Use of the sole stenting technique for the management of aneurysms in the posterior circulation in a prospective series of 20 patients

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Object. The use of intracranial stents in stent-assisted coil embolization is now a current neurosurgical practice worldwide. The clinical utility of these stents in the sole stenting (SS) technique, however, has not been thoroughly described, and the published reports of this experience are scarce. This study was designed to evaluate SS treatment of dissecting and nondissecting aneurysms of the posterior circulation.

Methods. This prospective and descriptive study was conducted in 20 consecutive patients who harbored single aneurysms of the posterior circulation and who were treated using the SS approach in the last 3 years. The clinical and radiological assessment and follow-up of the patients were evaluated using the modified Rankin scale as well as with computed tomography angiography and digital subtraction angiography at discharge and at 1, 3, 6, and 12 months.

Results. Eleven of the 20 patients had subarachnoid hemorrhages, 3 presented with ischemia, 1 presented with brain-stem compression, and the remaining 5 patients had incidentally discovered, asymptomatic lesions. Only 1 patient had a complication (occipital infarction) attributable to the SS procedure. One patient died of rebleeding 2 weeks after the procedure. At 1 month, 40% of the patients had a subtotal or total occlusion, which increased to 55% at 3 months and 85% at 6 months, with a final subtotal or total occlusion rate of 80% at 1 year. The SS procedure in 1 case was considered a failure at 6 months because no change had been noted since the 1-month follow-up. One case showed partial occlusion and 1 case showed recanalization.

Conclusions. Use of SS for aneurysms in the posterior circulation complex is a safe and effective technique, demonstrating an occlusion rate of 80% at the 1-year follow up. (DOI: 10.3171/JNS/2008/108/6/1104)

Key Words • dissecting aneurysm • endovascular management • posterior circulation • sole stenting

Posterior circulation aneurysms represent only 4–10% of intracranial aneurysms.5,47,81 Such lesions include wide-neck, fusiform, and dissecting aneurysms.22,31,52 For many years, surgical aneurysm clip placement has been regarded as the only effective and definitive treatment available for intracranial aneurysms. Treatment of posterior circulation aneurysms, however, is challenging in neurovascular surgery for many reasons. Some of these aneurysms are of complex morphology (such as fusiform, wide-neck, or calcified), are surgically difficult to approach, or require challenging or risky techniques (such as parent vessel occlusion, skull base approaches, or bypass arterial grafting). It is a matter of consequence that the surgical treatment of these lesions involves high morbidity and mortality rates, and perforating vessels are sometimes occluded.59,71,82

Since the approval of GDCs for the treatment of intracranial aneurysms, endovascular techniques have become widely accepted and represent the first choice of treatment in some centers, yielding excellent results that are comparable or superior to results from surgery.5,19,78 The morphological features of some intracranial aneurysms hamper the endovascular approach to such lesions because the coils may protrude into the vessel lumen, and accordingly the
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parent vessel or the perforating arteries nearby may occlude and initiate an ischemic complication.\textsuperscript{16,17,19,37,42,43,50,53,67,78}

To surmount this obstacle, several strategies have been applied to intracranial aneurysms, such as a new coil design, the balloon-remodeling technique,\textsuperscript{4,56,78} and finally the use of stents as an ancillary tool for coil embolization.\textsuperscript{32} The placement of a stent within the parent artery across the aneurysm neck may hemodynamically uncouple the lesion from the parent vessel, leading to thrombosis of the aneurysm. For complex wide-neck aneurysms, stent placement may also aid the packing of the aneurysm with a GDC by acting as a solid scaffold that prevents coil herniation into the parent vessel.\textsuperscript{1,2,7,9,10,16,18,25,26,38,40,45,46,49,54,65,74,75,87} These aneurysms may be considered as a separate entity because they display a complex clinical presentation, their evolution is particularly severe, their management is technically challenging, and their treatment opens new frontiers in endovascular management. Because the placement of a stent appears to induce the occlusion of the aneurysm while keeping the parent vessel patent, we have advocated the use of the SS technique to treat some posterior circulation aneurysms.\textsuperscript{85,87}

Clinical Materials and Methods

Study Design and Patient Population

This was a prospective study involving 20 patients treated between March 2003 and July 2006. All patients were enrolled consecutively on the basis of harboring a posterior circulation aneurysm suitable for management using the SS technique. All patients in our series had been previously evaluated in consultation with members of the neurosurgery department, were considered unsuitable for surgery, and were scheduled to undergo an endovascular procedure.

As a principle, we never attempt to occlude a vessel as the first treatment option, but rather try to preserve the parent artery even in cases in which collateral blood flow would be sufficient. Coil embolization and stent-assisted coil embolization of aneurysms are well-established techniques, but until now, no single endovascular group has embraced the SS technique as a systematic approach to treating intracranial aneurysms. We therefore designed this study to learn more about the possibility of treating aneurysms using SS.

All patients were clinically assessed using the mRS,\textsuperscript{64} whereas the Hunt and Kosnik scale\textsuperscript{91} was used for cases of ruptured aneurysms. Additionally, an initial CT scan allowed us to classify aneurysms according to the Fisher scale in cases involving SAH.\textsuperscript{21} The initial neuromaging evaluation included a nonenhanced CT scan or MR imaging sequence. To visualize the aneurysm, all patients underwent a helical CT scan (CT angiography) in addition to DS angiography; 3D DS angiography reconstruction was available beginning in April 2006.

Patient Preparation

All patients were routinely given antiplatelet drugs to prevent acute stent thrombosis. In cases of nonruptured aneurysms, a double regimen of 100 mg/day of aspirin and 75 mg/day of clopidogrel was administered 4 days before the procedure. When this regimen was not possible for any reason, a loading dose of 300 mg of clopidogrel was adminis-

tered orally at least 4 hours before the procedure. In the first 8 cases, a heparin bolus of 80 IU/kg was administered, followed by an infusion of heparin at a rate of 800 IU/hour, adjusted to reach an activated clotting time between 200 and 250 seconds.

In patients with ruptured aneurysms and a recent episode of SAH, the antiplatelet drugs were begun intravenously just after stent placement. The antiplatelet drug of choice was tirofiban, a glycoprotein IIb/IIIa inhibitor, at a conventional dosage of 0.4 µg/kg/min for 30 minutes and 0.1 µg/kg/min for the next 24 hours. The long-term antiplatelet regimen was the same for patients with either ruptured or nonruptured aneurysms.

Endovascular Procedure

All patients but 1 were treated after induction of general anesthesia and using neuroanesthesia monitoring. A 7 Fr introducer sheath was inserted into the femoral artery, or a 6 Fr sheath into the humeral/radial arteries. A 6 Fr guiding catheter (Envoy, Cordis) was typically inserted into the distal V2 segment of the VA. Digital subtraction angiography sequences were performed to choose a working projection view. All procedures were performed using a KXXO-200/DPF-60A angiography system (Toshiba Medical Systems Corp.) until April 2006, and then a flat-panel biplane system (3D Axiom Artis, InSpace 3D, Siemens) was used for the follow-up procedures.

A road mapping technique allowed us to navigate to the site of the aneurysm and ensure a correct placement of the stent, covering either the whole aneurysm neck when possible or the diseased portion of the vessel when no neck could be determined. When using BESs, we inflated the devices to their nominal pressure (8 atm in most cases).

Once the stent was placed in the vessel, DS angiography sequences were performed to assess the deployment of the stent; the patency of the parent vessel and of the perforating or adjacent vessels; the modification of the flow within the aneurysm; and the distal arterial tree. At the end of the procedure, the patients underwent a CT angiography assessment with maximum intensity projection and 3D reconstruction using a high-speed CT scanner (Advantage Window, Version 4.2, General Electric).

Choice of Endovascular Devices

Before choosing the endovascular device to use, we had to resolve 2 technical issues: 1) sharply define the required diameter of the device, and 2) precisely determine whether a BES or SES was to be deployed. To solve the first issue, we chose a device with a diameter closest to the size of the vessel to receive a stent, as determined by CT angiography. To select the appropriate type of stent, a BES was selected if we hoped to modify the angle of the vessel and an SES was chosen when a modification of the laminar flow was deemed to promote aneurysm thrombosis.

Postprocedural Management

All patients with satisfactory clinical status and no vasospasm or complications were transferred to the neurosurgical ward after the stent insertion procedure. Patients with Hunt and Kosnik Grade 3 or 4 lesions, vasospasm, or
a technical incident or complication were transferred to the intensive care unit. A double antiplatelet regimen was administered for the next 6 months and a single drug was administered for the following 6 months (at minimum).

Assessment of the Procedure

The patients were clinically assessed using the mRS at discharge and at 1, 3, 6, and 12 months after the procedure. The occlusion rate was estimated using CT angiography and DS angiography on the same dates and categorized as follows: minimal occlusion if shrinking of the aneurysm size was ≤ 30%; partial occlusion with shrinking between 31 and 70%; subtotal occlusion if shrinking was between 71 and 95%; and total occlusion with shrinking > 95%.

Ethical Considerations

The patient and/or his or her relatives were thoroughly informed about the experimental nature of this therapeutic approach, as well as its possible risks and benefits. The devices used in this study are widely used, as are the coils used for endovascular treatment. Most of the stents are approved by the US Food and Drug Administration for coronary use and not for intracranial stent placement (except for Neuroform stents). The Pharos stent, however, has received CE (Conformité Européene) marking in Europe for the treatment of intracranial aneurysms and for intracranial atherosclerosis as well.

Results

Twenty patients were included in the study. Of these 20 patients, 15 were male and 5 were female, with an average age of 46.2 years (range 21–71 years). Results from the first 3 patients studied in this series were previously published as a preliminary technical case report. Results from an additional 2 patients have also been recently published as a technical note on SS treatment for SCA aneurysms.

Previous Medical History

Systemic arterial hypertension was present in 8 patients (40%). Other medical conditions that were encountered included diabetes mellitus, history of cigarette smoking, hemifacial spasm, fibromuscular dysplasia, pituitary adenoma, prothrombotic state, or a ruptured intracranial aneurysm in the anterior circulation (Table 1).

Clinical Features

Eleven patients (55%) had SAH, 3 suffered an ischemic stroke (15%), and 1 patient presented with brainstem compression (Case 5; 5%). The remaining 5 patients (25%) had incidental, asymptomatic aneurysms. The patients who received a Hunt and Kosnik Grade 3 accounted for 30% of the cases (6 patients), Grade 2 for 15% (3 patients), and Grade 1 and 1a for 5% each.

To assess the amount of blood we used a modified Fisher scale, classifying the patients with both a diffuse SAH thicker than 1 mm and intraparenchymal or intraventricular hemorrhage as Grade 3 + 4. Thus, Fisher Grade 4 was present in 2 patients (10%), Grade 3 + 4 in 3 patients (15%), Grade 3 in 3 patients (15%), Grade 2 in 2 patients (10%), and Grade 1 in 1 patient (5%; Table 1). Hydrocephalus occurred in 6 patients (30%), and 3 of them required a shunting procedure before the SS procedure.

Angiographic Findings

The most frequently involved vessel was the right intracranial VA (the V4 segment) in 11 cases. In this particular location, we classified the lesion according to its relationship to the origin of the PICA (Fig. 1). The pre-PICA aneurysms arise proximal to the PICA and post-PICA aneurysms are distal to it. The in-PICA aneurysms were defined as lesions involving the origin of the PICA. The para-PICA aneurysms were defined as lesions not strictly involving the PICA, but whose treatment by stent placement involves the PICA origin because the aneurysm is extremely close to it. We found 1 pre-PICA, 3 para-PICA, 1 in-PICA, and 6 post-PICA aneurysms.

The next most frequently involved vessel was the BA, in 4 cases. Some other unusual locations included the VBJ (1 aneurysm), the SCA (2 aneurysms), the distal PCA (1 aneurysm at the P2-P3 junction), and the VA (1 aneurysm arising from the V1 segment). Details of the aneurysm locations are given in Table 1.

Eight fusiform and 7 wide-neck saccular aneurysms were found. Eleven patients (55%) also had aneurysms with a dissecting pattern, with a “pearl and string” sign, fusiform in 2 cases and “double lumen” in 2 cases. In dissecting aneurysms, a cervical trauma could be traced as a triggering factor in half of the cases.

Treatment and Devices

The SAH in patients was managed medically, and 3 patients with hydrocephalus received shunts. All of these patients were initially scheduled for SS endovascular treatment for their aneurysms. We planned to deploy the stent at the aneurysm neck in saccular aneurysms or at the diseased portion of the vessel in fusiform aneurysms. Initially, we had planned to place only BESs. In 2 cases, however, both the anatomical conditions of the approach and the necessity of modifying the blood flow pattern led us to choose another strategy, as the navigation in unusually tortuous vessels was more suitable for an SES. In the first of these 2 cases the aneurysm was located at the PCA–SCA junction, and the second was an aneurysm at V4 approached from the contralateral V4 due to inaccessibility from the ipsilateral side.

Concerning the choice of the device, we used 18 BESs (90%) and 2 SESs (10%). In 1 case of a BES deployment, the deflation of the balloon was insufficient, the stent was displaced proximally by the retrieval of the balloon, and a second device was needed.

In summary, we placed 9 Pharos stents (Biotronik AG; 45%), 4 Express stents (Boston Scientific; 20%), 1 Multi Link Zeta stent (Guidant Co.; 5%), 1 Multi-Link Pixel stent (Guidant Co.; 5%), 2 Liberté stents (Boston Scientific; 10%), and 1 Velocity stent (Cordis; 5%). As previously noted, we placed 2 Neuroform SESs (Boston Scientific; 10%).

Technical and Clinical Complications

Technical complications occurred in 3 patients (15%), but fortunately they resolved spontaneously and no clinical complication was observed (Table 2). One technical com-
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An ischemic stroke occurred due to an embolus from the guiding catheter in 1 patient. Because the lesion was in the right occipital area, the patient developed a left homonymous quadrantanopsia that progressively disappeared 6 months later. The antiplatelet treatment did not affect CSF shunting procedures.

Imaging Results

The immediate assessment of the SS technique was based on DS angiography sequences and showed some modification of the aneurysm in 17 cases (85%; Table 2). The main change was a sluggish intraaneurysmal vortex motion in 13 aneurysms (65%), a correction of the angle of the parent vessel in 7 cases (35%), and a decrease in contrast filling or shrinking of the aneurysm in 7 cases (35%). These last lesions were all dissecting aneurysms and 4 had an occlusion of > 90%. There was no change in angiographic appearance in 3 aneurysms (15%). The average postprocedural hospital stay was 4.5 days (range 2–14 days).

Postoperative Clinical Assessment

Every patient was evaluated at discharge and at 1, 3, 6,

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**TABLE 1**

Demographic features of the patients and characteristics of the aneurysms*  

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs)</th>
<th>Sex</th>
<th>Previous Medical Conditions</th>
<th>Clinical Presentation</th>
<th>Hunt &amp; Kosnik/Dissecting Aneurysm Grades</th>
<th>Aneurysm Pattern</th>
<th>Aneurysm Size (mm)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>41, M</td>
<td>none</td>
<td>SAH</td>
<td>3/3</td>
<td>yes</td>
<td>V4</td>
<td>7.2 × 13.4</td>
</tr>
<tr>
<td>2</td>
<td>37, M</td>
<td>none</td>
<td>SAH</td>
<td>3/3</td>
<td>yes</td>
<td>V4</td>
<td>22.3 × 13.5</td>
</tr>
<tr>
<td>3</td>
<td>40, F</td>
<td>none</td>
<td>pituitary adenoma</td>
<td>incidental aneurysm</td>
<td>NA</td>
<td>no</td>
<td>VBJ</td>
</tr>
<tr>
<td>4</td>
<td>36, M</td>
<td>hypertension</td>
<td>SAH</td>
<td>2/4</td>
<td>yes</td>
<td>V4</td>
<td>6 × 16</td>
</tr>
<tr>
<td>5</td>
<td>66, M</td>
<td>hypertension</td>
<td>cerebellar infarct</td>
<td>NA</td>
<td>no</td>
<td>LB</td>
<td>10 × 8.7</td>
</tr>
<tr>
<td>6</td>
<td>40, F</td>
<td>hypertension</td>
<td>SAH</td>
<td>1a/2</td>
<td>yes</td>
<td>V4</td>
<td>3.2 × 4</td>
</tr>
<tr>
<td>7</td>
<td>52, M</td>
<td>none</td>
<td>SAH</td>
<td>1/3</td>
<td>yes</td>
<td>V4</td>
<td>8 × 8</td>
</tr>
<tr>
<td>8</td>
<td>58, M</td>
<td>none</td>
<td>incidental aneurysm</td>
<td>NA</td>
<td>no</td>
<td>V4</td>
<td>3 × 6</td>
</tr>
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<td>9</td>
<td>45, M</td>
<td>hypertension, smoking history</td>
<td>SAH</td>
<td>3/3+4</td>
<td>yes</td>
<td>V4</td>
<td>6 × 10</td>
</tr>
<tr>
<td>10</td>
<td>36, M</td>
<td>fibromuscular dysplasia, hypertension</td>
<td>cerebellar infarct</td>
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<td>yes</td>
<td>BT</td>
<td>5.2 × 7</td>
</tr>
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<td>11</td>
<td>47, M</td>
<td>smoking history</td>
<td>lateral medullary infarct</td>
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<td>yes</td>
<td>V4</td>
<td>3.8 × 4.2</td>
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<td>12</td>
<td>47, M</td>
<td>none</td>
<td>vertigo</td>
<td>NA</td>
<td>yes</td>
<td>V4</td>
<td>6.3 × 9</td>
</tr>
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<td>13</td>
<td>63, F</td>
<td>hypertension, other aneurysm</td>
<td>incidental aneurysm</td>
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<td>no</td>
<td>PCA</td>
<td>3.2 × 3.6</td>
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<tr>
<td>14</td>
<td>71, F</td>
<td>hypertension, prothrombotic status</td>
<td>incidental aneurysm</td>
<td>NA</td>
<td>no</td>
<td>LB</td>
<td>5.5 × 5.5</td>
</tr>
<tr>
<td>15</td>
<td>49, F</td>
<td>none</td>
<td>incidental aneurysm</td>
<td>NA</td>
<td>no</td>
<td>V4</td>
<td>16.65 × 24</td>
</tr>
<tr>
<td>16</td>
<td>21, M</td>
<td>none</td>
<td>SAH</td>
<td>3/3+4</td>
<td>no</td>
<td>BT</td>
<td>6.5 × 8.7</td>
</tr>
<tr>
<td>17</td>
<td>37, M</td>
<td>none</td>
<td>SAH</td>
<td>2/4</td>
<td>no</td>
<td>SCA</td>
<td>3 × 3.5</td>
</tr>
<tr>
<td>18</td>
<td>35, M</td>
<td>none</td>
<td>SAH</td>
<td>3/3+4</td>
<td>no</td>
<td>SCA</td>
<td>3.5 × 3</td>
</tr>
<tr>
<td>19</td>
<td>51, M</td>
<td>none</td>
<td>SAH</td>
<td>2/2</td>
<td>yes</td>
<td>V4</td>
<td>2 × 4.2</td>
</tr>
<tr>
<td>20</td>
<td>52, M</td>
<td>diabetes mellitus, hypertension</td>
<td>SAH</td>
<td>3/1</td>
<td>yes</td>
<td>V1</td>
<td>3.3 × 18</td>
</tr>
</tbody>
</table>

* BT = basilar trunk; LB = laterobasilar; NA = not applicable.

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**Fig. 1.** Illustration of the 4 types of V4 aneurysms according to their relationship to the origin of the PICA. The number of each type found in this patient series is also noted in each panel.  
A: PrePICA = proximal to the PICA.  
B: ParaPICA = lesions not strictly involving the PICA, but whose treatment by stent placement involves the PICA origin because the aneurysm is extremely close to it.  
C: InPICA = lesions involving the origin of the PICA.  
D: PostPICA = distal to the PICA.
and 12 months using the mRS (Table 3). The patients were divided as follows, considering their clinical grade: initially (at discharge) there were 7 Grade 0 cases (35%), 4 Grade 1 cases (20%), 6 Grade 2 cases (30%), 2 Grade 3 cases (10%), and 1 Grade 4 case (5%). One month later, there were 12 Grade 0 cases (60%), 5 Grade 1 cases (25%), 2 Grade 2 cases (10%), and 1 patient who died due to rebleeding (5%). At 3 months, 15 of the remaining patients were Grade 0 (75%) and 4 were Grade 1 (20%). At 6 and 12 months, all 19 remaining patients had reached Grade 0 (95%).

### Imaging Follow-Up Results and Aneurysm Occlusion

The follow-up protocol consisted essentially of maximum intensity projection CT angiography and 3D DS angiography at 1, 3, 6, and 12 months (Table 3). At 6 and 12 months every single patient had had his or her follow-up imaging.

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Stent Type/Size (mm)</th>
<th>Technical/Clinical Complications</th>
<th>Immediate DS Angiography Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Express/2.5 × 20</td>
<td>no</td>
<td>SIAVM, angle correction, 40% AO</td>
</tr>
<tr>
<td>2</td>
<td>Express/3 × 24</td>
<td>no</td>
<td>SIAVM, angle correction, 70% AO</td>
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<tr>
<td>3</td>
<td>Express/2.5 × 20</td>
<td>occipital infarct</td>
<td>SIAVM, angle correction</td>
</tr>
<tr>
<td>4</td>
<td>Pharos/4 × 25</td>
<td>no</td>
<td>SIAVM</td>
</tr>
<tr>
<td>5</td>
<td>Neuroform 2/4 × 20</td>
<td>no</td>
<td>SIAVM</td>
</tr>
<tr>
<td>6</td>
<td>Pharos/4 × 25</td>
<td>inadequate first stent deployment</td>
<td>angle correction</td>
</tr>
<tr>
<td>7</td>
<td>Pharos/3 × 20</td>
<td>no</td>
<td>no changes</td>
</tr>
<tr>
<td>8</td>
<td>Neuroform 3/4 × 20</td>
<td>no</td>
<td>no changes</td>
</tr>
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<td>9</td>
<td>Pharos/3.5 × 20</td>
<td>no</td>
<td>SIAVM</td>
</tr>
<tr>
<td>10</td>
<td>Pharos/3.5 × 20</td>
<td>no</td>
<td>SIAVM, 90% AO</td>
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<td>11</td>
<td>Express/3 × 32</td>
<td>no</td>
<td>SIAVM</td>
</tr>
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<td>12</td>
<td>Liberté/3.5 × 20</td>
<td>air embolism</td>
<td>&gt;95% AO</td>
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<td>vasospasm</td>
<td>SIAVM</td>
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<td>no</td>
<td>no changes</td>
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<tr>
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<td>20</td>
<td>Liberté/3 × 8</td>
<td>no</td>
<td>100% AO</td>
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* AO = aneurysm occlusion; SIAVM = sluggish intraaneurysmal vortex motion.

### Summary of stent characteristics, complications of the procedures, and immediate DS angiography changes*

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Discharge mRS Grade</th>
<th>1 Mo mRS Grade</th>
<th>AO (%)</th>
<th>3 Mos mRS Grade</th>
<th>AO (%)</th>
<th>6 Mos mRS Grade</th>
<th>AO (%)</th>
<th>12 Mos mRS Grade</th>
<th>AO (%)</th>
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<tbody>
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<td>1</td>
<td>1</td>
<td>0</td>
<td>NA</td>
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<td>100</td>
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<td>60</td>
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* AO = aneurysm occlusion; NA = not available; — = not applicable.
† This aneurysm had recanalized at the 12-month follow-up (0% occlusion).
‡ Treatment was considered a failure in this patient and she underwent coil embolization after the 6th month.
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examination; however, some of our patients did not come to their 1- and 3-month follow-up appointments.

In the 1st month, only 14 patients (70%) attended a follow-up study. At 1 month, total occlusion was seen in 25% (5 patients), subtotal in 15% (3 patients), partial in 5% (1 patient), and minimal occlusion in 25% (5 patients). At 3 months, 13 aneurysms were assessed (65%); 8 of the 13 were completely occluded (40%), 3 showed subtotal occlusion (15%), and 2 were partially occluded (10%). At 6 months, 19 patients attended the follow-up studies (95%); globally, 13 aneurysms were completely occluded (65%), 4 subtotally occluded (20%), and partial and minimal occlusion were found in 1 case each (5%). The case that demonstrated minimal changes after 6 months (Case 15) was considered a treatment failure, and the aneurysm was treated by coil embolization later on.

At 12 months, 19 patients attended their CT angiography and DS angiography follow-up studies (95%). Sixteen patients had total aneurysm occlusion (80%), 1 showed partial occlusion (5%), and 1 (Case 7) presented with recanalization of the aneurysm (5%), for which coil embolization was necessary. We have illustrated the occlusion rate trends according to aneurysm pathophysiology in Fig. 2.

Illustrative Cases

Case 4

This 36-year-old man sustained a whiplash injury after a car crash 2 weeks earlier; this was accompanied by severe pain in the back of the head and a “pins and needles” sensation in the shoulders and arms. A more intense headache, as well as nausea and vomiting, developed suddenly later on. At his arrival at our hospital he was conscious, with no neurological deficit, but with neck stiffness. The neuroradiological workup showed an SAH distributed to the prebulbar and cerebellotentine cisterns. A DS angiogram disclosed a dissecting aneurysm with a fusiform pattern in the intracranial portion of the right VA (Fig. 3). A 4 × 25 mm Pharos BES was placed, correcting the angle of the vessel and provoking a reduction of the intrasaccular vortex. No complications occurred and the patient was discharged 3 days later. The imaging follow-up using DS angiography and CT angiography showed a progressive occlusion of the aneurysm, partially at 3 months, but at 6 months the occlusion was > 95%. This DS angiogram showed only slight protrusion of the contrast material through the struts of the stent into the thrombosed aneurysm, a so-called “saw image” (Fig. 3), which had disappeared at the 1-year follow-up.

Case 5

This 66-year-old man was a weight lifter with a medical history of systemic arterial hypertension. He presented with sudden headache, nausea, gait ataxia, and a marked lateralpulsion to the right. The physical examination disclosed a right cerebellar syndrome and a slight paresis with hyperreflexia of the left extremities. The imaging studies revealed a stroke in the SCA territory on MR imaging and a partially thrombosed aneurysm of the distal third of the BA, with compression of the right superior cerebellar peduncle. The DS angiography results confirmed a laterobasilar aneurysm of the superior cerebellar segment (Fig. 4). A 4 × 20 mm Neuroform 2 SES was placed in the basilar trunk across the aneurysm, anchoring distally to the PCA. No technical incidents occurred and the patient progressively improved. One year later, no pyramidal or cerebellar signs can be detected in the patient. Imaging studies showed progression of the thrombosis to a complete occlusion of the aneurysm. The MR imaging studies even showed a decrease in the mass effect of the thrombosed aneurysm on the mesencephalon (Fig. 4).

Case 8

This 58-year-old man presented with a 5-year history of left hemifacial spasm. The MR imaging studies disclosed an incidental aneurysm in the right prebulbar cistern, whereas DS angiography showed a para-PICA wide-neck saccular aneurysm of the right VA (Fig. 5). Endovascular management of this aneurysm using a BES was initially scheduled; however, an ipsilateral approach first required the correction of a severe kinking of the V1 segment of the ipsilateral VA. Two BESs were therefore deployed. Several days later, a control DS angiogram prior to the definitive treatment of the aneurysm was performed. A recoiling of this highly tortuous segment precluded any further navigation using this approach. An angiographic sequence from the left VA showed that the access to the right VA was feasible. An SES was chosen as the suitable device and a 4 × 20 mm Neuroform 3 stent was navigated via the left VA to the right VA and was deployed in the para-PICA segment of the right VA. No immediate change was noted, and follow-up studies showed a poor progression of the thrombosis. At the 1-year follow-up, however, the aneurysm had further occluded to a complete closure of the lesion (Fig. 5).
angiogram showed a wide-neck saccular aneurysm located at the angulation between the distal and middle thirds of the basilar trunk (Fig. 6). A 3.5 × 20 mm Pharos BES was deployed without complications. The immediate follow-up DS angiogram, however, showed neither a correction of the angle of the vessel nor any change in the shape of the aneurysm. We even observed an unusual stasis of the contrast medium within the aneurysm, which persisted later in the venous phase. The initial stent placement did not succeed in closing the aneurysm (Fig. 6), and, after the initial 1-week follow-up, a stent-assisted coil embolization procedure was planned, because this aneurysm was believed to be at high risk of rupture. The patient could not afford the costs of the procedure, and in spite of our insistence, he was hospitalized 3 weeks later, rebled, and died while waiting to be transferred to the angiography suite.

**Discussion**

**Complex and Dissecting Aneurysms of the Vertebrobasilar System**

In the present study, we included 9 fusiform and wide-neck aneurysms. Giant aneurysms were not included, because the pathophysiology and hemodynamics of these lesions are quite distinct and therefore their behavior is completely different, a subject that will be addressed in another paper.
The nature of complex and dissecting aneurysms of the vertebrobasilar system leads to complicated management and therefore to poorer surgical results. In addition, these lesions do not represent a lesser challenge to interventional neuroradiology. Simple coil embolization of these aneurysms is not always feasible. Stent-assisted embolization of wide-neck aneurysms allows one to mechanically retain the coils inside the aneurysm while the parent vessel remains patent, and these aneurysms can be approached endovascularly, decreasing morbidity and improving the final occlusion rate. Additionally, the modification of the blood flow away from the aneurysm in some way prevents coil compaction.

Arterial dissections cause ~ 2% of all strokes and intracranial VA dissections may be revealed by SAH or brainstem infarction. Dissecting aneurysms of the VA represent about 28% of all VA aneurysms and 3.3% of all intracranial aneurysms, and their rupture produces a severe SAH with devastating clinical consequences. The rerupture rate of these aneurysms is extremely high (~ 30%). Mizutani and colleagues showed that 40.5% of patients with vertebrobasilar dissecting aneurysms rebled during the 1st 24 hours, and 57.1% rebled during the 1st week. This high rebleeding rate is probably due to the very thin, friable wall of the aneurysm and to a very slow healing process of the vessel.

The endovascular approach to these complex lesions can involve either occluding the diseased arterial segment or trying to preserve or even improve the blood flow through the parent vessel (sometimes referred to as “reconstructive” techniques). Occlusion of the vessel is still an option, yielding fairly good long-term results even if severe and not uncommon complications also occur, including ischemic lesions of the brainstem or retrograde recanalization of the aneurysm. Because embolization using GDCs is not always possible, stents have been added to the armamentarium needed to treat dissecting lesions, as they were previously for cases involving saccular aneurysms.

**Sole Stenting Technique**

**Theoretical and Experimental Rationale.** The SS technique in intracranial aneurysm treatment has emerged as an ancillary tool in stent-assisted coil embolization. The indications for SS as an exclusive treatment in intracranial aneurysms have only recently been described in isolated reports, however, and its application as a systematic strategy is the focus of this paper.

In the previous patient series in which the SS technique was used to treat intracranial aneurysms, the authors generally did not intentionally and prospectively apply this strategy to occlude the aneurysms, and aneurysm closure was serendipitous. To our knowledge, this appears to be the first study completely focused on the use of this technique and its evolution. To summarize the hemodynamic effects of intravascular stent placement, the deviation of blood flow allows a change in the intraneurysmal flow pattern, shifting from a helical to a noncoherent pattern (turbulence), reducing the intrasaccular vortex, producing blood stasis within the aneurysm, and resulting in aneurysmal thrombosis and permanent occlusion. In addition to the thrombotic phenomenon, the luminal surface of the stent is covered with neointimal tissue and the arterial segment is remodeled. Our primary goal in this study was to modify the flow into the aneurysm by modifying either the angle of the vessel or the laminar flow.
Lesions potentially amenable to the SS technique can be divided into 2 groups: 1) aneurysms in which the geometric configuration of the parent vessel is the predominant mechanism in the generation of the aneurysm (for instance, when the lesion arises on the convex side of an angled vessel); and 2) those in which geometry and the sum of hemodynamic forces do not point toward the dome of the aneurysm (aneurysms arising on the concave side). This distinction is based on the angiographic aspect of the aneurysm and its relationship to the vessel. In the first situation, our idea was to modify the angle of the vessel and therefore to decrease the hemodynamic stress into the aneurysm. Accordingly, we intended to exclusively use BESs, as these devices tend to offer a more solid scaffold to correct the curved angle. In the second situation, we did not try to modify the angle but just attempted to modify the laminar flow pattern to decrease the hemodynamic forces. We believed that SESs were more suitable for this purpose.

Our study has evaluated the effects of the SS technique on aneurysm occlusion after 1 year in every patient, which means that the shortest follow-up duration is 1 year. As previously stated, 3 of our patients were treated at least 3 years ago, and the cases were reported in 2005. Of course, a longer follow-up duration in every patient would allow us...
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to assess issues such as in-stent stenosis or even recanalization of the aneurysm. We should note that our institutional follow-up protocol requires an imaging assessment for every patient at 1, 2, and 5 years. All patients included in this series underwent at least the 1-year follow-up assessment, but the 3 patients already included in our previous publication on the SS technique showed no modification of the vessel or of the aneurysm at the 2-year follow-up. We do, however, have a long experience with this technique: our first case, not reported in this series, has a follow-up duration of 10 years (making it the very first such case ever treated), and the aneurysm in that case has never recanalized nor undergone in-stent restenosis.

The concept of double stenting in some of the reported cases has been suggested. In the present series we performed only a single-stenting procedure and no overlapping or double-stenting was attempted. The utility of double stenting has to be proven in a prospective patient series with a precise follow-up schedule.

**Previous Clinical Experiences.** In a thorough review of the literature on complex and dissecting vertebrobasilar aneurysms treated using the SS technique, we only found 12 articles involving 28 cases (Table 4). We decided to exclude from this analysis a study by Lanzino and colleagues in which 3 posterior circulation aneurysms were treated using the SS technique, we only found 12 articles involving 28 cases (Table 4). We decided to exclude from this analysis a study by Lanzino and colleagues in which 3 posterior circulation aneurysms were treated using the SS technique. Because no angiographic changes were noted in that study, a subsequent coil embolization procedure was performed and cannot be fully considered as a failure of the SS technique. Considering that most of these cases are isolated experiences of different groups and no systematic protocol was followed, it is difficult to group such heterogeneous strategies as a single approach. The patient characteristics in these studies are not the same because patients with both ruptured and unruptured aneurysms were recruited. The technique used also differs between groups, as single stenting, double stenting, and even covered stenting were used. The angiographic results range from no modification at all to complete occlusion; one case of rebleeding was observed. The postoperative assessments in these studies were not homogeneous either because some series did not report any follow-up, whereas others reported follow-up periods of 3, 6, 10, 12, and 14 months.

**Causes of Delayed Occlusion**

In the postprocedural sequence, some angiographic features attracted our attention, such as the angle of the parent vessel, which did not change (Fig. 7C), and the contrast medium that stagnated beyond the late venous phase. We believe that the stent acted as a valve and prevented an outflow of the stagnating blood, probably increasing the intraluminal pressure. At a very early follow-up assessment (1 week), we noticed a similar pattern. Because of the patient’s financial situation, no coil embolization was possible at that time, and he rebled and died 3 weeks later.

**Causes of Treatment Failure**

Our treatment failed in 3 patients. In Case 7, an acutely ruptured V4 dissecting aneurysm recanalized at 12 months despite subtotal occlusion noted on follow-up angiograms. This recanalization occurred because the stent was undersized (Fig. 7A) due to an inadequate measurement of the vessel (during the initial moderate vasospasm), which lead to the incorrect stent choice. The aneurysm eventually underwent coil embolization. Case 15 had a fusiform, incidental, right in-PICA V4 aneurysm. At angiographic follow-up only a minimal occlusion was noted (30%). We have 3 explanations for this result: 1) the PICA emerged from the dome of the aneurysm (Fig. 7D); 2) the stent did not fully cover the diseased portion of the vessel (Fig. 7B); and 3) the initial angle of the vessel was not corrected (Fig. 7C). This patient was scheduled to undergo adjunctive coil embolization.

The patient in Case 16 experienced an acutely ruptured saccular aneurysm in the middle third of the BA (Fig. 6). In the postprocedural sequence, some angiographic features attracted our attention, such as the angle of the parent vessel, which did not change (Fig. 7C), and the contrast medium that stagnated beyond the late venous phase. We believe that the stent acted as a valve and prevented an outflow of the stagnating blood, probably increasing the intraluminal pressure. At a very early follow-up assessment (1 week), we noticed a similar pattern. Because of the patient’s financial situation, no coil embolization was possible at that time, and he rebled and died 3 weeks later.

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**Causes of Delayed Occlusion**

The patient in Case 14 had an incidental aneurysm of the lateral aspect of the terminal portion of the BA. This pa-
The patient had been treated using oral anticoagulation therapy for a possible prothrombotic state. A BES was deployed. The follow-up imaging assessment of the aneurysm revealed a slowly progressive thrombosis, with 65% occlusion at 1 year. It is possible that the full anticoagulation therapy prevented a total occlusion. We did not consider the SS procedure in this case to be a failure because the occlusion rate slowly but progressively increased.

**Advantages and Disadvantages of the SS Technique**

Several technical improvements have definitely ameliorated some negative features of stents, namely their navigability, even if the “perfect stent” has yet to be designed. The main advantages of using the SS technique are the following:

1) Avoids parent vessel sacrifice.
2) Facilitates the reconstruction of the diseased arterial segment.
3) Balloon occlusion test is often not needed, reducing risks and costs.
4) Technique is a true “endovascular bypass,” which in selected cases avoids the necessity of an open surgical bypass.

**Fig. 6. Case 16. Images showing a wide-neck saccular aneurysm.**

A and B: Preprocedural DS angiogram (A) and CT angiogram (B) show a wide-neck saccular aneurysm of the middle basilar trunk. The angulation of the parent vessel can be seen (dark arrow and line) and the aneurysm (open arrow) is precisely located at this point. C–E: Transprocedural imaging. The DS angiogram (C) displays the image of a straight vessel (thin arrows) during the placement of the device, with a patent aneurysm (open arrow). The immediate DS angiogram (D) shows no angiographic change of the aneurysm itself (open arrow) and no geometrical changes in the anatomy of the vessel and its angulation (dark arrow and line). There was an unusual sluggish intraaneurysmal vortex motion image (open arrow) going far beyond the late venous phase (E). F: Postprocedural CT angiogram at 1 week showed no change in hemodynamics (open arrow) or geometry (dark arrow and line). The patient rebled and died 3 weeks after this image was obtained.
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5) Minimizes manipulation of the aneurysm (perforation) and the stent (damage or displacement).
6) Could provide a safe and cost-effective solution.
7) Decreases time of procedure and therefore manipulation of vessels.
8) Technical developments have increased the flexibility of the stents and they are now able to navigate farther into the intracranial circulation (SCA or distal segments of the PCA).

Several caveats to using this procedure must be noted, however, and the use of stents may be limited by some disadvantages, such as:

1) In-stent thrombosis. The only 2 cases found in the literature, including our patient series, represent only 4.3% of all treated aneurysms, which might be explained by inadequate antiplatelet treatment.\(^{18,45}\)

2) Need for a long-term antiplatelet treatment. To avoid acute thrombosis, a double antiplatelet regimen is required. Theoretically, this regimen encompasses a risk of bleeding; however, in our experience, as well as in other reported series, hemorrhagic events (neurological or systemic) were not encountered. Unfortunately, this regimen produces a sharp slowdown in the thrombosis of the lesion and delays the healing of the aneurysm.

3) Stent-induced neointimal hyperplasia. This condition is widely studied in coronary stent placement, but is less well known in stenting procedures for nonatherosclerotic neurovascular disease. Some authors have specifically studied in-stent stenosis in the intracranial circulation and have found a rate of stenosis of < 1% (with SES).\(^{20}\) Other studies report just 1 case of stenosis in a series of 10 patients, with no distal flow decrease.\(^{22}\) In our patient series, only 1 case of 30% lumen reduction (due to intimal hyperplasia) was encountered at the 6-month follow-up, in a patient with severe dyslipidemia. This finding was asymptomatic and the patient healed at 12 months under medical treatment (statin therapy).

4) Occlusion of small perforating arteries by stent placement, which may result in ischemia of these vessels.\(^{42}\) This legitimate concern has never been encountered in the literature following stent placement for intracranial aneurysms. In our experience, some previously unnoticed vessels have even been more readily visualized after the stenting procedure.

5) Some stents are not easily seen along their entire length, or their angiographic appearance is very subtle.\(^{18}\) Recently, the Pharos stent has demonstrated an excellent visualization characteristic, which allows both SS or stent-assisted coil embolization if needed.\(^{85}\)

**Aneurysm Rupture Despite SS Treatment**

Further rupture of the aneurysm after the SS procedure should be one of the most worrisome complications, especially because antiplatelet treatment is needed. In the literature only 1 case of further rupture in a BA aneurysm (treated by Kaku and colleagues\(^ {40}\)) could be found; we experienced another case of a rupture in our patient series. We should note, however, that the patient in the study of Kaku et al. received heparin and was maintained on anticoagulation treatment after the procedure; therefore, the bleeding could be explained.\(^ {2,7,18,40,49,54}\) The reasons for the rebleeding in 1 patient in our series were explained earlier; however, we would like to point out some aspects of this incident. The initial SS procedure did not succeed in closing the aneurysm, and after the initial 1-week follow-up, a stent-assisted coil embolization procedure was planned because this aneurysm was deemed to be at high risk of rupture. The patient could not afford the costs of the procedure and refused to undergo treatment despite our insistence. As noted earlier, he was hospitalized 3 weeks later, rebled, and died while waiting to be transferred to the angiography suite.

After adding the 28 previously reported cases using SS to our 20 cases reported here, a 2.1% bleeding rate occurred in aneurysm treatment by sole stent placement (including ruptured and unruptured aneurysms). It has clearly been

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**Fig. 7.** Illustration showing the possible causes of failure of the SS technique. Arrows indicate blood flow. A: An undersized stent. B: Stent placed distal to the lesion. C: Noncorrection of the angle. D: Important vessel arising from the aneurysm.
shown that the placement of the stent across the neck of an intracranial aneurysm modifies the hemodynamic vectors, decreasing the flow of contrast medium within the aneurysm, which graphically translates into a decrease in the pulsatile forces against the aneurysmal dome. These hemodynamic modifications will facilitate thrombosis of the lesion and therefore protect against its rupture. This finding has been confirmed in vivo in the patients treated by other authors and in the present patient series. In addition, we can add our experience with this technique in aneurysms at other locations, which total ~ 70 aneurysms (both ruptured and unruptured). Only 1 case of rebleeding occurred, bringing that a second stent placement can hinder the additional coil embolization. We can therefore suggest that sole stent placement may protect against further aneurysm rupture in some cases, even if this finding remains to be confirmed in a study including only ruptured lesions. In cases of acutely ruptured aneurysms, if an inadequate correction of the angle of the parent vessel or an undesirable intraaneurysmal blood flow pattern is present, a more aggressive approach should be adopted with coil embolization to prevent further rupture. In contrast to the opinions of other authors, we believe that a second stent placement can hinder the additional coil embolization.

Conclusions

This study is the largest single-center patient series ever reported concerning posterior circulation aneurysms treated using the SS technique. The 12-month total occlusion rate of aneurysms was 80%; one partial occlusion (5%) was achieved, and 3 treatment failures occurred (15%, including 1 death), suggesting that this is a safe and effective technique, especially considering the difficulties involved in treating these lesions by other methods. The SS technique also provides protection against further rupture. This thorough patient follow-up of the SS technique has allowed us to observe a progressive thrombosis of the aneurysm over time. This aneurysm occlusion is produced by the hemodynamic changes induced by the placement of the stent. On the other hand, the necessity for coil embolization during follow-up shows that in some cases a progressive recanalization of the aneurysm can occur. This recanalization is produced by the persistence of the hemodynamic vectors because the coils do not modify these conditions. Given that the precise behavior of an aneurysm after stent placement is not completely understood to date, however, a thorough follow-up is mandatory because the placement of the stent is just the beginning of the treatment. In our experience, aneurysm recanalizations occur in the long term when an inadequate placement of the stent has been performed. The qualitative and quantitative contribution of the different factors that play a role in aneurysm occlusion has not yet been defined. Further cooperation is needed in a multidisciplinary approach based on profound awareness of the ultrastructural behavior of biological tissues and a greater understanding of the genesis of this kind of lesion, based on significant knowledge of mathematics and physics and the contribution of medical bioengineering for interventional techniques. This will greatly contribute to selecting the correct aneurysm, the suitable stent, and the correct way to perform the procedure, yielding an optimum hemodynamic, anatomical, and clinical result.

Disclaimer

The authors declare no conflicts of interest in this study. In particular, they declare no financial interest in any of the companies that produce the stents used in this study.

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