Acta Neurochir (2009) 151:1663–1672
DOI 10.1007/s00701-009-0436-9

NEUROSURGICAL TECHNIQUES

Y-stent-assisted coil embolization for the management of unruptured cerebral aneurysms: report of six cases

Andrew Lozen · Sunil Manjila · Richard Rhiew · Richard Fessler

Received: 13 April 2009 / Accepted: 22 May 2009 / Published online: 18 July 2009

Abstract
Background The advent of stent-assisted coil embolization has revolutionized the endovascular management of complex intracranial aneurysms. Although performed routinely in most cerebrovascular centers, there are not many case series reported about the Y-stent technique for coil placement in cerebral aneurysms. The authors present the second largest series available within the neurosurgical literature.
Methods The authors have retrospectively reviewed the medical records and angiographic data of six patients who were diagnosed as having unruptured cerebral aneurysms and subsequently treated using "Y" stent-assisted coil embolization. Five out of six cerebral aneurysms in this study were located at the basilar tip while the remaining one was at the left MCA trifurcation. Aneurysms ranged in size from 8–22 mm. All patients were female with ages ranging from 37–70 years. One patient presented with recurrence of an aneurysm previously managed with a balloon-assisted coil embolization. Another patient presented after a failed trial of a balloon-assisted procedure. One patient had originally been diagnosed with multiple aneurysms of varying size and location.
Results A “Y” configuration was successfully established in all six patients. Five patients have had a symptom-free recovery period at average follow-up period of 36.7 months. The remaining patient is notable for recurrence that was discovered on angiogram 32 months postoperatively.
Conclusions The proposed Y-stent technique is a safe and effective option that can be employed in the endovascular reconstruction of unruptured intracranial aneurysms of complex location and orientation. These methods serve as an acceptable alternative in the management of aneurysms traditionally managed with microsurgery. Hemodynamic assessment has shown Y-stenting to be an advantageous therapy option, yet further studies are required to assess these parameters in alternative therapies.

A. Lozen
Department of Neurosurgery,
Froedtert Hospital & The Medical College of Wisconsin,
Milwaukee, WI 53226, USA

S. Manjila · R. Rhiew
Department of Neurosurgery, Wayne State University,
Detroit, MI 48201, USA

R. Fessler
Department of Neurosurgery, Providence Hospital,
Southfield, MI 48075, USA

A. Lozen (✉)
Department of Neurosurgery,
9200 West Wisconsin Ave.,
Milwaukee, WI 53226, USA
e-mail: alozen@mcw.edu

Introduction

Since the advent of stent-assisted coil embolization there has been much debate over the optimal course of management for cerebral vascular aneurysms. Various authors have described techniques in the management of aneurysms with stent-assisted vascular reconstruction before coil embolization [30, 33, 34, 42, 53, 54]. The publication of the International Subarachnoid Trial (2002) encouraged the acceptance of endovascular therapy as a primary treatment for ruptured intracranial aneurysms [21]. ISAT and its follow-up (2005) revealed that patients managed with endovascular techniques achieved a survival benefit that may last as long as 7 years. Despite this encouraging evidence, barriers have remained to their broad application. Difficult-to-access aneurysms and those spanning vascular bifurcations have posed a particular challenge. In a case report, Malek et al. described the early usage of tandem intracranial stent placement. A tandem stent was drawn through the lumen another stent to manage an iatrogenic basilar artery dissection [35]. Likewise, Lopes et al. demonstrated that stenting across a branched vascular network could be accomplished safely and effectively [32]. Both of these stent techniques have proven valuable in the management of aneurysms located at vascular bifurcations.

The Neuroform stent is the first stent designed specifically for use in cerebral vasculature. It is a self-expanding device comprised of an MRI-safe metal alloy called nitinol. Since its introduction, the Neuroform stent has widened the spectrum of aneurismal lesions amenable to endovascular treatment [20]. Its flexibility allows for the navigation of tortuous vasculature. Likewise, its open-cell design has been permissive of the innovative technique of deploying a stent inside another previously deployed stent by drawing the catheter through the stents struts. This method has proven useful in managing aneurysms found at points of arterial bifurcation.

Stent-assisted embolization is commonly used in the treatment of posterior circulation aneurysms [6, 14, 15, 19, 23, 39, 41, 44, 48, 58]. Perez-Arjona and Fessler described the management of unruptured basilar artery (BA) apex aneurysms with two Neurform stents deployed in a "Y" configuration traversing the BA as it bifurcates into the each proximal posterior cerebral artery (PCA) [43]. Sani and Lopez described a case report wherein this configuration was applied at the middle cerebral artery trifurcation [47]. To date, however, few anecdotal case reports on y-stenting are available within the neurosurgical literature. We present a case series where stent-assisted coil embolization with a "Y" configuration was utilized for management of six unruptured cerebral aneurysms.

Technique

Prior to catheterization, patients are treated with 3 days of dual antiplatelet therapy consisting of 75 mg clopidogrel and 325 mg aspirin. Following establishment of upper extremity intravenous access, a left radial arterial line is obtained to allow continuous observation of blood pressure and serial blood draws for activated coagulation time assessment. The patient is placed in the supine position and undergoes induction of general anesthesia. Arterial access is then obtained through the right femoral artery via placement of a 6F sheath. Intravenous heparin is utilized to attain a target ACT of 300 s.

In the management of Basilar tip aneurysms, a 6F guide catheter is first advanced through the dominate vertebral artery under constant road map fluoroscopy. The standard over-the-wire technique is used to advance a microcatheter to the P2–P3 junction. A microwire (300 cm 0.014 inch — Xcelerator, MTI, Irvine CA) is passed through the mircocatheter and the microcatheter is withdrawn. A pair of Neuroform stents (SMART Therapeutics Inc., San Leandro, CA) are then prepared (3.0×20 mm and 3.0×15 mm were used, respectively). The stabilizer and stent catheter are then fixed to heparinized flushes and advanced over the wire. To facilitate deployment of the second stent the first ought to be advanced into the PCA with the most acute angle relative to the basilar artery. The first stent is then deployed from the P1 back into the mid basilar. The microwire is pulled back into the BA apex before being advanced through the stent struts and into the contralateral PCA. The second stent is then advanced over the wire from the P1 back into the BA in a fashion that partially overlaps the first. A so-called "Y" configuration is thus established about the BA apex. The microwire and catheter are then carefully advanced back into the BA. Subsequently the wire is drawn into the aneurysm and the catheter is advanced over the wire. Coil embolization is then attempted (Fig. 1).

Aneurysms affecting the MCA trifurcation are managed in a similar fashion. In the case described herein, the microwire and catheter were advanced through the straight portion of the angular artery off the inferior division of the left MCA. A Neuroform II (3.5×20 mm) stent was then advanced to cover the inferior division to the mid portion of the left M1 and deployed. All wires were removed and the catheter advanced into the candelabra of the left superior

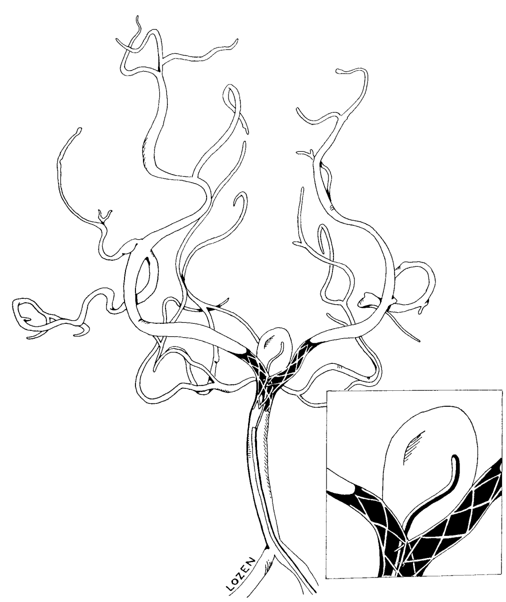

Fig. 1 Line drawing of a basilar bifurcation aneurysm that is being treated with "Y" configuration placement of open-cell design stents through which a catheter is passed directly into the aneurysm; the *inset* shows the navigation of framing coil into the aneurysm sac. Note the "Y" configuration made by the stents in situ

division, exchanged to an exchange length Transend floppy and a Neuroform III (3.5×20 mm) stent was advanced through the struts and Y-stented so as to overlap the M1 to its mid portion.

Patients are typically heparinized overnight in the ICU and placed on oral antiplatelet therapy as outpatients for no less than 4 weeks. Follow-up angiograms are typically performed between 3 and 6 months (Fig. 2).

Patients

Six patients underwent "Y" configuration stent placement for the appropriate aneurysms. Five of such aneurysms were basilar tip in location; the remaining one was a left MCA trifurcation aneurysm. Aneurysms ranged in size from 8 to 22 mm. All patients were female with ages ranging from 37 to 70 years. One patient presented with recurrence of an aneurysm previously managed with a balloon-assisted coil embolization. Another patient presented after a failed trial of a balloon-assisted procedure. One patient had originally been diagnosed with multiple aneurysms of varying size and location. In whom Y-stent assisted coil embolization was performed for her basilar tip aneurysm prior to management of the remaining lesions.

Illustrative cases

Case 1

A 65-year-old Caucasian female presented with history of severe headaches and diplopia. MRI brain revealed a 12 mm aneurysm located at the basilar apex. DSA confirmed the presence of the aneurysm and revealed the involvement of the bilateral P1 segments without obstruction to distal flow. Stent-assisted coiling with "Y" configuration was elected as primary management therapy. Successful embolization through Y-stents was then accomplished with the following coils: Sapphire 3D 12×16, Sapphire 3D 10×13, Helix standard 10×30, Helix standard 10 × 30, multidiameter 8×30, multidiameter 6×20, multidiameter 5×15, multidiameter 4×10. The patient remained neurologically intact and stable following completion of the coiling procedure. Follow-up angiogram obtained at 3 months showed complete exclusion of the aneurysm from parent circulation (Fig. 3).

Case 2

A 42-year-old female of Filipino decent presented with a history of recurrent left-sided headaches and episodic left

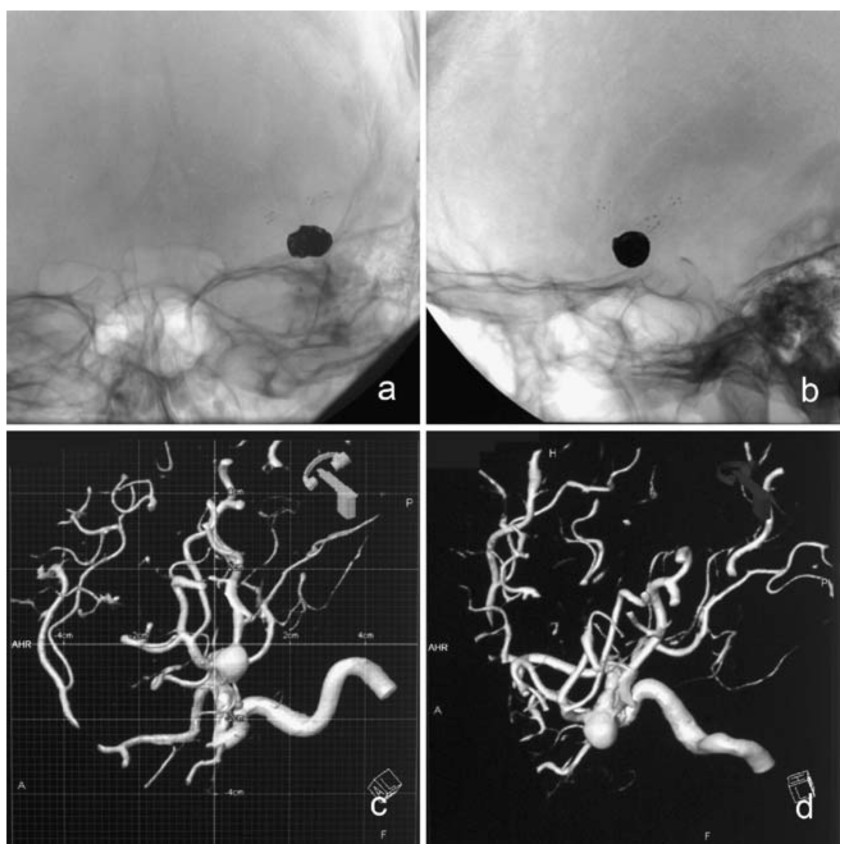

Fig. 2 **a** and **b** Anteroposterior and lateral views of a middle cerebral artery (MCA) trifurcation aneurysm treated using a y-stent technique showing total occlusion of the aneurysm. **c**, **d** Orientation of aneurysm sac, neck, and the branches of the parent vessel, in a CT angiogram. The point markers along the stent are clearly visualized demonstrating the y-pattern of stent deployment used in this procedure

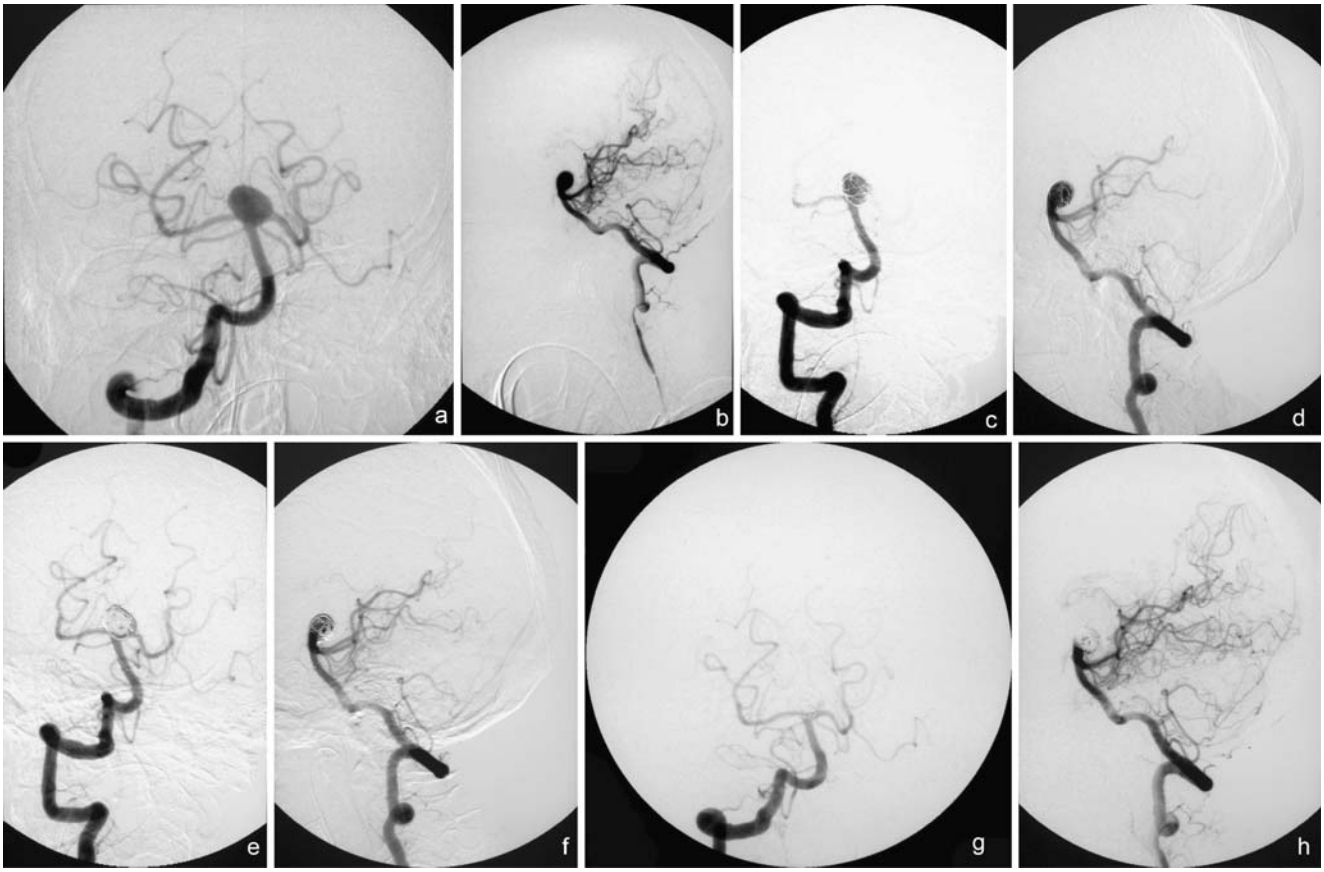

Fig. 3 **a**, **b** AP and lateral views of a basilar bifurcation aneurysm; **c-f** depict stages of coil deployment and **g** and **h** show the AP and lateral position of a completely occluded aneurysm after the procedure

facial numbness. She had a family history significant for subarachnoid hemorrhage. MRI brain and DSA revealed a left MCA trifurcation aneurysm of 11-mm diameter, with an apex oriented laterally and inferiorly. Normal flow-related enhancement was observed in the major intracranial arteries without evidence of branch occlusion or stenosis. The right vertebral artery appeared to be dominant, while the left was hypoplastic and terminated in the left PICA. Treatment of the aneurysm with parent vessel reconstruction and coil embolization was planned.

The procedure was executed in a staged fashion with "Y" configuration stent placement performed two months prior to coiling. Y-stenting was accomplished without incident and the patient remained in preoperative neurological condition. During the second stage procedure the following coils were placed within the aneurysm: GDC 18, 10×30; GDC 10, 8×30, 7×25, 6×20, 5×10, and 4×8 Ultra soft stretch resistant. Final angiographic runs showed no evidence of parent vessel occlusion. The aneurysm appeared to have been grossly excluded from circulation and the patient had no signs of neurological deficit. Follow-up angiograms were negative and the patient continued to be neurologically stable (Fig. 4).

Results

All six patients eventually achieved adequate coil embolization as demonstrated by follow-up angiograms and post procedural angiographic runs. Four of the cases (three basilar apex, one MCA) showed radiographic evidence of complete occlusion after a single attempt at embolization. A particularly challenging case involving a large aneurysm (basilar apex) of 22 mm in diameter appeared at least 90% occluded. During the procedure it was decided to handle this case in a staged manner. Gross total occlusion was later accomplished in a follow-up after an 8-month period had elapsed. This patient suffered a recurrence observed at 32 months follow-up and is now being followed. The remaining patient endured a coil malfunction during an attempt to reposition the final coil.

A "Y" configuration was successfully established in all six patients. Difficulty in stent deployment was encountered in only one case. This occurred while an attempt was made to deliver the second stent. The friction within the system prevented the delivery of the stent with mere utilization of the stabilizer. Removal of the exchange length wire was necessary and ultimately deployment was achieved with use of a 16-coil pusher.

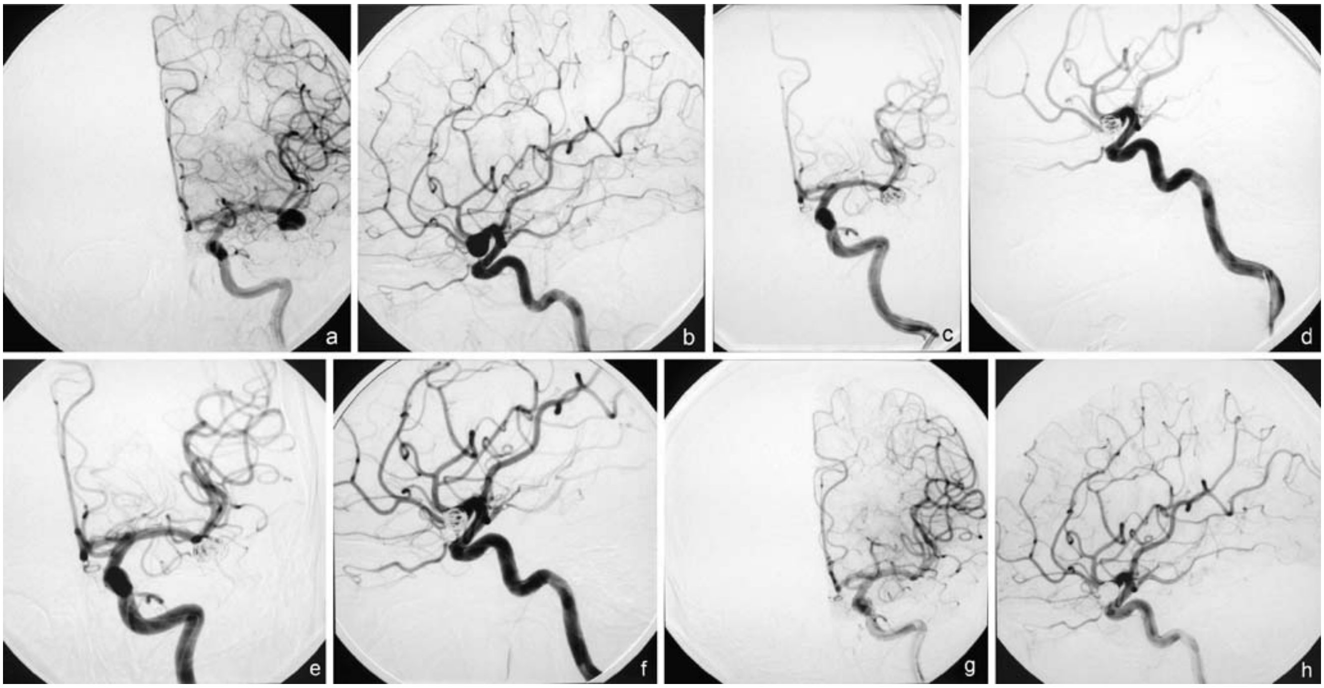

Fig. 4 **a**, **b** AP and lateral views of an MCA trifurcation aneurysm; **c-f** show progressive coil remobilization and **g** and **h** depict total occlusion of aneurysm with coils using the Y-stent assisted technique

Five patients have had a symptom-free recovery period at average follow-up period of 36.7 months. The remaining patient is notable for recurrence that was discovered on angiogram 32 months postoperatively. She continues to experience intermittent headaches and is currently being closely followed with no immediate plans for further embolization.

Complications were encountered in two cases, both involving BA apex aneurysms. One patient suffered a minor subarachnoid hemorrhage during the coiling procedure. The hemorrhage occurred during the predetachment phase of a 360-GDC 10 soft stretch resistant 5 × 9 coil. A single coil loop extruded through the apex of the aneurysm and a small amount of contrast was observed to leak from the aneurismal wall. The patient was immediately given protamine for reversal of heparin. Complete embolization was accomplished and subsequently emergent ventriculostomy was performed. The patient was discharged 15 days later having been returned to her previous state of health. Six months later, successful coiling without incident was accomplished through the patent Y-stents.

Coil malfunction was reported in one patient, following a positioning maneuver for final coil placement. After coil deployment an alteration in flow was observed as excess contrast was seen within the neck of the aneurysm. During an effort to reposition the coil it was felt to stretch and an attempted removal was undertaken. During this maneuver the coil mass broke and it was decided to terminate the procedure with a length of coil left remaining within the lumen of the vertebral artery. A 2- year hiatus was allowed before further intervention in order to allow the coil to endothelialize completely. (Table. 1)

Discussion

Established methods for securing a broad-necked cerebral aneurysm with parent artery reconstruction include: the Jailed catheter, stent-first, and balloon-remodeling techniques. The Jailed catheter (coil-first) method involves the placement of the microdelivery catheter into the arterial lumen at the start of coil delivery. The stent is then positioned and immediately delivered across the aneurysm in a manner that "jails" the microcatheter between the stent and the vessel wall. This technique has several advantages: (a) less manipulation of the parent artery; (b) it optimizes the coil basket using a buttressing stent; and (c) it eliminates the need for difficult navigation of the microcatheter through the stent struts. Reducing the manipulation of the parent artery presumably diminishes the likelihood of aneurysmal rupture. The utilization of a coil basket with buttressing stent diminishes the chance of shift or migration. Unfortunately, this construct does not allow the possibility of modifying the microcatheter position through manipulation of the tip after the stent is placed, which makes it more challenging to position the coil in an ideal

Table 1 Patient demographics and follow-up

Age/Sex	Location	Diameter (mm)	Prev. intervention	Complications	Follow-up (months)
37/f	BA apex	Residual volume (10%) of a prev. treated 12 mm aneurysm	Successful balloon-assisted complete coil embolization	Coil failure	57.6
41/f	BA apex	22	N/A	N/A	52.6 (recurrence at 32 months, currently followed)
44/f	BA apex	9	N/A	SAH-minor	51.3
42/f	MCA trifurcation	11	N/A	N/A	13.1
65/f	BA apex	12	N/A	N/A	40.6
70/f	BA apex	8	Failed balloon-assisted coil embolization	N/A	5.0

location. The stent-first method requires the initial delivery of the stent across the aneurysm neck followed by microcatheter placement within the sac through the stent struts. Stent-first techniques are associated with infrequent complications such as cell impingement or stent displacement. Balloon-in-stent techniques have also been shown to be a successful alternative to traditional coiling methods. Fiorella et al. reported a case series of seven patients who successfully underwent balloon-in-stent-assisted embolization [11]. This procedure involves the placement of a stent followed by the in-stent inflation of a temporary occlusion balloon to protect the parent vessel. Currently, the use of balloon assistance in placement of Guglielmi detachable coils is widely represented within the neurosurgical literature [2, 29, 31, 36, 56]. Advocates have cited improved control of blood flow, potential to attain increased coil density, as well as increased delineation of the aneurismal neck in support of their usage [22, 45]. Known risks include ischemic events, thomboembolism, and even vessel tears secondary to over-inflation [40, 46]. High complication rates associated with balloon usage have been demonstrated and have been used in support of alternative techniques [17, 37, 49].

Various authors have proposed novel stent-assisted therapies to be used in the management of aneurysms located at vascular bifurcations. The use of a single stent placed perpendicular to the BA axis in a fashion that spans from the right to the left P1 segments has been utilized [7, 24, 55]. Cross et al. described a case report where this technique was used in the management of a basilar apex aneurysm. They remark that this technique limits the amount of hardware left within the cerebral vasculature, a perceived benefit to the risk of postoperative thrombosis. A single perpendicular stent also serves to limit the space between the aneurismal neck and the body of the stent. According to Cross et al., this serves as an advantage in coil placement. However, horizontal stent deployment requires the navigation of the posterior communicating artery (PCOM) through the internal carotid artery (ICA), a factor that may limit its application. Patients without an adequate PCOM require an approach from the posterior circulation.

Horowitz et al. described the use of a “waffle cone” arrangement in the management of wide-necked bifurcation aneurysms [18]. This technique involves the deployment of a single Neuroform stent placed in the basilar artery. The distal component of the stent is allowed to fan out as it is extruded into the bifurcation at the neck of the aneurysm. Following placement of the coils distal to the midline stent, the apparatus is said to resemble an ice cream cone. In his case series, Horowitz described seven patients with BA apex aneurysms successfully managed with this technique. It remains to be known if an aneurysm location at the MCA trifurcation could be treated effectively and safely with this technique. Another variation of stent-assisted coil embolization was described by De Paula Lucas et al. In their report, the authors demonstrated a "stent-jack" technique, which avoids navigation of the microcatheter through the stent strut. The coil loops are constrained within the sac before detachment of the first coil. Unlike other stent-assisted techniques, the primary function of the stent is to stabilize the system in the detachment phase of coil delivery. With this technique, the function of the stent in preventing coil distraction into the parent artery during initial coil placement is lost. However, De Paula Lucas et al. remark that this method was helpful in the critical placement of the first coils [8].

There is evidence available to suggest that stent placement alone may promote aneurysmal thrombosis and occlusion [1]. Both significant complications observed in our case series occurred independently of stent positioning and deployment, an observation that makes the theory of stent-only treatment a tempting alternative. However, trials of stent-only therapy have proven inadequate as both high failure rates and subtotal occlusion have been reported [27]. This therapy is often avoided because the likelihood of observing intraprocedural thrombosis is greatly reduced. Zentino et al. described the use of stent-only therapy in 15 aneurysms at various locations. In his series, only a single case (7%) showed evidence of immediate total occlusion [59].

Critics of the "Y" configuration have sited migration of the first stent and friction between stents during deployment as causes for concern. Intraoperative stent migration of sufficient magnitude to compromise the formation of a "Y" configuration was reported in a case series published by Thorell et al. [51]. In his series of seven patients treated with Y-stenting, Thorell notes that in the sole case wherein migration prevented the formation of a "Y" configuration, satisfactory occlusion of the aneurysm was obtained. Modest stent migration was observed in all cases herein reported involving the basilar apex. Migration during the management of these aneurysms was always in the cephalad direction pertaining to the BA and laterally within the P1. Successful navigation of the primary stent in the case involving the MCA trifurcation was accomplished without incident. In the remaining cases, movement of the primary stent did not lead to procedural complications and should be considered of minimal risk.

Friction between stents may occur as one stent is drawn through the struts of a previously placed stent. Strut dimensions will vary dependent on arterial vascular diameter. The Neuroform stent supplies an outward force of traction that is counteracted by resistance within the arterial wall. Only a single case within this series was significant for appreciable friction between stents. The authors feel that prudent usage of Y-stenting in cases with agreeable anatomy may eliminate this concern entirely. Utilization of these techniques in arterial systems with larger caliber arteries may ensure the attainment of sufficient strut dimensions to limit intraoperative friction. Likewise, large strut configuration may serve to provide an advantageous disturbance of flow and reduce the risk of in-stent stenosis [16].

It is of note that the sole case which endured a recurrence was the largest aneurysm in this series. This is consistent with other sources within the Neurosurgical literature which have suggested that aneurysms with a neck width more that 4 mm and a maximum diameter greater than 10 mm may have a three-fold risk of recurrence following treatment [9]. Suzuki et al. recently reported on their experiences with endovascular treatment of 115 MCA aneurysms (ruptured and unruptured). They report a recanilization rate of 10% at this location. All aneurysms to suffer recurrence were large or giant [50]. The relative risk of recanilization may take on particular significance when considering treatment modalities for aneurysms located at arterial bifurcations. In these lesions, aneurysm/parent vessel architecture may predispose the coil mass to elevated and repetitive impingement forces [5]. While it has been suggested that higher coil packing densities may serve to combat unfavorable flow dynamics, bifurcating vessel aneurysms likely comprise a distinct and unfavorable risk stratification variable. Large and giant aneurysms of arterial bifurcations are thus likely to require multistage treatment. These lesions may best be addressed with multimodality treatment with cooperation of neuro-interventionalists and neurosurgeons.

As the application base for stent-assisted coil embolization has evolved questions have followed. Both stent-induced thrombosis and in-stent stenosis have been described as potential pitfalls of stent placement in endovascular therapy [10, 28, 52, 57]. Stent-induced thrombosis is widely owed to hyperactive platelets. Research in their usage in percutaneous cardiac intervention has shown a reason for concern even into the late post-operative period [12, 13]. It is well established that intravascular stent placement serves to disrupt the functional endothelium. This may result in inflammation followed by neointimal proliferation and in-stent stenosis [26]. The significance of this disruption in the management of difficult to coil aneurysms is yet debated. Likewise, it is yet unknown whether the hemodynamic environment unique to arterial bifurcation significantly alters the risk of stent-induced stenosis or thrombosis. It is encouraging that at an average follow-up of 36.7 months, no patient in our case series has endured symptomatic thrombosis. However, the definitive utility of this technique and broader application of stent-assisted therapy depend on long-term results. It remains possible that the ultimate risk of thrombosis and inflammation may be unmasked several years or even decades down the road. Until this information becomes available, an indefinite radiological follow-up may be necessary.

Post-procedural hemodynamic alterations are likely to be an important factor in determining the long-term morbidity and mortality of endovascular intervention [3]. The possibility that late rebleeding may ultimately compromise the superiority of endovascular therapy raises important questions regarding the effect these treatment modalities have on vascular flow patterns [38]. Hemodynamic assessment has shown the "Y" configuration to be advantageous with respect to reduction in the strength of flow vortices and peak flow velocity [4]. Multiple stent placement seems to have an additive effect at reducing wall-shear stress, an advantage unique to the "Y" configuration compared to alternative approaches [25]. Whether this advantage outweighs the perceived embolic risk of increasing intracerebral hardware is indeterminate. Both the passage of time and further experience are required to access the long-term efficacy of Y-stent assisted coil embolization as well as the risk of recanalization associated with aneurysms.

Conclusions

The proposed Y-stent technique is a safe and effective option that can be employed in the endovascular reconstruction of unruptured intracranial aneurysms of complex location and orientation. These methods are an acceptable alternative in the management of aneurysms traditionally treated surgically. The risk of cerebral embolism and delayed recanalization associated with Y-stent technique remain unknown, but likely resemble those of traditional stent-assisted techniques. Further study is required to assess these risks. Postoperative hemodynamic assessment has shown Y-stenting to be an advantageous therapy option yet further studies are required to assess these parameters in alternative therapies.

References

1. Ahlhelm F, Roth C, Kaufmann R, Schulte-Altedorneburg G, Romeike B, Reith W (2007) Treatment of wide-necked intracranial aneurysms with a novel self-expanding two-zonal endovascular stent device. Neuroradiology :17703295. PSEBD
2. Aletich VA, Debrun GM, Misra M, Charbel F, Ausman JI (2000) The remodeling technique of balloon-assisted detachable coil placement in wide-necked aneurysms: experience at the University of Chicago. J Neurosurg 93(3):388–396
3. Banerjee RK, Gonzalez CF, Cho YI, Picard L (1996) Hemodynamic changes in recurrent intracranial terminal aneurysm after endovascular treatment. Acad Radiol 3(3):202–211. doi:10.1016/S1076-6332(96)80441-7
4. Cantón G, Levy DI, Lasheras JC (2005) Hemodynamic changes due to stent placement in bifurcating intracranial aneurysms. J Neurosurg 103(1):146–155
5. Cha KS, Balaras E, Lieber BB, Sadasivan C, Wakhloo AK (2007) Modeling the interaction of coils with the local blood flow after coil embolization of intracranial aneurysms. J Biomech Eng 129 (6):873–879. doi:10.1115/1.2800773
6. Cohen JE, Gomori JM, Umansky F (2003) Endovascular management of symptomatic vertebral artery dissection achieved using stent angioplasty and emboli protection device 25:418–422
7. Cross DT, Moran CJ, Derdeyn CP, Mazumdar A, River D, Chicoine MM (2005) Neroform stent deployment for treatment of a basilar tip aneurysm via posterior communicating artery route. AJNR Am J Neuroradiol 26:2578–2581
8. de Paula Lucas C, Piotin M, Spelle L, Moret J (2008) Sten-jack technique in stent-assisted coiling of wide-necked aneurysms. Neurosurgery 62(2):ONS414–ONS416 ONS416-7
9. Fiehler J, Byrne JV (2009) Factors effecting outcome after endovascular treatment of intracranial aneurysms. Curr Opin Neurosurg 22(1):103–108. doi:10.1097/WCO.0b013e32831af1c1
10. Fiorella D, Albuquerque FC, Felipe C, Woo H, Rasussen PA, Peter A, Masaryk TJ, Cameron G (2006) Neuroform in-stent stenosis: incidence, natural history and treatment strategies. Neurosurgery 59 (1):34–42. doi:10.1227/01.NEU.0000219853.56553.71
11. Fiorella D, Albuquerque FC, Masaryk TJ, Rasmussen PA, McDougall CG (2005) Balloon-in-stent technique for the constructive endovascular treatment of "ultra-wide necked" circumferential aneurysms. Neurosurgery 57(6):1218–1227. doi:10.1227/01.NEU.0000186036.35823.10
12. Fineschi M, Gori T (2008) Vary late thrombosis in a bare metal stent: an under-recognized problem. Can J Cardiol 24(2):e6–e7
13. Flores-Ríos X, Marzoa-Rivas R, Abugattás-de Torres JP, Piñón-Esteban P, Aldama-López G, Salgado-Fernández J, Calviño-Santos R, Vázquez-Rodríguez JM, Vázquez-González N, Castro-Beiras A (2008) Late thrombosis of paclitaxel-eluting stents: long-term incidence, clinical consequences, and risk factors in a cohort of 604 patients. Am Coll Cardiol 51(16):1543–1552. doi:10.1016/j.jacc.2008.01.020
14. Gomez CR, Misra VK, Liu MW et al (2000) Elective stenting of basilar artery stenosis. Stroke 31:95–99
15. Hayashi K, Kitagawa N, Yoshioka T, Morikawa M, Ochi M, Kaminogo M, Shibata S (2002) A case of basilar artery stenosis treated by stent placement. No To Shinkei 54:527–531
16. He Y, Duraiswamy N, Frank AO, Moore JE Jr (2005) Blood flow in stented arteries: a parametric comparison of strut design patterns in three dimensions. J Biomech Eng 127(4):637–647. doi:10.1115/1.1934122
17. Heros RC (2006) Complications of balloon-assisted coil embolization of intracranial aneurysms. J Neurosurg 105(3):396–399. doi:10.3171/jns.2006.105.3.393
18. Horowitz M, Levy E, Sauvageau E, Genevro J, Guterman LR, Hanel R, Wehman C, Gupta R, Jovin T (2006) Inta/extra-aneurysmal stent placement for management of complex and wide-necked bifurcation aneurysms: eight cases using the waffle cone technique. Neurosurgery 58(2):258–262
19. Horowitz MB, Pride GL, Graybeal DF, Purdy PD (1999) Percutaneous transluminal angioplasty and stenting of midbasilar stenosis: three case reports and literature review. Neurosurgery 45:925–930. doi:10.1097/00006123-199910000-00043
20. Howington JU, Hanel RA, Harringan MR, Levy EI, Guterman LR, Hopkins LN (2004) The Neuroform stent, the first microcatheter-delivered stent for use in the intracranial circulation. Neurosurgery 54 (1):2–5. doi:10.1227/01.NEU.0000099370.05758.4D
21. Molyneux AJ, Kerr RS, Mee Yu L, Clarke M, Sneade M, Yarnold JA, Sandercock P (2005) International subarachnoid aneurysm trial (ISAT) of neurological clippings versus endovascular coiling in 2143 patients with ruptured intracranial aneurysm: a randomized comparison of effects on survival, dependency, seizures, rebleeding, subgroups, and aneurysm occlusion. Lancet 366:809–817. doi:10.1016/S0140-6736(05)67214-5
22. Irie K, Kawanishi M, Nagao S (2000) Balloon-assisted placement in wide-necked cerebral aneurysms: preliminary experience. Neurol Med Chir (Tokyo) 40(12):603–608. doi:10.2176/nmc.40.603
23. Joseph GJ, Goldstein J, Cloft H, Tong F, Dion J (2000) Endovascular stenting of arthrosclerotic stenosis in a basilar artery after successful angioplasty. AJR Am J Roentgenol 174:383–385
24. Kelly ME, Turner R, Gonugunta V, Woo HH, Rasumussen PA, Masaryk TJ, Fiorella D (2007) Stent reconstruction of wide-necked aneurysms across the circle of Willis. Neurosurgery 61 (5):249–254. doi:10.1227/01.neu.0000303977.04128.3e Suppl 2
25. Kim M, Levy EI, Meng H, Hopkins L (2007) Quantification of hemodynamic changes induced by virtual placement of multiple stents across a wide-necked basilar trunk aneurysm. Neurosurgery 61(6):1305–1312. doi:10.1227/01.neu.0000306110.55174.30
26. Kipshidze N, Dangas G, Tsapenko M, Moses J, Leon MB, Kutryk M, Serruys P (2004) Role of endothelium in modulating neointimal formation: vasculoprotective approaches to attenuate restenosis after percutaneous coronary interventions. J Am Coll Cardiol 44:733–739
27. Lanzino G, Wakhloo AK, Fessler RD, Hartney ML, Guterman LR, Hopkins LN (1999) Efficacy and current limitations of internal carotid, vertebral, and basilar artery aneurysms. J Neurosurg 91(4):538–546

28. Lee YJ, Kim DJ, Suh SH, Lee SK, Kim J, Kim DI (2005) Stent-assisted embolization of intracranial wide-necked aneurysms. Neuroradiology 47(9):680–689. doi:10.1007/s00234-005-1402-8
29. Levy DI, Ku A (2007) Balloon-assisted coil placement in wide-necked aneurysms. Technical note. J Neurosurg 86(4):724–727
30. El L, Boulos AS, Bendok BR et al (2002) Brainstem infarction after delayed thrombosis of a stented vertebral artery fusiform aneurysm case report. Neurosurgery 51:1280–1284. doi:10.1097/00006123-200211000-00026
31. Lefkowitz MA, Gobin YP, Akiba Y, Duckwiler GR, Murayama Y, Gulielmi G, Martin NA, Vinuela F (1999) Balloon-assisted Guglielmi detachable coiling of wide-necked aneurysms: Part II-clinical results. Neurosurgery 45(3):531–537. doi:10.1097/00006123-199909000-00024
32. Lopes DK, Ringer AJ, Boulos AS, Qureshi AI, Lieber BB, Guterman LR, Hopkins LN (2003) Fate of branch arteries after intracranial stenting. Neurosurgery 52(6):1275–1278. doi:10.1227/01.NEU.0000064567.15270.27
33. Lusseveld E, Brilstra EH, Nijssen PC et al (2002) Endovascualr coiling versus neurosurgical clipping in patients with ruptured basilar tip aneurysm. J Neurosurg Psychiatry 73:591–593. doi:10.1136/jnnp. 73.5.591
34. Lylyk P, Cohen JE, Ceratto R, Ferrario A, Miranda C (2002) Endovascular reconstruction of intracranial arteries by stent placement and combined technique. J Neurosurg 97:1306–1313
35. Malek AM, Higasha RT, Halbach VV, Phatouros CC, Meyers PM, Dowd CF (1999) Tandem intracranial stent deployment for treatment of an iatrogenic, flow-limiting, basilar artery dissection: technical case report. Neurosurgery 45(4):919–924. doi:10.1097/00006123-199910000-00042
36. Mericle RA, Wakhloo AK, Rodriguez R, Guterman LR, Hopkins LN (1997) Temporary balloon protection as an adjunct to endovascular coiling of wide-necked aneurysms: a technical note. Neurosurgery 41 (4):975–978. doi:10.1097/00006123-199710000-00045
37. Meyers FB (2006) Balloon-assisted coil embolization of intracranial aneurysms. J Neurosurg 105(3):392. doi:10.3171/jns.2006.105.3.392
38. Mitchell P, Kerr R, Mendelow AD, Molyneux A (2008) Could late rebleeding overturn the superiority of cranial aneurysm coil embolization over clip ligation seen in the International Subarachnoid Aneurysm Trial? J Neurosurg 108(3):437–442. doi:10.3171/JNS/2008/108/3/0437
39. Nakahara T, Sakamoto S, Hamasaki O, Sakoda K (2002) Stent-assisted angioplasty for intracranial atherosclerosis. Neuroradiology 44:706–710. doi:10.1007/s00234-002-0794-y
40. Nelson PK, Levy DI (2001) Balloon-assisted coil embolization of a wide-necked aneurysms of the internal carotid artery: medium-term angiographic and clinical follow-up in 22 patients. AJNR Am J Neuroradiol 22(1):19–26
41. Phatouros CC, Higashida RT, Malek AM et al (1999) Endovascualr stenting of an acutely thrombosed basilar artery: technical case report and review of literature. Neurosurgery 44:667–673. doi:10.1097/00006123-199903000-00134
42. Phatouros CC, Sasaki TY, Higashida RT (2000) Stent-supported coil embolization: the treatment of fusiform and wide-necked aneurysms and pseudo-aneurysms. Neurosurgery 47:107–115. doi:10.1097/00006123-200007000-00023
43. Perez-Arjona E, Fessler RD (2004) Basilar artery to bilateral posterior cerebral artery 'Y stenting' for endovascular reconstruction of wide-necked basilar apex aneurysms: report of three cases. Neurol Res 26(3):276–281. doi:10.1179/016164104225013969
44. Price RF, Sellar R, Leung C, O'Sullivan MJ (1998) Traumatic arterial dissection and vertibrobasilar thrombosis successfully treated with endovascular thrombolysis and stenting. AJNR Am J Neuroradiol 19:1677–1680
45. Ross IB, Gurmeet SD (2006) Balloon assistance as a routine adjunct to the endovascular treatment of cerebral aneurysms. Surg Neurol 66(6):593–601. doi:10.1016/j.surneu.2006.03.050
46. Ross IB, Gurmeet SD (2005) Complications of endovascular treatment of cerebral aneurysms. Surg Neurol 64(1):12–18. doi:10.1016/j.surneu.2004.09.045
47. Sani S, Lopes DK (2005) Treatment of a middle cerebral artery bifurcation aneurysm using a double neuroform stent "Y" configuration and coil embolization: technical case report. Neurosurgery 57(1):E209. doi:10.1227/01.NEU.0000163684.75204.CD
48. Spreer J, Els T, Hetzel A et al (2002) Primary stenting as emergency therapy in acute basilar artery occlusion. Neuroradiology 44:791–795. doi:10.1007/s00234-002-0798-7
49. Sluzewski M, van Rooij WJ, Beute GN, Nijssen PC (2006) Balloon-assisted coil embolization of intracranial aneurysms: incidence, complications, and angiography result. J Neurosurg 105(3):396–399. doi:10.3171/jns.2006.105.3.396
50. Suzuki S, Tateshima S, Jahan R, Duckwiler GR, Murayama Y, Gonzalez NR, Frazee JG, Vinuela F (2009) Endovascular treatment of middle cerebral artery aneurysms with detachable coils: angiographic and clinical outcomes in 115 consecutive patients. Neurosurgery (March):6. E pub
51. Thorell WE, Chow MM, Woo HH, Masaryk TJ, Ramussen PA (2005) Y-configured stent-assisted coil embolization for the treatment of wide-necked basilar tip aneurysms. Neurosurgery 56(5):1035–1040
52. Vanninen R, Manninen H, Ronkainen A (2003) Broad-based intracranial aneurysms: thrombosis induced by stent placement. AJNR Am J Neuroradiol 24(2):263–266
53. Vallee JN, Aymard A, Vicaut E, Reis M, Merland JJ (2003) Endovascular treatment of basilar tip aneurysms with Guglielmi detachable coils: predictors of immediate and long-term results with multivariate analysis 6-year experience. Radiology 226 (3):867–879. doi:10.1148/radiol.2263011957
54. Wanke I, Doerfler A, Schoch B, Stolke D, Forsting M (2003) Treatment of wide-necked intracranial aneurysms with a self expanding stent system: initial clinical experience. AJNR Am J Neuroradiol 24:1192–1199
55. Wanke I, Gizewski E, Forsting M (2006) Horizontal stent placement plus coiling in a broad-based basilar tip aneurysm: an alternative to the Y-stent technique. Neuroradiology 48(11):817–820. doi:10.1007/s00234-006-0128-6
56. Wells-Roth D, Biondi A, Janardhan V, Chapple K, Gobin YP, Riina HA (2005) Endovascular procedures for treating wide-necked aneurysms. Neurosurg Focus 15 18(2):E7
57. Yahia AM, Gordon V, Whapham J, Malek A, Steel J, Fessler RD (2008) Complications of Neuroform stent in endovascular treatment of intracranial aneurysms. Neurocrit Care 8(1):19–30. doi:10.1007/s12028-007-9001-7
58. Yano S, Houkin K, Abe S et al (2001) Angioplasty with stenting for intracranial vertebral and basilar artery stenosis: three technical case reports and literature review. No Shinkei Geka 29:1081–1090
59. Zenteno M, Modensi Freitas JM, Aburto-Murrieta Y, Koppe G, Machado E, Lee A (2006) Balloon-expandable stenting with and without coiling for wide-necked and complex aneurysms. Surg Neurol 66(6):603–610. doi:10.1016/j.surneu.2006.05.058

Comment

So far, microsurgery has been in most cases of large and giant aneurysms the treatment of choice because of the high risk of re-canalization after endovascular treatment which may furthermore be contraindicated because of an existing thrombus. With new development of stents some of the previously uncoilable aneurysms that may have also been difficult to treat with microsurgery may become coilable. However, very promising early results and enthusiasm may turn into disappointments after long-term follow-up. As the techniques and recommendations in endovascular therapy are constantly changing with new equipment coming to the market every month, it may be difficult to look back after 10–20 years as the current stents may be considered to be from the time of dinosaurs and not even worth analyzing at that time. During this time, so many other new techniques/devices will be used in different combinations each with a relatively small number of patients. Most likely, no real comparison between different methods will ever be done and only the latest equipment will be recommended by the endovascular society and industry. It will be interesting and important to see what happens inside and around the stent after several decades. Will we see parental artery occlusions or stents migrating out of the vessel wall? However, if the new stents and technology also work in the long-run, they are a welcome adjunct in the treatment of these challenging lesions and may even replace microsurgical treatment in many cases.

Mika Niemelä
Juha Hernesniemi
Helsinki, Finland