URING the last decade, the field of endovascular surgery for the treatment of intracranial aneurysms has undergone tremendous growth. As new technologies are developed and more experience is gained, lesions with greater complexity will be able to be treated. The present state of the art in the endovascular treatment of aneurysms consists in placing platinum coils into the lumen of the aneurysm, excluding the lesion from the circulation. In some cases, however, the endovascular treatment of wide-necked aneurysms is technically difficult and leads to less favorable treatment results and long-term patient outcomes.

To achieve reconstruction of intracranial vessels with preservation of the parent artery in such cases, the use of stents has the greatest potential for assisted coil embolization. Intravascular stents are currently available for use in coronary vessels and the peripheral circulation. The use of such stents is expanding rapidly into the cerebrovascular system and the placement of microstents in intracranial vessels has become a reality. Recently, a self-expanding nitinol stent, Neuroform (Boston Scientific/Target Therapeutics, Inc., Natick, MA), was developed and became available for clinical use. In this article we report our experience in the use of the Neuroform stent for the treatment of complex wide-necked intracranial aneurysms.

Clinical Material and Methods

Patient Population

Between October 2002 and January 2004, we selected 50 patients for Neuroform stent placement on the basis of anatomical features identified on DS and 3D angiography studies. The interventional review board at our institution approved the treatment. The inclusion criteria were as follows: the patient had to harbor a ruptured or unruptured complex wide-necked aneurysm (neck > 4 mm) or an aneurysm with a neck diameter smaller than 4 mm in which the dome/neck ratio was
less than 2, denoting a segmental defect of the parent vessel; the parent artery had to have a diameter between 1.5 and 5.5 mm, and signed written informed consent was necessary. We excluded patients with fusiform aneurysms, those with lesions whose neck diameters exceeded 12 mm, those with a contraindication for antiplatelet agents or heparin use, and patients who were pregnant.

Surgical Procedure

Antiplatelet agents were indicated in every case. For those patients who presented for elective treatment (unruptured aneurysm), pretreatment was initiated at least 3 days before the procedure with 500 mg aspirin and 75 mg of clopidogrel or 500 mg of ticlopidine. Initially, in the majority of patients we used general anesthetic, and only a few procedures were performed while the patient was merely sedated. A bolus of 10,000 IU of heparin was administered after insertion of a No. 8 French introducer sheath followed by 1000 IU/hour of heparin during the procedure to yield an activated clotting time of between 200 and 300 seconds. After the procedure, a dual antiplatelet regimen was continued for 30 days. Thereafter, only aspirin was prescribed for the patient’s lifetime.

Digital subtraction angiography and complete cerebral rotational DS angiography with 3D reconstruction were performed using an Allura Biplane system (model 5000; Phillips Medical, Eindhoven, The Netherlands) to obtain at least two working projections, one which best demonstrated the parent vessel for stent placement and one which optimally depicted the aneurysm neck. Adequate measurements were recorded before stent selection.

The nitinol stent is currently available at diameters ranging from 2.5 to 4.5 mm and at lengths of 10 mm and 20 mm. The stent length was selected to anchor at least 4 mm on either side of the aneurysm neck according to the manufacturer’s instructions. For the stenting procedure, a No. 6 French guiding catheter was required and the Neuroform stent was placed in position by using an over-the-wire system with a 0.014-in exchange microwire with a floppy tip. Once the desired position was reached by the microdelivery catheter, the stent was kept in position by using a No. 2 French stabilizer and was unsheathed at the same time by pulling back the microcatheter. The stent has four distal and proximal radiopaque markers that are used to evaluate adequate device aperture.

Three different therapeutic strategies were chosen: 1) stent alone, which was used exclusively for patients harboring an unruptured aneurysm; 2) initial stent implantation followed by coil placement; and 3) placement of coils followed by stent implantation. Stent implantation was recorded as optimal or suboptimal based on the findings of an im-

Fig. 1. Angiograms obtained in a 65-year-old woman with a history of SAH. A and B: Two DS angiograms depicting a wide-necked aneurysm of the left posterior communicating artery. C: A 3D angiogram demonstrating the complex anatomy of the lesion. D: Initially, the dome was secured with regular coils. E and F: Endovascular reconstruction with the Neuroform2 stent. G and H: Total aneurysm occlusion with coils across the stent.
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mediate postoperative angiographic examination. The optimal angiographic result is the finding of total aneurysm neck covering by the stent, which is located in a rectilinear portion of the artery and is anchored at least 4 mm on either side of the neck. Such a finding was made using rotational angiography with 3D reconstruction but no injection of contrast agent, which demonstrates appropriately the radiopaque markers (distal and proximal) indicating the accurate opening of the stent.

In cases of stent implantation and later coil placement, the exchange microwire was left in the distal position, and the delivery microcatheter and stabilizer were withdrawn together and replaced by an Excel 14 microcatheter (Boston Scientific/Target Therapeutics, Inc.). In a slow and controlled manner, the system was retracted up into the interior of the stent, the aneurysm was catheterized using the microwire, and the microcatheter was advanced through the stent cells, so that the stent acted as an endovascular scaffold, preventing coil herniation, improving the density of coil packing to obtain a better angiographic result, and enabling final endovascular reconstruction of the arterial wall (Fig. 1).

A comparison of pre- and postprocedure angiograms determined the grade of occlusion of the aneurysms in which coils were used in addition to the stent. The angiographic occlusion rate was graduated in three levels: 1) total occlusion if no entry of contrast agent into the aneurysm sac was observed; 2) neck remnant if entry of contrast agent was evidenced at this level without dome opacification; and 3) subtotal or incomplete occlusion if opacity due to the contrast agent was seen at the dome or among the coil interstices.

After stent placement, patients were transferred to the intensive care unit, maintained with the femoral sheath still in place for 24 hours, and monitored using transcranial Doppler ultrasonography (SonoSite 180; SonoSite, Inc., Bothell, WA) to detect any variation in procedure intracranial flow.

Results

Of the 50 selected patients, forty-six harboring 48 complex wide-necked aneurysms were treated with stent placement, resulting in a technical effectiveness rate of 92%. The clinical and radiological features of the patient population are shown in Table 1.

There were 31 women among the patients and the ages of all patients ranged from 26 to 78 years (mean age 54.5 years). Seven patients (14%) had already undergone an ineffective attempt at conventional surgical clipping. In this series four patients presented with multiple aneurysms. Anatomically, 42 lesions were located in the anterior circulation (carotid artery–ophthalmic artery, 12 patients; posterior communicating artery, 16 patients; choroidal artery, three patients; cavernous ICA, three patients; superior hypophyseal artery–middle cerebral artery, three patients; middle cerebral artery, five patients) and six aneurysms were located into the posterior circulation (P1 segment, one patient; P1–P2 segments, one patient; and vertebrobasilar junction, four patients). The majority of aneurysms were smaller than 10 mm (mean size 8.8 mm) with a dome/neck ratio less than 2.

Twenty-three aneurysms were identified after SAH, 20 lesions were identified incidentally, and five were documented by a mass effect. In 17 of the 23 patients with ruptured aneurysms, the neurological status was good (Hunt and Hess Scale Scores I–III) and in six patients the neurological condition was poor (Hunt and Hess Scale Score IV or V).

The first-generation Neuroform device was used to treat 30 aneurysms (62.5%) (Fig. 2). Since it first became commercially available at the end of 2003, the second-generation Neuroform2 stent has been used and, in this study, was implanted to treat 18 patients (Fig. 3). Early in our experience, specifically when we were using the first-generation Neuroform stent, stent placement was not feasible in four cases (8%) because vascular tortuosity made it impossible to reach the target. These cases were finally excluded from the analysis. Data regarding the strategy we used and the angiographic results are shown in Table 2.

Stent placement was determined to be optimal in the treatment of 39 lesions (81.2%); in cases in which stent placement was recorded as suboptimal only the first-generation Neuroform device had been used. In those patients treated with a combined approach (stent and coils), the angiographic examination performed immediately postprocedure disclosed complete occlusion of the aneurysm in more than 85% of cases.

A total of 49 Neuroform self-expanding stents were implanted. Remarkably, in one case a single 20-mm stent was sufficient to cover the neck of two aneurysms in the cavernous ICA segment and a single stent-in-tandem technique was conducted for the treatment of a large carotid artery–ophthalmic artery aneurysm.

Angiographic follow up ranging from 3 to 17 months was available, with a mean of 7.3 months in 29 patients (63%). All follow-up angiograms demonstrated a stable appearance of the stent. Thrombosis of the lesion was identified in only one case treated with a stent alone; no later coil placement was required.

Complications of the Procedure

In 15 procedures (31%) a 0.016-in coil pusher was required to deliver the stent. This was only necessary in patients treated with the first-generation Neuroform device at the beginning of our experience. In one case an undesirable premature stent delivery occurred during the insertion
phase, after the protector sheath was removed and before the introduction of the hemostatic valve. One patient experienced gastric bleeding due to the antiplatelet therapy and required multiple transfusions. Two patients experienced complications at the puncture site: a small retroperitoneal hematoma and a pseudoaneurysm that resolved in response to compression maneuvers.

During our early experience, six thromboembolic complications were witnessed, all of which occurred when we used the first-generation Neuroform stent. In four cases, the thrombotic events were noticed as the coils were passed through the stent mesh, and in all of them abciximab (ReoPro; Eli Lilly Co., Indianapolis, IN; maximal dose 30 mg) was administered through selective intraarterial and venous routes, with complete resolution in three cases (Fig. 4). One patient suffered a left temporal stroke, which resulted in aphasia and right hemiplegia. An activated clotting time longer than 250 seconds was documented during the procedure. In the other two cases the complication was noticed immediately after stent delivery and was also managed with IIb-IIIa inhibitors. A single case of dissection of the cervical ICA was recorded; this had an impact both clinically and hemodynamically and was followed by the development of a minor stroke in a watershed area. A 3-month regimen of anticoagulation therapy was suggested and followed, resulting in complete clinical and radiological resolution. There was a single procedure-related death due to an intracranial hematoma secondary to arterial rupture. The rupture was caused by manipulation of the distally placed microwire. The procedure-related morbidity and mortality rates were 8.6 and 2.1%, respectively.

Discussion

Technological developments have enabled the production of more flexible stents with better properties allowing them to be advanced into the tortuous intracranial vasculature and to treat increasingly complex clinicopathological entities. The use of stents for the treatment of cerebral aneurysms had its origin in the field of interventional cardiology. A variety of stainless-steel balloon-expanding stents has been used in the intracranial circulation in an effort to obtain endovascular reconstruction of the parent vessel at sites of segmental defects, where an embozilization technique in which coils alone are used is insufficient to exclude the lesion completely from the circulation. Such is the case with wide-necked complex aneurysms.

Even with the development of 3D coils and the expansion of remodeling techniques and intracranial stent placement, wide-necked aneurysms represent a major challenge for the endovascular therapist because there is a greater risk of complications such as coil migration to the parent vessel, intraoperative rupture, thromboembolic events, and difficulties in navigation and implantation of stents at anatomical sites difficult to treat and associated with the risk of a secondary arterial insult to balloon inflation at high pressure, which demands a meticulous stent selection and an appropriate measurement of the parent vessel.

The need for a more flexible device with a greater capacity for neuronavigation has led to the development of very-low-profile self-expanding stents made of nitinol and specifically designed for intracranial placement, among which the LEO (BALT Extrusion, Montmorency, France), the CereStent (Micrus Corp., Sunnyvale, CA [preclinical experience]), and the Neuroform stents are outstanding. At our center our greatest clinical experience has been with the Neuroform device.

The Neuroform stent, the first such device approved for neurovascular use, consists of a thin layer of nitinol (15 μm) composed of six to eight cells that are joined to one another and have a radiolucent character. The stent possesses four radiopaque markers at its ends, which demarcate

![Image](image_url)
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the position of the stent during its navigation inside the No. 3 French delivery microcatheter. On stent delivery, these markers denote the distal and proximal openings. This device has a high porosity and low radial force (10 mm Hg), features that no doubt favor its navigability but limit its support capacity when used together with coils to prevent herniation into the parent vessel. Recently, thanks to modifications in microcatheter delivery and to the decrease in and adjustment of the profile at the ends of the device, the second-generation stent, the Neuroform2, has been largely able to overcome its predecessor’s obstacles, especially those evident during the delivery phase.

In our initial practice with the use of the first-generation Neuroform stent, we encountered some difficulties with stent delivery in almost 50% of cases; whereas in 31% it was necessary to use a 0.016-in coil pusher, especially in aneurysms located above the supraclinoid ICA. This limitation is in agreement with descriptions by other investigators. In the last 18 cases in which we used the Neuroform2 stent we did not observe difficulties during this phase and the duration of the procedure decreased between 15 and 20%, indicating that the greater experience we acquired in the technique is also largely attributable to changes in the system. Regarding the radiological features of the device, the poor visibility of the nitinol is compensated by the radiopaque markers, which ensure an appropriate delivery position.

Concerning inaccuracy in stent position and suboptimal results, we report nine procedures (19%) in which factors such as device shortening (1.8–5.4%), backward movement of the stent after its delivery, movement of the No. 3 French microcatheter due to uncontrolled tension in the system, and stent displacement and deformity during the microcatheter advance through cells of the stent should be kept in consideration. Like other authors, we continue to promote the use of a triaxial system composed of a No. 8 French guide catheter, a No. 6 French catheter, and a No. 3 French delivery microcatheter, particularly in the treatment of complex lesions in the anterior circulation with a difficult proximal access that require a better support of the whole system.

By performing rotational 3D angiography without a contrast agent, we have been able to evaluate appropriately the

| TABLE 2 |
| Strategy and angiographic results for aneurysms treated with the Neuroform stent* |

<table>
<thead>
<tr>
<th>Strategy</th>
<th>No. of Lesions</th>
<th>Neuroform Generation</th>
<th>Stent Placement</th>
<th>Aneurysm Immediate Occlusion Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1st</td>
<td>2nd</td>
<td>Optimal</td>
<td>Suboptimal</td>
</tr>
<tr>
<td>stent alone</td>
<td>14</td>
<td>10</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>stent followed by coils</td>
<td>26</td>
<td>13</td>
<td>13</td>
<td>22</td>
</tr>
<tr>
<td>coils followed by stent</td>
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<td>7</td>
<td>1</td>
<td>22</td>
</tr>
<tr>
<td>total</td>
<td>48</td>
<td>30</td>
<td>18</td>
<td>39</td>
</tr>
</tbody>
</table>

* NA = not applicable.
† In all cases the first-generation Neuroform stent was used.

<FIG. 3. Angiograms obtained in a 57-year-old man with a history of migraine. A and B: Both DS (A) and 3D (B) angiograms revealing a right middle cerebral artery wide-necked aneurysm that was found incidentally. C: During the procedure, the microwire (GUIA) is placed in the M1 segment, distal to the aneurysm neck. D: The Neuroform2 stent is implanted. E and F: A control DS angiogram demonstrating an optimal stent position. Note the radiopaque markers.>
opening of the stent in multiple planes and in cases in which coils were used. This technique has allowed us to assess more accurately the relationship of the spires and coil loops to the stent and the parent vessel lumen, because, for complex aneurysms involving nearly the entire parent vessel circumference, a two-dimensional image may be difficult to interpret.

As in previous reports, we failed to demonstrate any drawback with perforating branches after placement of the Neuroform stent in relation with the low metal/artery ratio, a factor that can also be used to explain the absence of neo-intimal hyperplasia during control angiography. During follow up in one case an aneurysm treated with the stent alone evolved into complete thrombosis and disappearance of the lesion. The high porosity of the Neuroform device exerts a negligible effect on intraaneurysm flow, hardly altering the vorticity or intralesion diffusion with later stasis, which ensures its low capacity to generate thrombosis, so that the use of coils is invariably recommended as an adjuvant therapy. In our series the implantation of a stent alone was limited to unruptured lesions. In these cases endovascular reconstruction was the primary endpoint and thus the stent served as a support for the extracellular matrix in addition to ensuring an organized layering of endothelial cells to repair the vascular wall defect.

In a deferred fashion for a second therapeutic approach we would use a filler material, either platinum microcoils or a liquid polymer agent such as Onyx. In cases in which both a stent and coils were implanted, angiographic evaluation demonstrated a complete occlusion rate exceeding 80% of cases, a result supported by other authors, which confirms the leading role of stents as support devices that constitute an endovascular scaffold, prevent coil herniation, and improve packing of the lesions. The complications we identified were mostly thromboembolic events despite a rigorous antiplatelet therapy, confirming the thrombogenicity associated with the procedure. No neurologically adverse event or increased rebleeding rate was recorded in patients with SAH when compared with those with unruptured aneurysms who were placed on a similar dual antiplatelet regimen.

The major role of IIb-IIIa inhibitors to solve acute intra-procedure thromboembolic complications should be highlighted. In our series, the results were favorable, with high recanalization rates and few secondary effects, so that in addition to the antiplatelet protocol followed before the procedure we recommend keeping these parenteral agents close at hand during intracranial stent placement. Regarding the design of an ideal stent for intracerebral use, the Neuroform device combines several features essential to achiev-
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ing this goal. Meanwhile, we should familiarize ourselves with the procedure and stimulate the development of other devices that offer solutions to current problems and improve clinical results.

Conclusions

On the basis of our results, we conclude that the Neuroform self-expanding stent is a flexible and useful device that can be readily and safely maneuvered through tortuous intracranial vessels, enabling the endovascular treatment of complex wide-necked aneurysms in which endovascular reconstruction of the parent vessel is necessary. Early in our experience, we found that stent delivery presented difficulties; however, a second generation of devices has resolved this limitation. Although our early results are promising, the long-term benefit of this technique has to be proved by follow-up angiographic and clinical examinations.

References


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