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ABSTRACT

BACKGROUND AND PURPOSE: Stent-assisted coiling with two stents has been described in some series for the treatment of complex and wide-neck bifurcation aneurysms. Our aim was to report our experience of a stent-assisted coiling technique with double stents in "Y" and "X" configurations, with emphasis on safety, feasibility, and efficacy.

MATERIALS AND METHODS: Clinical and angiographic outcomes of patients for whom the strategic therapeutic option was the stent-assisted coiling technique in a Y or X configuration for neck scaffolding from June 2006 to June 2013 were retrospectively analyzed.

RESULTS: One hundred five aneurysms in 97 patients were treated during 100 consecutive procedures. There were 54.2% (57/105) MCA, 28.6% (30/105) anterior communicating artery, 16.2% (17/105) basilar tip, and 1.0% (1/105) ICA termination aneurysms. A Y stent placement was used to treat 87 aneurysms in 85 procedures; an X stent placement was used to treat 7 aneurysms in 6 procedures, while 9 procedures failed for 11 aneurysms. There were 10.0% (10/100) procedure-related permanent neurologic deficits and 1.0% (1/100) death. The immediate angiographic controls showed a complete occlusion in 47.6% (50/105) of the aneurysms and a partial (neck or sac remnant) occlusion in 52.4% (55/105). To date, 81.0% (85/105) of the aneurysms have been followed up (mean, 17 months) with angiography, disclosing a recanalization in 5.9% (5/85) and an improvement in 42.4% (36/85). At discharge and follow-up, the mRS score was 0 in 83.5% (81/97) of patients, 1 in 4.1% (4/97), 2 in 3.1% (3/97), 3 in 4.1% (4/97), 4 in 3.1% (3/97), and 6 in 2.1% (2/97).

CONCLUSIONS: Y and X stent-assisted coiling of complex and wide-neck intracranial bifurcation aneurysms is an effective technique.

ABBREVIATION: AcomA = anterior communicating artery

In the past decade, endovascular treatment of intracranial aneurysms became a valid alternative to neurosurgery[1] and is now performed as a first option in many centers. Recently, the treatment of wide-neck intracranial aneurysms with self-expandable intracranial stents has also been reported to be feasible and effective in many clinical series[2-6] at bifurcation sites,[7-9] at the price of an increased risk of thromboembolic and ischemic complications compared with coiling.[10] Unfortunately, endovascular treatment of complex or wide-neck bifurcation aneurysms still remains a challenge for the endovascular surgeon. Different techniques have been proposed, such as balloon and double-balloon remodeling,[11,12] neck bridge,[13] linear stent placement,[14] and waffle-cone[15] techniques. Small series and case reports have described novel stent placement techniques such as "X" and "Y" stent placement to treat complex and wide-neck bifurcation aneurysms, with promising results.[16-23] Recently, the efficacy, feasibility, and long-term durability were described in a large retrospective series.[24] Although several concerns remain regarding stent combinations and the rate of neurologic complications, in our institution since 2006, we have been using this technique with different stent combinations to treat complex and wide-neck bifurcation intracranial aneurysms. Our purpose is to present our experience with double stents in X and Y configurations, with an emphasis on safety, feasibility, and efficacy.

MATERIALS AND METHODS

Patient Selection

From June 2006 to June 2013, clinical and angiographic outcomes of consecutive patients treated in a single center with double stents in a Y or X configuration for bifurcation aneurysms were prospectively collected. Patients for whom the preprocedural

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strategy was to use a stent-assisted coiling technique in a Y or X configuration but which ultimately failed were also included (intention to treat). The wide-neck aneurysms were defined as having a large neck (>4 mm) and/or a fundus-to-neck ratio of <2. The complex aneurysms were defined as having the origin in a branch from the sac or being located at a vascular trifurcation or being multiple at the same bifurcation.

Endovascular Procedures

Endovascular procedures were performed with the patient under general anesthesia and full anticoagulation with heparin. In addition, all patients with no history of recent subarachnoid hemorrhage were given dual antiplatelet therapy (aspirin, 250 mg, and clopidogrel, 75–150 mg) 2 weeks before the treatment. Patients were kept under dual antiplatelet therapy for 3 months, followed by aspirin daily for 3 months. Platelet-aggregation inhibition has been tested in all patients (VerifyNow P2Y12 assay; Accumetrics, San Diego, California) since 2008. In case of bailout stent placement, an intravenous bolus of 0.25 mg/kg of abciximab (ReoPro) was administrated and a continuous intravenous perfusion of 0.125 μg/kg per minute for 12 hours was started immediately after the procedure. Aspirin and clopidogrel were started the day after the treatment. Distal and proximal vessel diameters were taken into consideration in the choice of stent dimension and type. After the deployment of the stents, a flat panel CT (XperCT, Allura series; Philips Healthcare, Best, the Netherlands) was performed. The proximal landing zone of the first stent was chosen at least 10 mm away from the bifurcation, to navigate the second stent with a margin of error. Coiling was performed before and after stent delivery, with or without a jailed catheter. Angiographic images were acquired in anteroposterior, lateral, and working projections before and immediately after the treatment. There were no strict exclusion criteria, but a massive SAH requiring drainage and a low (0%–20%) response to clopidogrel were thought to be contraindications to stent placement.

Clinical Events

Any clinical events appearing in the postoperative course up to 42 months were noted. A neurologic assessment was performed before the treatment, at discharge (Glasgow Outcome Score and mRS), and at follow-up (mRS).

Follow-Up Protocol

The standard angiographic follow-up protocol consisted of a first angiographic follow-up performed at 6–12 months after endovascular treatment and a second angiographic follow-up performed 1 year after the first follow-up. A third angiographic follow-up was performed 2 years after the second one.

Data Collection and Statistical Analysis

Patient age and sex; aneurysm location, size, and rupture status at presentation; degree of aneurysm occlusion; stent type (open- versus closed-cell) and configuration (Y versus X stent placement); and technical and clinical complications in successful and attempted stent placement were noted. A single reader evaluated all the angiograms. Aneurysm occlusion was classified as described by Roy et al.[25]

Table 1: Summary of demographics and clinical data

Demographics	No.	%
Sex		
Male	35	36.1
Female	62	63.9
Aneurysm location		
MCA	57	54.2
AcomA	30	28.6
Basilar tip	17	16.2
Carotid termination	1	1.0
Clinical finding		
Incidental discovery	79	75.2
Recurrence	20	19.0
SAH	5	4.8
Compression	1	1.0
Aneurysm size		
Small: 0–10 mm	90	85.7
Large: 10–25 mm	13	12.4
Giant: >25 mm	2	1.9

Table 2: Summary of aneurysm characteristics

Aneurysm Size (No.) (%)	Mean ± σ (mm)	Ruptured (No.) (%)	Complex (No.) (%)
Small: 90 (85.7)		5 (5.5)	27 (30.0)
Largest diameter	6.5 ± 2.1		
Neck	5.0 ± 1.3		
Dome/neck	1.1 ± 0.3		
Large: 13 (12.4)		0 (0)	7 (54.0)
Largest diameter	12.7 ± 2.6		
Neck	6.8 ± 2.0		
Dome/neck	1.6 ± 0.7		
Giant: 2 (1.9)		0 (0)	0 (0)
Largest diameter	28.3 ± 3.9		
Neck	5.5 ± 1.1		
Dome/neck	2.3 ± 1.7		

RESULTS

Population

One hundred five aneurysms were treated in 97 patients (age, 28–86 years; mean, 54 years) during 100 procedures. MCA bifurcation aneurysms were 54.2% (57/105), anterior communicating artery (AcomA) aneurysms were 28.6% (30/105), basilar tip aneurysms were 16.2% (17/105), and carotid termination aneurysm was 1.0% (1/105). Clinical presentations were the following: incidental discovery in 75.2% (79/105), compression in 1.0% (1/105), angiographic recurrences of previously coiled aneurysms in 19.0% (20/105), and SAH in 4.8% (5/105). A Y stent placement was used to treat 87 aneurysms in 85 procedures; an X stent placement was used to treat 7 aneurysms in 6 procedures, while 9 procedures failed for 11 aneurysms. Of 91 successful procedures, stents were delivered after coiling in 5.5% (5/91), including a subgroup of 2 bailout stent placements to prevent parent vessel occlusion, and before coiling in 93.4% (85/91). In 1.1% (1/91), no coils were delivered. Demographics and clinical data are detailed in Table 1. Aneurysm characteristics are detailed in Table 2. Stent types and configurations are detailed in Table 3.

Attempted Stent Placement

We failed to perform a stent-assisted procedure in Y or X fashion in 9 cases as described in Table 4.

Stent-Related Technical Complications in Successful Stent Placement

We encountered 5 asymptomatic technical complications. In 1 procedure, we broke the proximal module of the first stent. In 2 cases, we partially dislocated the proximal end of the first stent with the microcatheter; and in another procedure, we partially unraveled the last coil and secured it with an Enterprise stent (Codman & Shurtleff, Raynham, Massachusetts) in the second segment of the vertebral artery. In the last case, after deployment of the 2 stents, a coil protruded between the stent and the parent artery wall with a reduction of distal outflow. The flow was reestablished with a balloon angioplasty inside the stent.

Clinical Complications

There were 19 procedure-related neurologic complications; 84.2% (16/19) were perioperative (within 30 days), while 15.8% (3/19) were delayed (after 30 days). Complications associated with transitory (<24 hours) or reversible (<7 days) neurologic deficits were encountered in 8.0% (8/100) of the procedures, while permanent neurologic deficits were noted in 10.0% (10/100) of the procedures. The mortality rate was 1.0% (1/100), a Y stent-assisted coiling of an unruptured AcomA aneurysm; this patient had a hyper-response to clopidogrel (81%), was discharged at day 5 asymptomatic, and was re-admitted at day 12 with a mild left hemiparesis. Brain CT found a frontal intraparenchymal hematoma. Aspirin was stopped, but he presented with hemiplegia at day 20 secondary to an increase of the hematoma and an intraventricular hemorrhage. The level of consciousness deteriorated; therefore, the patient was sedated and intubated and an external ventricular drain was placed. The patient died at day 28; brain CT showed a larger hematoma with a severe midline shift. Neurologic complications are detailed in the On-line Table.

Table 3: Summary of stent types and configurations in successful treatments

	Y	X
Neuroform[a] + Neuroform	47	3
Neuroform + Enterprise[b]	27	2
Enterprise + Enterprise	4	1
Neuroform + Solitaire AB[c]	2	–
LVIS[d] + LVIS	1	–
LVIS Jr[d] + LVIS Jr	3	–
Neuroform + Baby LEO[e]	1	–

[a] Stryker Neurovascular, Fremont, California.
[b] Cordis Neurovascular, Miami, Florida.
[c] Covidien, Irvine, California.
[d] MicroVention, Tustin, California.
[e] Balt Extrusion, Montmorency, France.

Bailout Stent Placement

In 2 cases, stents were delivered after thromboembolic events related to coil protrusion. The first patient presented with a ruptured basilar tip aneurysm, treated primarily with double-balloon remodeling. The second patient presented with an unruptured right MCA aneurysm treated with simple coiling.

Immediate Angiographic Results

The immediate angiographic controls showed a complete occlusion in 47.6% (50/105) of the aneurysms, a neck remnant in 17.1% (18/105), and a sac remnant in 35.2% (37/105).

Angiographic Follow-Up

To date, 81.0% (85/105) of the aneurysms have been followed up (mean, 17 months) with angiography. Of 50 initially occluded aneurysms, so far we have controlled 41 (82.0%) aneurysms, disclosing a neck recurrence in 1 case. Of 18 aneurysms with neck remnants, so far we have controlled 13 (72.2%) aneurysms, disclosing, in 10 cases, complete occlusions; in 1 case, a neck remnant; and in 2 cases, sac recurrences. Of 37 aneurysms with sac remnants, we have controlled, so far, 31 (83.8%) aneurysms, disclosing a complete occlusion in 23 aneurysms, a neck remnant in 4, and a sac remnant in 4. Overall, in 81.0% (85/105) of aneurysms controlled, follow-up disclosed complete occlusion in 85.8% (73/85), neck remnant in 7.1% (6/85), and sac remnant in 7.1% (6/85). We performed 2 retreatments. No aneurysm bled or rebled during the follow-up period. We observed 1 asymptomatic occlusion of the 2 stents in a Y configuration at the first follow-up and 4 cases of asymptomatic in-stent stenosis at the first follow-up. In 1 case, in a partially thrombosed aneurysm, the neck was excluded but there was late contrast enhancement of the aneurysmal wall.

Clinical Follow-Up

On clinical follow-up, the modified Rankin Scale score was 0 in 83.5% (81/97) of the patients; 1 in 4.1% (4/97); 2 in 3.1% (3/97); 3 in 4.1% (4/97); 4 in 3.1% (3/97); and 6 in 2.1% (2/97).

Table 4: Summary of attempted stenting

Age (yr), Sex	Aneurysm Location	Aneurysms Treated during the Procedure	Stents	Event	Final Result	F/U	mRS Score
50, F	MCA	1	0	Sac perforation with the guidewire	C	–	0
62, F	MCA	1	0	Sac perforation with the microdelivery stent system and exchange guidewire	A	–	4
70, F	MCA	2	1	First stent was delivered too distally, with the proximal end covering the neck; impossible to navigate the microcatheter in the second branch	C, C	B, B	0
38, M	AcomA	1	1	Guidewire tip broke in the parent vessel and a single stent was delivered due to the impossibility of navigating the microcatheter in the second branch	C	A	0
48, F	MCA	1	2	First stent was delivered too distally, no overlapping	C	C	0
30, F	AcomA	1	2	First stent was delivered too distally, no overlapping	B	A	0
86, F	BA	1	2	First stent fell into aneurysmal sac, no overlapping	C	C	2
51, F	CT	1	2	First stent fell into aneurysmal sac, no overlapping	C	–	0
58, F	AcomA	2	2	Second stent was deployed inside the first one (coaxial)	C, C	C, C	0

Note:—F/U indicates follow-up; BA, basilar artery; CT, carotid termination; A, complete occlusion; B, neck remnant; C, sac remnant.

DISCUSSION

Complex and wide-neck bifurcation aneurysms that incorporate ≥2 parent vessels are rarely treated with a single stent, due to the risk of coil prolapse and parent vessel occlusion. Different techniques have been proposed to obviate this problem. Balloon remodeling and double-balloon remodeling were the first endovascular techniques used to treat wide-neck aneurysms.[11,12] Safety and efficacy are similar to those in standard coiling,[26] and the immediate occlusion rate in ruptured aneurysms is higher than that in standard coiling.[27] These techniques are effective for the treatment of aneurysms in the setting of SAH, to minimize the risk of early rebleeding even if total aneurysm occlusion is not obtained. Unfortunately, this technique does not provide an arterial reconstruction, and long-term follow-up showed a recurrence rate similar to that in standard coiling, in particular for wide-neck and large aneurysms.[2]

Crossover stent placement for basilar tip and AcomA aneurysms has been illustrated in few publications. Kelly et al[28] described this technique in bifurcation aneurysms with unfavorable distal limb configuration. For the authors, this technique, compared with Y stent placement, offered a better coverage of the aneurysmal neck and limited the use of multiple stents, decreasing the risk of thrombogenicity. Nevertheless, this technique cannot be used with MCA aneurysms and in AcomA and basilar tip aneurysms when the circle of Willis is incomplete.

The waffle-cone technique has been described in small series[15,29] as a valid alternative to Y and X stent placement when the latter cannot be performed due to an unfavorable distal limb configuration. In this case, the distal part of the stent is placed inside the aneurysmal sac and the blood flow is direct into the aneurysmal sac. This technique is technically easier than Y stent placement but probably presents a higher risk of coil protrusion due to the incomplete neck coverage. The major drawback is the risk of recurrence due to the redirection of the flow inside the aneurysm.

In our single-center retrospective series, all cases of unruptured aneurysms were previously discussed during our interventional meetings. We treated most small aneurysms (85.7%) that we considered suitable for Y or X stent-assisted coiling. We could have treated some with single stent-assisted coiling for wide-neck aneurysms or with a flow diverter for complex aneurysms, but during the discussion, we finally decided to perform Y or X stent-assisted coiling. Concerning the indication to treat this subgroup of aneurysms, 17/90 (18.9%) were recurrences and 33/90 (36.7%) were in patients with multiple intracranial aneurysms with or without a previous history of SAH.

In our series, stent placement was performed before coiling in most cases, to scaffold the aneurysmal neck and reduce the risk of coil protrusion. We used different stent combinations, always overlapping. In most of our cases, an open-cell stent was deployed as a first stent in the smaller and more acute vascular branch. This stent, compared with closed-cell-design stents, presented 2 advantages, a better vessel conformability in acute curvature and an outward prolapse of the struts at the convexity.[30] A better conformability reduces the risk of thromboembolic events[31]; the outward prolapse improves neck coverage and should reduce friction during the deployment of the second stent. The second stent, open- or closed-cell, was delivered in the larger and less angulated vascular branch. We used flat panel CT to evaluate stent apposition. Recently, Cho et al,[32] described a nonoverlapping Y stent placement technique in wide-neck basilar tip aneurysms with the Enterprise stent, advising that this technique presents the advantages of both open and closed stents together. Cekirge et al[21] described an overlapping Y stent placement technique by using 2 closed-cell-design stents without endosaccular coiling; they preferred this combination of stents because it is easier to deliver and deploy but also seems more likely to provide superior modification on aneurysm hemodynamic parameters. However, 2 closed stents in overlapping configuration, in particular in an acute curvature, may lead to inappropriate vessel wall apposition and to higher thrombogenicity. Furthermore, there is a high risk of kinking of the second stent and, therefore, minor scaffolding at the neck.

Technical problems were previously encountered, but in our series the friction between the stents was not a major matter. Our major problem was the navigation of the microcatheter in the most angulated branch. To obviate this matter, we always used a triaxial access to improve proximal support, and in few cases, we turned the microguidewire inside the aneurysmal sac with a higher risk of perforation. Another difficulty was to achieve a correct proximal position of the first stent to avoid its displacement during the navigation of the microcatheter in the second branch. A proper length selection of the first stent of at least 20 mm is necessary to cover the neck completely and to stabilize the stent, in particular in MCA and AcomA aneurysms. However in these locations, the proximal part of the first stent must not land in the terminal carotid artery; otherwise catheterization of the second branch becomes more difficult to achieve.

In our series, including successful and attempted stent placements, we observed a relatively high rate of complications, with a mortality rate of 1.0% and permanent neurologic morbidity of 10.0%. The comparison of complications across reported series is difficult due to the limited number of procedures performed with Y and X stent placement in other series. Recently, a larger retrospective multicenter series,[23] with ruptured and unruptured aneurysms, reported a good outcome (mRS 0–2) in 93% of the patients. In this series, most were basilar tip aneurysms (87%), a location where the navigation and the deployment of stents are easier due to favorable distal limb configuration. In a large retrospective series[24] consisting of 193 bifurcation aneurysms, by using mostly closed-cell stents, the authors reported a low rate of permanent morbidity (1.1%) and mortality (0.5%). Although we also applied a strict antiaggregation protocol and checked 1 week before the procedure, our hemorrhagic and ischemic complications led to a higher rate of permanent morbidity.

Our immediate angiographic complete occlusion rate was quite low, as previously reported[2,3,6,33] in stent-assisted coiling. The procedure was performed with the patient under heparin, clopidogrel, and aspirin; therefore, thrombus formation was slow and achieving attenuated packing, in particular at the neck, was quite difficult due to the immobility of the microcatheter. Nevertheless, Chalouhi et al[34] suggested that a moderate packing attenuation seems to be effective in stent-assisted coiling to achieve complete occlusion. At angiographic follow-up, we observed an improvement in 42.4% (36/85) of the aneurysms. This progressive thrombosis was reported in many stent-assisted coiling series,[2,6,33] probably due to antiplatelet discontinuity and "intimal overgrowth" at the neck. Cekirge et al[21] also described a "flow remodeling effect" in aneurysms treated by Y closed-cell stent placement, which showed promising results in their retrospective series consisting of 193 bifurcation aneurysms, with a recanalization rate of 2.2%.[24]

CONCLUSIONS

Y and X stent-assisted coiling of complex and wide-neck intracranial bifurcation aneurysms is an effective technique, leading to long-term stability of aneurysm occlusion. Nevertheless, we encountered a higher rate of technical failures and clinical complications compared with those of other endovascular techniques, such as single stent–assisted coiling or balloon-assisted coiling. Our results concerning safety and feasibility show the limits of this technique, in particular for AcomA and MCA aneurysms. We learned from our experience to apply more rigorous criteria for the selection of suitable patients. Advances in stent design and newer antiplatelet drugs may improve the feasibility and the safety in the future.

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