ). Long-term occlusion was significantly higher among small and medium-sized versus large or very large/giant aneurysms (98/107 = 92%; 95% CI, 86%–96%;  $I^2 = 0\%$  versus 33/43 = 79%; 95% CI, 67%–91%;  $I^2 = 25\%$ ) ( $P = .02$ ) and among aneurysms treated with Y-stent placement used as the first treatment versus retreatment (119/128 = 94%; 95% CI, 89%–98%;  $I^2 = 0\%$  versus 40/48 = 82%; 95% CI, 71%–92%;  $I^2 = 0\%$ ) ( $P = .01$ ) (On-line Table 5). MCA aneurysms had higher occlusion rates (52/54 = 94.9%; 95% CI, 89%–97%;  $I^2 = 0\%$ ) compared with basilar tip aneurysms (126/145 = 88.8%; 95% CI, 83%–93%;  $I^2 = 0\%$ ) and anterior cerebral artery location (42/46 = 87%; 95% CI, 78%–96%;  $I^2 = 0\%$ ) ( $P > .05$ ).

### **Factors Related to Complications after Treatment**

The complication rate was higher for ruptured (11/52 = 18%; 95% CI, 7%–28%;  $I^2 = 21\%$ ) compared with unruptured aneurysms (29/236 = 8%; 95% CI, 4.5%–13%;  $I^2 = 36\%$ ) ( $P = .02$ ). There was no statistically significant difference in complication rates in relation to aneurysm location, patient age, aneurysm size, and technical factors (On-line Table 5).

### **Relationship between Type of Stent Used and Treatment-Related Outcomes**

Treatment with the Enterprise stent was associated with 96% (98/101; 95% CI, 93%–98%;  $I^2 = 0\%$ ) long-term occlusion and 6.5% (8/99; 95% CI, 1.6%–11%;  $I^2 = 0\%$ ) complications. Aneurysm occlusion during follow-up and treatment-related complications after Neuroform stent placement were 94% (119/130; 95% CI, 90%–98%;  $I^2 = 14\%$ ) and 14% (20/131; 95% CI, 5%–26%;  $I^2 = 69\%$ ), respectively. Finally, treatment with the LVIS and LVIS Jr stents yielded 92% (52/56; 95% CI, 85%–99%;  $I^2 = 0\%$ ) and 11% (9/64; 95% CI, 3%–20%;  $I^2 = 18\%$ ) long-term occlusion and complications rates, respectively.

### **Study Heterogeneity**

Substantial heterogeneity was reported in the following outcomes: technical success rate, overall rate of treatment-related complications, occlusion rate among patients younger than 60 years, and complications after treatment with the Neuroform stent.

## **DISCUSSION**

### **Angiographic Outcomes**

Our meta-analysis stressed several important findings related to the treatment of complex wide-neck bifurcation aneurysms requiring Y-SAC. Y-stent placement always needs the catheterization of both bifurcation branches, which sometimes may be complex in case of steep angles. Moreover, Y-stent placement with the crossing technique, which is more common than the kissing one, needs the passage of a second stent through the interstices of the first deployed device, necessitating microcatheterization through a recently placed stent, with the risk of damage/dislodgement of the first stent.<sup>12</sup> However, our study showed a high technical success rate (97%), demonstrating that Y-SAC is a feasible technique in experienced centers.

While 82.2% of aneurysms were occluded immediately after treatment, nearly 95% of the lesions had complete/near-complete occlusion during the 14 months of radiologic follow-up. The immediate occlusion rate reported in the literature is quite variable, ranging from 50% to 100%,<sup>8,12,13</sup> whereas long-term occlusion rates appear homogeneous. Assessing the heterogeneity of the data, we found a low rate of  $I^2$  for the long-term occlusion rate and a very high rate of  $I^2$  for the immediate occlusion rate. It is likely that the flow-diversion effect of the 2 Y-configured stents influenced the aneurysm thrombosis, and lesions with a lower occlusion rate immediately after treatment were completely occluded at the last angiographic follow-up. Cekirge et al<sup>14</sup> reported a series of 8 bifurcation aneurysms treated by placing 2 stents in a Y-configuration with no accompanying endosaccular packing. Given the flow-diversion effect of the stents, 6 aneurysms had complete occlusion and 2 lesions showed residual filling during about 12 months of follow-up. Because we analyzed a period of about 13 years, it is likely that the evolution of the devices (low-profile stents compatible with 0.0165-inch inner microcatheters) and the improvement of the operator experience would have influenced the outcomes. Accordingly, although it was not statistically significant, we found a trend ( $P = .056$ ) toward a higher occlusion rate over the analyzed period (On-line Fig 2). Given the high rate of long-term occlusion, only 3% of aneurysms were recanalized during follow-up, without statistically significant differences between the anterior and posterior circulation. These results appear comparable with those reported in a series of wide-neck aneurysms treated with PulseRider<sup>6</sup> and pCONus<sup>5</sup> devices, showing rates of Raymond-Roy 1–2 occlusion close to 95%, with 5% recanalization. Among large meta-analyses of aneurysms treated with the Woven EndoBridge (WEB; Sequent Medical, Aliso Viejo, California) devices, long-term complete/near-complete occlusion ranged from 80% to 85%, with a nearly 7% retreatment rate.<sup>4,15</sup>

Long-term occlusion of large and giant aneurysms is notoriously challenging after selective endovascular treatment.<sup>17</sup> Our study found that an occlusion rate after Y-stent placement was



lower among large/giant aneurysms (79% versus 92%,  $P = .02$ ), and the mean size of recanalized aneurysms was higher (11 mm) compared with nonrecanalized lesions (7 mm) ( $P = .0001$ ).

Y-SAC can be used as a first treatment or in the retreatment of recanalized aneurysms. Jeon et al,<sup>17</sup> in a series of 25 patients with basilar tip aneurysms treated using Y-stent placement with closed-cell stents, reported 70% complete occlusion among recanalized aneurysms, and 100% occlusion among those directly treated with Y-stent placement. Our meta-analysis confirmed higher occlusion rates after Y-stent placement used as a first treatment (94% versus 82%,  $P = .01$ ), probably because recanalized aneurysms are generally those with more complex anatomy.

### **Treatment-Related Complications**

One of the main concerns of Y-SAC is the risk of ischemic complications related to the increased metal density of the overlapped double stents that promotes platelet aggregation. In our meta-analysis, Y-stent placement was associated with an 8.9% complication rate, with a moderate statistical heterogeneity over the included studies. Most complications occurred in the periprocedural/early period after treatment (6.7%), with a low rate of treatment-related morbidity (2.4%) and mortality (1%). Delayed complications were 2.1%, and most were associated with asymptomatic in-stent occlusion.<sup>18-20</sup> Overall, thromboembolism was the most common complication (6.5%), whereas acute in-stent occlusion was reported among 2% of cases. Hemorrhagic events were uncommon and were generally related to technical complications during the crossing maneuver through the interstices of the first stent (aneurysm or vessel perforation).<sup>8</sup> No lesions ruptured (delayed hemorrhage) after treatment during follow-up, demonstrating that the aneurysms were successfully secured.

In a meta-analysis of nearly 2500 wide-neck aneurysms treated endovascularly, the permanent complication rates were 2% and 3% for coiling and SAC, respectively.<sup>21</sup> Flow-diverter stents have become a suitable tool for complex wide-neck aneurysms. However, an important concern is the patency of the covered side branches when the stent is deployed at the bifurcation points. Recently, a meta-analysis of approximately 250 MCA aneurysms treated with flow-diverter stents showed an overall complication rate of 20%, with 10% treatment-related morbidity. In addition, nearly 10% of jailed arteries were occluded during follow-up.<sup>3</sup> Intracardiac flow disruption with WEB devices appeared to be relatively safe, with 8% thromboembolic complications, which were lower (6%) among studies published after 2013, due to the improvement in the operators' experience.<sup>4</sup> Similarly, although current evidence is still limited, PulseRider can be a suitable option for wide-neck aneurysms: A recent review showed 8% intraprocedural complications, which is quite comparable with the treatment-related outcomes of Y-SAC.<sup>22</sup>

According to a large series and meta-analysis of very large and giant aneurysms treated endovascularly,<sup>16</sup> we found higher complication rates among large-giant lesions (17%) compared with small- or medium-sized aneurysms (9%). In addition, patients who underwent retreatment with Y-stent placement of a recanalized aneurysm experienced a higher complication rate (14% versus 7.6%). This is likely a reflection of a more complex anatomic

configuration and larger neck of the recanalized aneurysms; in this situation, retreatment can be technically challenging.

In our study, Y-stent placement for MCA aneurysms showed better results, especially if compared with anterior cerebral artery lesions, which were associated with complication rates close to 20%. Anterior communicating artery aneurysms usually have a complex anatomy, while pericallosal lesions are characterized by distal access and small arterial caliber, increasing the risk of complications.<sup>20,23,24</sup>

### **Crossing-versus-Kissing Technique**

In general, the crossing-Y-stent placement is the most commonly used technique; the second stent is deployed through the cells of the first stent. In our study, 92% of patients were treated with the crossing technique, and 8%, with the kissing approach. The crossing technique necessitates passing a wire and stent through a recently placed stent, thus risking damage/dislodgement of the first device.<sup>19</sup> The kissing technique avoids this problem due to the use of 2 stents placed side by side in the parent artery with the distal segment of each stent going into 1 bifurcation vessel.<sup>19,25</sup> However, no studies compared these 2 techniques. In our review (On-line Table 5) complete/near complete occlusion rate (Raymond-Roi grade 1 and 2) was quite comparable, and it was achieved in 95% and 90% of aneurysms treated with crossing and kissing Y-stent placement, respectively. However, the complication rate appeared to be slightly higher after kissing stent placement (12.7% versus 8.4%), though the difference was not statistically significant, probably due to the small number of patients in the kissing group.

Brassel et al<sup>27</sup> reported 14% ischemic complications in a series of 7 complex aneurysms treated with the kissing-Y-technique with the closed-cell Acclino flex Stent. Complete occlusion was reported in all 7 aneurysms. Jankowitz et al<sup>19</sup> reported an 80% complete occlusion after Y-stent placement with the kissing technique in 11 wide-neck aneurysms. One patient had a procedural aneurysm rupture, and 1 patient experienced delayed in-stent thrombosis. Accordingly, the efficacy and safety of kissing Y-stent placement probably needs larger series to be proved.

### **Closed-Cell and Open-Cell Stents**

Y-stent placement embolization can be achieved by using various combinations of different types of stent: closed/closed-cell (such as the Enterprise), open/open-cell (Neuroform), or a hybrid combination between closed and open-cell stents. Limbucci et al<sup>8</sup> reported a high rate of long-term occlusion (97%) and a relatively low rate of complications (4%) after Y-stent placement performed with 2 Enterprise stents in a crossing fashion. Laser-cut closed-cell devices had good navigability, and they are usually easily deployed because they can be partially recapturable. In addition, the linear profile of 2 closed-cell stents may allow a better scaffold and protection of the parent artery during coiling.<sup>8</sup> However, an important concern using 2 closed-cell stents is that the first device may limit the expansion of the second one, resulting in in-stent stenosis. In our study, Y-stent placement with 2 Enterprise devices was associated with high rates of occlusion (96%) and a low rate of complications (6.5%) (On-line Table 6).

Although infrequently specified in the included studies, most Neuroform stents were the older generation devices. Castaño et al<sup>26</sup> described a series of patients treated with different generations of Neuroform stents, including the Neuroform Atlas Stent System in past years, reporting 95% occlusion and a very low rate of treatment-related complications (2.5%) after Y-stent placement. The authors reported that in their experience, open-cell stents had good conformability to tortuous anatomies, minor rectification of the vessels, high vessel wall apposition, and easier microcatheterization through the mesh of the first stent. However, if one investigated the literature, complications after Y-stent placement with the Neuroform stent appear quite variable, ranging from 2% to 25%. Spiotta et al<sup>27</sup> reported 5 periprocedural events during Y-stent placement in 19 patients with the Neuroform stent. Our meta-analysis showed 14% complications associated with Y-stent placement using the Neuroform stent. However, most were transient events without clinical sequelae.

Recently, braided stents have been used to perform Y-SAC. Compared with other stents that are laser-cut from nitinol hypotubes, LVIS stents are braided from a single nitinol wire with a closed-cell design. Theoretically, they have a smaller cell size and higher metal coverage and flow-diversion effect than other conventional self-expandable devices.<sup>24,28</sup> We found 92% occlusion and 11% complications using LVIS stents.

Finally, 4 studies<sup>12,19,29,30</sup> reported results after Y-stent placement performed with a combination (hybrid design) of closed/open-cell stents (Enterprise/Neuroform). Usually the Neuroform stent was chosen as a first stent to stabilize the structure; a second Enterprise stent can be better deployed through the interstices of the Neuroform stent that are wider than those in closed-cell devices. In our study, the overall occlusion rate was 90%, with 7.5% treatment-related complications.

### Strengths and Limitations

Our study has limitations. The series are retrospective studies or small single-institution experiences. Because of the small number of cases in some subgroup analyses, the comparisons among them may not provide power to show a statistically significant difference among the studied outcomes. However, publication bias was excluded, and our review is the largest to date.

### CONCLUSIONS

Although Y-SAC is usually performed in complex aneurysms, high rates of long-term angiographic occlusion are achieved with a relatively low rate of treatment-related complications. Y-stent placement with a crossing configuration appears associated with better outcomes. Even though a Y-configuration can be obtained with many types of stents with comparable occlusion rates, the Enterprise stent appears to be associated with lower rates of complications.

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