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*AJNR Am J Neuroradiol* 2005, 26 (9) 2342-2348
http://www.ajnr.org/content/26/9/2342

# The Use of Balloon-Expandable Stents in the Management of Intracranial Arterial Diseases: A 5-Year Single-Center Experience

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***BACKGROUND AND PURPOSE:*** **Although stent-assisted intracranial procedures are becoming a routine clinical practice, there have been relatively few large studies published in the literature regarding the application of the balloon-expandable stent technology in the treatment of intracranial arterial diseases. In this report, the authors reviewed their experience with 75 cases at a single center.**

***METHODS:*** **From 1998 to 2003, 75 patients underwent percutaneous transluminal intracranial stent placement as a treatment for wide-necked intracranial aneurysms and atherosclerotic stenoses. The anatomy of the target lesions, technical details of the procedures, device functionality, procedure-related complications, and short-term outcomes were reviewed in a retrospective fashion.**

***RESULTS:*** **The clinical indications included wide-necked intracranial aneurysms (59) and atherosclerotic stenoses (16). The stent was successfully deployed in 92% of the patients (69 of 75 cases). In the remaining 6 cases, the causes of failed stent deployment included arterial tortuosities (2), stent migration (2), fracture of the stent (1), and arterial perforation (1). The short-term outcome (mean follow-up, 7.5 months; range, 3–12 months) was evaluated by using the modified Rankin scale (MR spectroscopy 0–6). Fifty-three patients (70.6%) had excellent outcomes (MR spectroscopy 0–1), 12 (16%) had good outcomes (MR spectroscopy 2), and 5 (6.7%) had poor outcomes (MR spectroscopy 4–5). Five patients (6.7%) died.**

***CONCLUSION:*** **The use of BES is associated with a high rate of hemorrhagic and ischemic complications, more specifically when used in the anterior circulation. Cases of large-necked aneurysms not treatable with balloon remodeling technique and atheromatous sclerosis could be eligible for this treatment.**

The new millennium promises many exciting and innovative endovascular treatment strategies and devices. With rapidly advancing technology, stent-assisted intracranial procedures are becoming a routine clinical practice. There have been, however, relatively few large studies published in the literature regarding the application of balloon-expandable stent (BES) technology in the treatment of intracranial arterial disease, including large or wide-necked aneurysms and atherosclerotic stenoses (1).

The endovascular treatment of large and wide-necked aneurysms represents a technical challenge. The conventional single-catheter endovascular technique works well in patients with saccular aneurysms with narrow necks. Wide-necked (>4 mm or a fundus-to-neck ratio <2) or fusiform aneurysms are frequently treated by performing parent artery occlusion, provided that there is a sufficient collateral blood supply (2). Several options, either alone or in combination, have been proposed, including the use of coils with a complex 3D shape, bioactive and hydrogel coils, or TriSpan coils (Target Therapeutics/Boston Scientific, Natick, MA; 3–5). Such liquid polymer agents as Onyx (Micro Therapeutics, Inc., Irvine, CA) have also been reported as a filling material (6).

Henkes et al (7) reported a large retrospective series of 1811 aneurysms that were treated by endovascular coil occlusion at a single institution. Complete or almost-complete occlusion was achieved in 86.5% of the aneurysms, and 82.3% of the procedures were performed without complication. Otherwise, they found that large diameter and wide neck were also

Received August 5, 2004; accepted after revision April 28, 2005.

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factors related to increased frequency of periprocedural complications as well as lower occlusion rates (7).

Recently, flexible balloon-expandable metallic microstents have been used as alternative to obliterate the neck of large aneurysms, with some success. Nevertheless, both experimental and early clinical results have led to the conclusion that a stent alone is usually insufficient to obliterate an aneurysm. Although a stent placed across the neck of an aneurysm alters the blood flow and redirects the shear stress in such a way that it may lead to partial thrombosis, an additional embolic device is usually needed as filler to obliterate the lumen of the aneurysm. Most investigators have used Guglielmi detachable coils or Onyx as a filler material (8).

In light of the fact that wide-necked aneurysms increase the risk of coil migration into the parent vessel, the balloon-remodeling technique (BRT), first described by Moret et al (9) in 1997, may be the better option.

With regard to intracranial arterial stenosis, the treatment has traditionally consisted of antithrombotic therapy (antiplatelet agents or anticoagulation) and management of vascular risks factors.

Since 1980, when Sundt et al (10) performed the first intracranial angioplasty in the basilar artery, many authors have reported their experiences in treating intracranial arterial stenosis with percutaneous transluminal angioplasty (PTA). Several have described good results with such treatment, though others have reported high rates of procedure-related complications, including dissection, local thrombosis, or vessel rupture, as well as high rates of late restenosis leading to stroke (11).

Recently, several reports have been published concerning the successful deployment of BESs with a relatively low rate of morbidity and mortality for intracranial atherosclerotic stenoses. Technical advances in neurovascular stents such as flexibility, trackability, and radiopacity have been markedly improved, which allow more distal navigation. Furthermore, stent-assisted angioplasty appears to produce better angiographic results than PTA alone (12).

## Patients and Methods

From 1998 to 2003, 75 patients presented to our department with intracranial saccular, dissecting, or fusiform aneurysms and atheromatous stenotic lesions. They were divided into 2 groups: group 1, which consisted of 59 patients (76.6%) with wide-necked, large, or giant intracranial aneurysms, and group 2, which consisted of 16 patients (20.8%) with atheromatous intracranial stenoses. They underwent intracranial BES placements alone or as a first step of the procedure. A senior neuroradiologist (C.M., M.P., L.S., and J.M.) reviewed their medical records. Clinical data were collected and recorded in a specifically designed case, which included the collection of modified Rankin scale (MR spectroscopy) (13), cranial nerve deficits, adverse events, and each change from baseline neurologic status. Whether morbidity or mortality was related to the device, the procedure, or the disease or was unrelated to the procedure was also recorded.

The clinical and radiologic outcomes were determined mainly by review of medical records and by neurologic evaluation during control angiography.

### *Anticoagulation Protocol*

All patients received an initial 5000 IU intravenous heparin bolus. This was followed by a 3000–4000 IU/h continuous heparin infusion to keep the activated clotting time close to 300 seconds. All patients also received an initial 250 mg intravenous bolus of acetyl-salicylic acid except the ones who experienced a recent subarachnoid hemorrhage (SAH). All patients received subcutaneous fractionated heparin for 1 week. Oral acetyl-salicylic acid (150 mg) and an inhibitor of platelet aggregation and wall deposition, clopidogrel (75 mg), were administered prophylactically 1 day before the stent procedure and were continued for at least 1 month, after which clopidogrel was discontinued. In cases of thromboembolic events occurring during stent placement or aneurysm coil placement, abciximab was administered intra-arterially through a microcatheter as a bolus of 4–10 mg during a period of 10–20 minutes (14–16).

### *General Procedure-Related Information*

General anesthesia was induced in all cases. After a complete cerebral angiographic evaluation and 3D spin by using the Integris BN 5000 biplane system (Philips Medical Systems, Best, the Netherlands), the target lesion was outlined in multiple projections and the 2 best working projections were defined.

In patients with large cavernous or ophthalmic artery aneurysms, balloon test occlusion was routinely performed before the stent-assisted procedures. Occlusion of the parent vessel would be considered in the event of failed primary procedures. The stents used were Cerebrence, AVE gfx, AVE inx, AVE S670 (Arterial Vascular Engineering, Inc., Santa Rosa, CA), CrossFlex (Cordis Endovascular Systems, Miami Lakes, FL), and Express (Boston Scientific). These stents were chosen on the basis of their availability in the department.

### *Choice of the Stent*

The use of stents varied and depended on the judgment of the treating physician. In these cases, the flexible and compatible stents available in the department were balloon-expandable coronary stents. Stent size was chosen in accordance with the nominal diameter of the target artery and landing zone (aneurysm neck or stenosis). After full angiographic cerebral evaluation, 2 working projections were chosen and the target lesion was outlined in multiple projections with rotational 3D angiography. The diameters of the parent vessel above and below the target lesion (aneurysm, stenosis, or dissection), the aneurysm/neck diameters, as well as the length of stenosis, were measured. In general, the stent length was chosen to provide at least a 5-mm landing zone (5 mm extra coverage by the stent, beyond the aneurysm neck on either side anchoring with 5 mm of the device on each side into normal artery). Thus, for an aneurysm with a 4-mm neck, a 14-mm-long stent should be selected. To implant the stent appropriately in front of the aneurysm neck, it should be positioned across the lesion with enough overlap on each side of the parent artery to anchor the device properly—the stent should be centered on the aneurysm neck. The diameter of the implanted stent should be equal to the diameter of vessel—that is, a 1:1 ratio. An appropriately sized stent was selected (available sizes included 2.5–5.0-mm nominal diameters with 8.0–25.0-mm nominal lengths).

### *Statistical Analysis*

Statistical analysis was performed by using SPSS version 7.5 software (SPSS, Inc., Chicago, IL). The relationship between type of treatment (BES simultaneously to embolization or as the first step of the treatment) and morbimortality was assessed with logistic regression analysis. $P$ values $<.05$ were considered to indicate a statistically significant difference.

*Group 1: 59 Patients with Wide-Necked Intracranial Aneurysms*

*Selection of the patients.* All patients underwent full neurologic evaluation, and a team of neurosurgeons, neurologists, and interventional neuroradiologists determined the indication for endovascular treatment The final decision of intracranial stent deployment was made by one of the senior neuroradiologist. (C.M., M.P., L.S., or J.M.).

*Inclusion criteria for stent placement.* Candidates for stent placement included those with: large or broad-necked aneurysms whose treatment was considered as being impossible or difficult by using the BRT, fusiform and/or dissecting aneurysms (these aneurysms without neck) or dysplasic parent artery, and giant aneurysms for which a treatment with Onyx (Micro Therapeutics) had been elected. The goal of this strategy was to place a stent and inject Onyx during the first session of treatment without "pushing" for complete occlusion of the neck, with the intention to reduce the size. During the second step, taking advantage of a stable stent, the neck was treated with coils.

*Filling material.* Possible material to fill aneurysms included coils, Onyx and coils, or Onyx alone for giant intracranial aneurysms that had failed to respond to prior surgical or endovascular treatment and impossibility of parent artery occlusion. Onyx and coils were chosen for aneurysms satisfying the same criteria given above and for recanalization of the aneurysm after use of Onyx and recurrence of previous coil embolization. Coils alone were chosen for all of the other cases suitable for coil occlusion.

*Occlusion rates of aneurysms.* Immediate and postprocedural angiographic results were graded according to the modified criteria established by Raymond et al (17), as complete occlusion (grade A); dog-ear and residual neck (grade B), and residual aneurysm (grade C).

*Group 2: 16 Patients with Atheromatous Intracranial Stenoses*

*Inclusion criteria.* Candidates for stent placement included those with significant stenoses (60% or more) associated with recurrent symptoms despite a well-conducted antiplatelet treatment (we never used angioplasty and stent placement if the patient's condition was fully controlled just with medication) and acute stroke caused by high-grade stenoses of the major intracranial arteries.

*Exclusion criteria.* Candidates for stent placement were excluded if there was a severe neurologic deficit from a major stroke, chronic total occlusion of >6 months duration, or chronic total occlusion without a visible distal segment on angiograms.

*Classification of the lesions.* Before treatment, the patients were assigned to 3 groups according to the angiographic system of Mori et al (18) as follows: type A, short (5 mm or less in length), concentric or moderately eccentric lesions less than totally occlusive; type B, tubular (5–10 mm in length), extremely eccentric, or totally occluded lesions, <3 months old; and type C, diffuse (>10 mm in length).

*Immediate and follow-up anatomic outcome of these patients.* Employing the criteria developed by the North American Symptomatic Carotid endarterectomy trial (NASCET; 19), we calculated the stenoses rate on angiograms before and immediately after angioplasty and at follow-up to compare the diameter of the vessel at the site of greatest narrowing with the diameter of a normal artery distal to the lesion. When a stenosis rate of 60% or greater before treatment was reduced to <50% immediately after angioplasty along with absence of in-hospital major events, the procedure was considered successful.

Arteriographic restenosis was defined as occlusion of 50% or more of the diameter of the vessel at the follow-up examination.

**TABLE 1: Location of lesions in each group**

| Location | Group, *n* (%) I | Group, *n* (%) II |
|---|---|---|
| Internal carotid artery | | |
| Posterior communicating artery | 7 (12.0) | |
| Carotid bifurcation | 3 (5.1) | |
| Ophthalmic artery | 26 (44.0) | |
| Middle cerebral artery (M1) | 2 (3.3) | |
| Intracavernous | 11 (18.7) | |
| Posterior inferior cerebellar artery | | 1 (6.5) |
| Basilar artery | 7 (11.9) | 10 (62.5) |
| Basilar artery (P1 origin) | 1 (1.7) | 1 (6.25) |
| Vertebral artery (V4) | 2 (3.3) | 4 (25.0) |
| Total | 59 | 16 |

**TABLE 2: Clinical manifestations**

| Symptoms | Group, *n* (%) I | Group, *n* (%) II |
|---|---|---|
| Ischemic cerebrovascular accident | | 3 (18.5) |
| Compression | 17 (28.8) | |
| Incidental | 16 (27.1) | |
| Subarachnoid hemorrhage | 22 (37.3) | 2 (12.5) |
| Transient ischemic attack | 4 (6.8) | 11 (68.75) |
| Total | 59 | 16 |

## Results

### *Overall Data*

A total of 75 patients (45 women and 30 men; age range, 9–76 years; mean age, 51 years) were divided into 2 groups: group 1 consisted of 59 patients (78.6%) with wide-necked intracranial aneurysms; group 2 consisted of 16 patients (21.4%) with atheromatous intracranial stenoses. Tables 1 and 2 summarize each group by locations and clinical presentations, respectively. The short-term outcomes (follow-up range, 3–12 months; mean follow-up, 7.5 months) were evaluated by using the modified Rankin scale (MR spectroscopy 0–6). Fifty-three patients (68.8%) had excellent outcomes (MR spectroscopy 0–1), 12 (15.7%) had good outcomes (MR spectroscopy 2), and 5 (9%) had poor outcomes (MR spectroscopy 4–5). Five patients (6.5%) died.

The stent was successfully deployed in 92% of the patients (69 of 75 cases). In the remaining 6 cases, the causes of failed stent deployment included arterial tortuosities (2), stent migration (2), fracture of the stent (1), and arterial perforation (1). All of the failed cases were from patients with wide-necked intracranial aneurysms. We used 9 types of stents and in all but 2 cases (AVE Inx/Cerebrence and AVE Inx/AVE S670), a single stent per lesion was deployed: The Cerebrence stent was used in 34 (44%) cases, the AVE S670 stent was used in 27 cases (35.5%), the AVE Inx stent was used in 8 cases (10.4%), the AVE Gfx stent was used in 2 cases (2.5%), and others were used in 4 cases (7.6%).

**TABLE 3: Follow-up occlusion rates of aneurysms**

| | All Aneurysms | Large (10–24 mm) | Giant (≥25 mm) |
|---|---|---|---|
| Postembolization occlusion rates | | | |
| Grade A | 44 (74.6)* | 39 (85) | 7 (53.8) |
| Grade B | 9 (15.25) | 5 (11) | 5 (38.5) |
| Grade C | 6 (10.15) | 2 (4) | 1 (7.7) |
| Total | 59 | 46 | 13 |
| 3–6 mo follow-up occlusion rates | | | |
| Grade A | 26 (71) | 24 (80) | 4 (57.1) |
| Grade B | 7 (19) | 4 (13) | 2 (28.6) |
| Grade C | 4 (10) | 2 (7) | 1 (14.3) |
| Total | 37 | 30 | 7 |
| 12-month follow-up occlusion rates | | | |
| Grade A | 24 (78) | 20 (77) | 3 (60) |
| Grade B | 5 (16) | 4 (15.4) | 1 (20) |
| Grade C | 2 (6) | 2 (7.6) | 1 (20) |
| Total | 31 | 26 | 5 |

* Values in parentheses are percentages.

### *Group 1: 59 Patients (78.6%) with Wide-Necked Intracranial Aneurysms*

Fifty-nine patients (43 women and 16 men; age range, 9–73 years; mean age, 50 years) were treated with a combined approach: 46 (78%) patients with stent placement and coiling (performed in the same procedure in 41 patients); 8 (13.5%) with stent placement and Onyx embolization (performed in the same procedure in 4 patients); and 5 (8.5%) with stent placement, coiling, and Onyx embolization. (In all 5 patients treated with coiling and Onyx the embolization was performed in subsequent procedures.)

Of 59 aneurysms, 22 were ruptured and 37 were unruptured. The interim between the SAH and treatment was between 2 days and 17 months (mean, 8.5 months).

### *Immediate and Follow-Up Angiographic Outcome of These Patients*

From the 59 treated aneurysms, the rate of occlusion at the end of the procedure was grade A in 44 cases (74.6%), grade B in 9 cases (15.25%), and grade C in 6 cases (10.15%). Thirty-seven of the cases (62.7%) had a follow-up from 3 to 6 months, with grade A in 26 cases (71%), grade B in 7 cases (19%), and grade C in 4 cases (10%). Thirty-one of the cases (52.5%) had a follow-up of 12 months, with grade A in 24 cases (78%), grade B in 5 cases (16%), and grade C in 2 cases (6%) (Table 3).

There were 46 large or wide-necked aneurysms. The size of these aneurysm sacs ranged from 10 to 25 mm, and the average neck size was 5.2 mm (range, 3.0–10.0 mm). Thirteen aneurysms were giant, and their aneurysm sac size ranged from 25 to 40 mm, with average neck size of 6.1 mm (range, 5.0–10.0 mm).

### *Complications*

There were a total of 19 technical complications: 7 cases of arterial perforation (36.8%), 4 cases of stent migration (21.1%), 4 cases of stent rupture (15.8%), 6 cases of intrastent thrombosis (10.5%), and 3 cases of distal thromboembolization (15.8%). These were translated into clinical complications in 11 patients, with 5 being hemorrhagic (4 SAHs and 1 acute subdural hematoma [ASDH]) in nature and 6 ischemic (4 cerebrovascular accidents [CVAs] and 2 transient ischemic attacks). Nine (81.8%), including all 4 deaths, of these 11 patients had the combined approach performed in the same procedure, which suggested a significant statistical correlation ($P < .001$) between type of treatment (BES simultaneous to embolization or as the first step of the treatment) and morbidity and mortality. At a mean follow-up of 3–12 months (range, 7.5 months), of these 11 patients, 5 had good outcomes (MR spectroscopy 2), 2 had poor outcomes (MR spectroscopy 4–5), and 4 had died. The causes of death included 2 SAHs, 1 ASDH, and 1 CVA.

### *Group 2: 16 patients (21.4%) with Atheromatous Intracranial Stenoses*

A total of 16 patients (2 women and 14 men; age range, 47–76 years; mean age, 62 years) (21.4%) with atheromatous intracranial stenoses were treated. There were 12 cases of vertebrobasilar (VB) ischemic attack (75%) and 4 cases of VB stroke (25%). The locations of lesion included 7 in the midbasilar artery (43.75%), 4 in the vertebral artery (V4; 25%), 2 in the proximal basilar artery (12.5%), and 3 in the distal basilar artery (18.75%). According to the classification by Mori et al (18), there were 3 Mori A (18.75%), 9 Mori B (56.25%), and 4 Mori C (25%).

Of 16 patients, 4 (25%) were treated with angioplasty before stent deployment and 12 (75%) were treated with primary stent placement.

The immediate anatomic follow-up poststent placement has showed a reduction of stenoses from a median of 84% (range, 67%–98%) to a median of 12% (range, 2%–20%). The procedural success rate was 81.2%. The median follow-up period was 6 months (range, 3–12 months). Among 16 patients, 13 underwent arteriographic follow-up 3 months after the procedure (81.2%). There was narrowing in the stent in all cases, and restenosis ranged from 10% to 32% luminal narrowing. Of 8 patients (50%) treated with angiography in 12 months, only 1 presented severe restenosis (>70% diameter stenosis).

### *Complications*

Clinical complications occurred in 4 patients (3 SAHs and 1 CVA from distal embolization). Of the 3 patients with SAHs, 2 developed clinical and radiologic manifestations recognized as cerebral hyperpefusion syndrome and the other experienced a procedure-related basilar artery perforation. Three of the 4 complications presented high-grade stenoses (>90%),

and all of them belonged to a high-risk cohort, according the NASCET trial. Of these 4 patients, one had excellent outcome (MR spectroscopy 0), 2 had poor outcomes (MR spectroscopy 4–5), and one died. In a follow-up at 12 months, no recurrent symptoms were observed.

## Discussion

With rapidly advancing technology, stent-assisted intracranial procedures are becoming routine clinical practice. Nevertheless, there have been relatively few large studies published in the literature regarding the application of the BES technology in the treatment of intracranial arterial diseases (20).

Possible indications for the deployment of microstents in intracranial vessels are the balloon dilation of atherosclerotic stenoses, endovascular occlusion of arteriovenous fistulas, and stent-assisted coil occlusion of wide-necked aneurysms. Rare conditions treatable by stent deployment are vessel dissections and herniations of coil loops into the parent vessel during coil occlusion of intracranial aneurysms (21).

The stent itself reduces aneurysm inflow and might thereby induce stasis and thrombosis with occlusion of the aneurysm. In combination with embolization by using detachable coils, the stent serves as a scaffold that prevents coil herniation. A stent may also provide an endoluminal matrix for endothelial growth (22). Furthermore, BES provides endovascular reconstruction at the aneurysmal site to allow for more attenuated packing of coils and possibly to reduce the occurrence of coil compaction through the hemodynamic flow (23).

Several authors have achieved good results with BES-assisted coil occlusion of intracranial aneurysms, whereas others have encountered significant complications related to these devices, mostly dissection or rupture of the parent vessel (24).

The disadvantage of these BESs is their relatively poor flexibility and pushability, which often makes it impossible to navigate the systems to a suitable position. Stent placement always poses a risk of acute in-stent thrombosis, necessitating sufficient premedication with antiplatelet drugs. Therefore, in the treatment of acutely ruptured broad-necked aneurysms, stent placement should be avoided, unless there is no other solution.

The use of self-expandable stents can be an alternative, because it is less traumatic to the patient and should carry a lower risk of dissection or vessel rupture. Unless an additional remodeling balloon is used, the risk of coil loop protrusion through the self-expandable stent struts exists (25).

The BRT, first introduced in 1997 by Moret et al, revolutionized the treatment of wide-necked intracranial aneurysms. BRT (ie, temporary occlusion of the parent vessel and the aneurysm neck with a nondetachable balloon during aneurysm coiling through a second microcatheter) has the obvious advantage of avoiding a permanent intravascular implant and the associated antiplatelet medication. The low-pressure (4–6-atmosphere) inflation of a soft balloon during the remodeling procedure may cause less injury to the vessel wall than balloon deployment of a stent. When compared with stent coil–assisted technique (19.5%), BRT has had significantly lower morbimortality rates in our department (1%). That is why, instead of being riskier, we indicated the former, only in cases where the conventional techniques or BRT were not feasible.

Technical complications observed in our series have also been described in the literature. Some authors have achieved good results with BES-assisted coil occlusion of intracranial aneurysms, whereas others have encountered significant complications related to these devices, mostly due to dissection or rupture of the parent vessel (26).

Nevertheless, we underscore that this treatment option was reserved, first, for patients with no other therapeutic option and, second, for patients who have been discussed in another center before coming to our institution and finally sent to our department.

We should also consider that the hemodynamic effect of a porous stent bridging the neck of an aneurysm is insufficient to induce thrombosis of the aneurysmal sac alone, often requiring an association of an embolic agent. This is partly due to the high porosity of available stents and required use of anticoagulation, as well as antiplatelet medication.

The choice of standard coils as embolic agent has been made on the basis of good results already obtained (46 cases), but Onyx (8 cases) or coil and Onyx combined (5 cases) were also used to treat giant aneurysms, with satisfying immediate total occlusion rates of 74.6%, 71% in 3–6 months, and 78% in 12 months, respectively.

The finding of highest morbimortality in the patients embolized at the same time as stent placement ($P < .001$) should be considered. In all likelihood, the most recent flexible stents, with better trackability, or the self-expandable stents are promising devices to improve the performance of the procedure, saving time and minimizing risk.

### *Atherosclerotic Diseases*

Intracranial atherosclerotic disease is a high-risk cause of stroke that is potentially treatable. The Northern Manhattan Stroke Study (27) found a 5.9% adjusted risk of recurrent stroke at 30 days in 57 patients relative to a nonatherosclerotic stroke group. Stroke rates in patients with symptomatic intracranial stenoses who are receiving medical therapy may be as high as 10%–24% per year (28). The risk of stroke and death appears to increase early and dramatically for patients whose medical therapy is not successful. Although the first treatment choice for patients with intracranial atherosclerotic stenoses is medical therapy, adjunctive stroke-prevention therapies should be given. Because the angioplastic microballoon catheter, which can be used in intracranial vessels, emerged in the field of neuroendovascular treatment, reports of PTA for intracranial atherosclerotic stenoses have

shown an increasing trend. Several investigators reported the efficacy of PTA for intracranial atherosclerotic stenoses. There has, however, been a reluctance to apply it more widely because of complication rates as high as 9.1%–38%. The shortcomings of PTA alone are elastic recoil, severe dissection, vessel rupture, distal embolization, and high rate of late restenosis leading to stroke (29).

The use of stent-assisted angioplasty is an alternative treatment for intracranial atherosclerotic stenoses in symptomatic patients resistant to medical therapy and at high risk for stroke. Several reports have been published concerning the successful deployment of stents with a relatively low rate of mortality and morbidity. The advent of more flexible coronary BESs has allowed safe and relatively reliable endovascular access to intracranial arteries. These stents are of an appropriate length to follow arterial tortuosity and can be made to conform to vascular morphology (30).

Moreover, stent-assisted angioplasty, which can achieve satisfactory angiographic results, minimizes the risk of elastic recoil and intimal dissection. Kiyosue et al (31) reported 2 cases of endovascular stent placement for restenosis of the intracranial vertebrobasilar artery after balloon angioplasty and reviewed 33 cases from the literature. They found an estimated risk of periprocedural complications and restenosis after PTA alone of approximately 20% and 27%, respectively. Otherwise, the overall complication rates related to stent placement and restenosis were 5.6% and 7.8%, respectively. Procedural complications of stent placement—such as vessel rupture—are strongly related to the diameter of the balloon and the stent.

Because the intracranial vessel is a thin-walled artery, careful sizing of the balloon is needed. Oversizing the stent may result in intimal dissection at the stent margins by dumbbell-shaped balloon expansion. Therefore, to avoid these complications sizing the stent 0.5 mm smaller than the assumed diameter has been used. De Rochemont et al (32) evaluated prospectively the safety and efficacy of undersized stents used in 18 patients with high-grade intracranial stenoses and recurrent ischemic symptoms. The technical success rate was 90% and the degree of stenosis was reduced from a median of 82% to a median of 16%. No immediate complication—including thromboembolism, dissection compromising the blood flow, or vessel ruptures—occurred.

Despite being less common—but harboring potentially more serious complications—cerebral hyperperfusion syndrome after percutaneous intracranial stent placement has been described in the literature (0.3%–1.2%) (33). Meyers et al (34) performed a retrospective review of 140 patients who underwent PTA/stent placement of the craniocervical arteries. They found 5% of cerebral hyperperfusion syndrome with prevalence greater in patients who belonged to a high-risk cohort according to the NASCET Trial as well as in cases of carotid stenoses rated as >80%.

The complication rate of 25% (4 of 16) described in our report is relatively high compared with other series of intracranial stenoses and stent placement. All 4 patients who experienced complications belonged to a high-risk cohort according to the NASCET trial, and the diameter of the stent deployed was in the 1 : 1 ratio to the parent artery. Three of the 4 patients presented with SAHs. Among these 3 patients, 2 developed clinical and radiologic manifestations recognized as cerebral hyperpefusion syndrome and presented with high-grade stenoses (>90%).

Our findings suggest that, in high-risk cohorts and in cases of high-grade stenoses, a possible technical strategy would be the use of undersized stents, as well as the adoption of prophylactic measures, including prevention of cerebral hyperfusion syndrome.

## Conclusion

Development of stents for the management of intracranial atherosclerotic stenoses and aneurysms has been a challenge. The combination of endovascular reconstruction of the parent vessel by using this kind of neurovascular stent followed by a device of embolization offers a promising therapeutic alternative in the treatment of wide-necked aneurysms not amenable to coil embolization alone or BRTs, or when the occlusion of the main artery is not allowed.

Although recent experience suggests that there have been significant improvements in techniques and materials, several factors must be addressed to reduce complications.

Because coil-assisted stenting has been found to be riskier than BRTs in our practice, it is essential that the treating physicians have expertise in managing the potential complications. Probably, recent development of self-expandable stents, with better trackability and flexibility, might reduce these risks in general.

On the other hand, the use of more flexible BESs may prove useful and effective in treating intracranial atherosclerotic lesions, because the advantages and limitations of this endovascular device, lesion-specific characteristics, and proper selection of patient must be considered.

Prospective and controlled clinical studies are necessary to support the routine use of stents in intracranial vessels.

## Acknowledgments

We thank Dr. Huan Wang, from the Department of Neurologic Surgery, University of Illinois, for his help with our English and data revision.

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