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## Intravascular stents for intracranial internal carotid and vertebral artery aneurysms: preliminary clinical experience

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Results of previous in vitro and in vivo experimental studies have suggested that the placement of a porous stent within the parent artery across the aneurysm neck may hemodynamically uncouple the aneurysm from the parent vessel, leading to thrombosis of the aneurysm. For complex wide-necked aneurysms, a stent may also aid the packing of the aneurysm with Guglielmi detachable coils (GDCs) by acting as a rigid scaffold that prevents coil herniation into the parent vessel. Recently, improved stent system delivery technology has allowed access to the tortuous vascular segments of the intracranial system. The authors report here the intracranial stenting of aneurysms involving different segments of the internal carotid artery (ICA) and the vertebral artery (VA).

Four patients with intracranial aneurysms located at the petrous, cavernous, and paraclinoid segments of the ICA and at the VA proximal to the origin of the posterior inferior cerebellar artery, respectively, were treated since January 1998. In three of these patients, stent placement across the aneurysm neck was followed by GDC placement, accomplished via a microcatheter through stent mesh. In one patient, the aneurysm was treated solely by stenting.

No periprocedural complications were observed, and at follow up, no patient was found to have suffered symptoms referable to aneurysm growth or thromboembolic complications. More than 90% occlusion of the aneurysm was achieved in the three cases treated by stenting and GDC placement. One of these patients underwent 6-month follow-up angiography that did not reveal any in-stent stenosis. In the case treated solely by stent placement, no evidence of aneurysm thrombosis was observed either immediately postprocedure or on follow-up angiography performed 24 hours later.

A new generation of flexible stents can be used to treat intracranial aneurysms in difficult-to-access areas such as the proximal intracranial segments of the ICA or the VA. The stent allows tight coil packing even in the presence of a wide-necked, irregularly shaped aneurysm and may provide an endoluminal matrix for endothelial growth. Although convincing experimental evidence suggests that stent placement across the aneurysm neck may by itself promote intraluminal thrombosis, the role of this phenomenon in clinical practice may be limited at present by the high porosity of currently available stents.

Intracranial internal carotid artery (ICA) aneurysms located at or near the skull base and wide-necked intracranial vertebral artery (VA) aneurysms represent therapeutic challenges. A direct surgical approach, although feasible, is technically difficult and accompanied by significant risks. Endovascular occlusion using Guglielmi detachable coils (GDCs) is frequently prevented by the complexity of the wide-necked, irregularly shaped aneurysms in this location. Thus, parent vessel sacrifice, with or without surgical bypass, with its attendant limitations remains the primary therapeutic modality in many cases.

With the recent availability of flexible intravascular stents, a fresh therapeutic approach has become possible, heralding a new era in the endovascular treatment of intracranial aneurysms. The placement of an endovascular stent within the parent artery across the aneurysm neck may divert blood from the aneurysm inflow tract and promote intraaneurysm stasis and thrombosis.[2,14-16] In addition, a stent may act as a scaffold to prevent coil herniation within the parent artery lumen,[6,12-14] which has been a problem frequently encountered in wide-necked, irregularly shaped proximal ICA and VA aneurysms. Furthermore, stents also appear to provide a luminal matrix for endothelial growth.[14-16] We report here our preliminary clinical experience with ICA and VA aneurysms located at or near the skull base that were treated with endovascular stents, with or without secondary coiling.

### **CLINICAL MATERIAL AND METHODS**

Since January 1998, four patients with intact intracranial aneurysms located in the petrous, cavernous, and paraclinoid segments of the ICA and in the VA adjacent to posterior inferior cerebellar artery (PICA) origin, respectively, were treated at our institution with intracranial stents (AVE GFX coronary stent [three patients] and AVE INR stent [one patient]). A detailed report on one of these patients has previously been reported.[7] Indications for treatment included the progressive growth of an iatrogenic petrous segment pseudoaneurysm (Case 1); intermittent diplopia and progressive headaches in a patient with an intracavernous lesion (Case 2); severe retroorbital headaches in a patient with a paraclinoid aneurysm (Case 3); and aneurysm growth and coil compaction in a patient with a dissecting aneurysm of the VA adjacent to PICA origin treated with GDCs 2 years earlier (Case 4). Each patient underwent balloon test occlusion with hypotensive challenge to assess risk in case carotid sacrifice would be necessary.[11] Only one patient (Case 3) developed contralateral transient hemiparesis a few seconds following inflation of a balloon in the right ICA under normotensive conditions, and her deficit resolved immediately after balloon deflation.

### **RESULTS**

No periprocedural complications occurred. In each case, the stent was easily navigated through the tortuous segments of the intracranial ICA. In Cases 1, 2, and 4, stent placement across the aneurysm neck was followed by secondary GDC placement by using a microcatheter positioned within the aneurysm via an opening in the stent mesh. In these cases, more than 90% aneurysm occlusion was achieved. The patient in Case 3 was treated by primary stenting with minimal slowing of intraaneurysmal flow as seen on immediate postprocedural and 24-hour follow-up angiograms. The patient is currently receiving antiplatelet medications (ticlopidine and aspirin) to reduce the risk of thrombosis and she will undergo repeated angiography 6 weeks after the discontinuation of antiplatelet therapy. If no evidence of aneurysm thrombosis is observed, she will then undergo secondary GDC placement in the aneurysm.

Both of the symptomatic patients (Cases 2 and 3) have experienced improvement in clinical symptomatology. No symptoms referable to thromboembolic phenomena have been observed in any of the four patients 6 months (Case 1), 2 months (Case 2), 1 month (Case 3), and 1 week (Case 4) after treatment. The patient in Case 1 underwent repeated 6-month follow-up angiography that revealed persistent partial filling of the aneurysm neck and no evidence of in-stent stenosis.

## ILLUSTRATIVE CASE

### *Case 2*

**History and Examination.** This 43-year-old woman with a history of headaches and intermittent diplopia was referred for evaluation of a giant, wide-necked, irregularly shaped aneurysm originating from the cavernous portion of the right ICA. Magnetic resonance (MR) imaging of the brain revealed minimal intradural extension of the aneurysm. The patient tolerated a balloon test occlusion with hypotensive challenge and was later readmitted for endovascular treatment of the aneurysm. Primary coiling was not considered a viable option due to the wide neck and irregular shape of the aneurysm. Consequently, combined stenting with secondary coiling was performed.

**Procedure.** A No. 8 French introducer sheath was positioned in the right femoral artery by using the Seldinger technique.[9] The patient received 5000 Units of intravenously administered heparin. Intermittent doses of heparin were given to maintain an activated clotting time between 250 and 300 seconds throughout the procedure. A No. 7 French guide catheter with a straight tip was advanced under fluoroscopic guidance and positioned selectively in the right proximal ICA. Using this coaxial system, a microcatheter with two tip markers was advanced over a microguidewire and carefully positioned distal to the aneurysm at the origin of the right middle cerebral artery. The microcatheter was then exchanged for an AVE GFX 4 3 18-mm coronary stent that was navigated intracranially and deployed across the aneurysm neck (Fig. 1).



Fig. 1. Digital subtraction angiogram, oblique projection, revealing a giant aneurysm at the junction of the petrous and cavernous portion of the ICA. An intravascular balloon-expandable stent, mounted on its delivery system (arrows), is present across the neck of the aneurysm.

Following stent deployment, digital subtraction angiography with selective ICA injection showed persistent filling of the aneurysm; however, intraaneurysmal flow appeared to be slower. Due to the persistent aneurysm filling and the need for postprocedural antiplatelet therapy that would interfere with aneurysm thrombosis, we elected to perform secondary GDC placement in the aneurysm. Selective aneurysm catheterization with a microcatheter over a microguidewire was performed through the stent struts. A total of 13 GDCs of different sizes and characteristics were progressively delivered into the aneurysm sac (Fig. 2). At this point, significant (> 90%) aneurysm occlusion was achieved. The aneurysm's irregular shape, however, precluded angiographic visualization of the separation between it and the parent vessel, thus incapacitating the safe delivery of additional coils. Therefore, the procedure was considered to be complete after placement of the 13 coils. Contrast material stasis in the aneurysm remnant was observed, leading us to conclude that, given the extensive coil packing, complete aneurysm thrombosis was likely to occur after discontinuation of anticoagulation therapy.





Fig. 2. Left: Following stent deployment and GDC placement, a dense coil mass is visible within the aneurysm. In this projection, it appears as if coil loops are herniating within the parent vessel (arrow). Right: Plain x-ray film (different projection than in left) clearly showing that the coils are on each side of the stent (arrows) at the point where the neck of the redundant aneurysm surrounds the parent vessel. The stent thus acts as a rigid endoluminal scaffold that allows for the relatively tight packing of this wide-necked, irregularly shaped aneurysm.

### *Sources of Supplies and Equipment*

The GDCs were obtained from Target Therapeutics/Boston Scientific (Fremont, CA). The stents (AVE GFX and AVE INR) were acquired from Arterial Vascular Engineering (Santa Rosa, CA). The microcatheter (model no. 14) and the No. 7 French guide catheter were obtained from Cordis (Miami Lakes, FL); the All Star microguidewire from ACS (Temecula, CA); and the Transcend microguidewire from Medi-tech (Natick, MA).

### **DISCUSSION**

Tremendous progress has been made with the use of intravascular stents since the pioneering stent work of Sigwart, et al.,[10] 10 years ago in the field of coronary circulation. The enduring results achieved in the coronary and peripheral circulation have provided the impetus for preliminary clinical series that have shown that angioplasty and stenting of the extracranial carotid artery can be accomplished with an acceptable degree of safety combined with an excellent angiographic and clinical outcome.[4,17] The extension of stent technology to the intracranial vasculature, however, has been limited until recently by the lack of availability of stents and stent delivery systems capable of safe, effective navigation to the intracranial vessels. Results in the four cases we report demonstrate that the new generation of flexible

stents is indeed suitable for intracranial vascular navigation.

With the development and refinement of intravascular stents, the potential for the treatment of both extracranial and intracranial aneurysms has been realized. We can effectively use stents to treat aneurysms by diverting flow from the aneurysm orifice, thereby promoting stasis and inducing thrombosis within the aneurysm.[2,14-16] In our experience, some stasis was observed angiographically following stent placement, possibly explaining the improvement in the severity of headache in the patient in Case 3 who was treated by stenting alone. In this latter patient, however, no significant changes in the extent of aneurysm filling were observed on a follow-up angiogram obtained 24 hours later. The need for systemic anticoagulation to lessen the risk of thromboembolic complications during endovascular procedures as well as the need to reduce the risk of subacute stent thrombosis by prolonged antiplatelet postprocedural therapy may interfere with and delay aneurysm thrombosis in clinical practice despite the hemodynamic changes observed following stent deployment in experimental aneurysms. The high porosity of the intravascular stents used is another factor that limits aneurysm thrombosis following primary stenting.

Stent placement can be successfully used in conjunction with more established endovascular methods such as GDC replacement to improve the density of coil packing.[6,12-14] Following stent placement, the aneurysm sac can be filled with coils by introducing a microcatheter through the stent mesh. In this situation, the stent acts as a rigid endoluminal scaffold, preventing coil herniation. Thus, the combined stenting-coiling technique allows for the dense packing of even those complex, large, wide-necked, fusiform aneurysms that are notoriously difficult to approach surgically.[6,12-14] Furthermore, stent placement in this setting may prevent or reduce the phenomenon of coil compaction by changing intraaneurysmal flow dynamics. Recently, a few clinical cases involving aneurysms of the petrous ICA, [7] intracranial VA, [5,8] and basilar artery [3] successfully treated by the stenting-coiling technique have been reported, suggesting that this breakthrough approach is both a feasible and safe alternative to surgical exclusion of these challenging lesions. Our preliminary experience corroborates these pioneering observations.

Several possible limitations of the combined stenting-coiling treatment of aneurysms are evident at the present time. First, stents are known to induce intimal hyperplasia.[1] Excessive proliferation of neointimae in reaction to the stent placement can result in a hemodynamically significant stenosis, especially of the smaller intracranial branches. In our Case 1, however, no evidence of any intimal hyperplasia was evident on the 6-month follow-up angiogram. Second, as exemplified by our Cases 1, 2, and 4, complete obliteration of irregularly shaped, wide-necked aneurysms is difficult even with the combined stenting-coiling approach. Third, occlusion of the ostia of small perforating arteries by stent placement, with the obvious risk of ischemia or infarction in the branches of the basilar and intracranial carotid arteries, is currently a poorly understood and much dreaded potential hazard that at present limits stent placement only to vessel segments devoid of small, critical perforating branches. Experimental evidence in dogs suggests that small, lateral carotid branches, which approximate intracranial perforating vessels relative to their diameter and angle of origin, tend to stay patent if less than 50% of the ostial diameter is covered by the stent struts. [6] These results from the canine study were mirrored in the case of one patient who presented with a fusiform aneurysm of the basilar trunk treated by stent placement, and no difficulties involving perforating branch occlusions were encountered. [3] A corroboration of this successful result was demonstrated in the patient in our Case 3, in whom the stent was placed across the origin of the ophthalmic artery. The vessel remained patent, as confirmed by both immediate and 24-hour postprocedural cerebral angiography.

## CONCLUSIONS

We report our preliminary experience with intracranial stents used alone or in combination with GDC placement for the treatment of aneurysms originating from different ICA segments and a VA aneurysm adjacent to PICA origin. Our account demonstrates that this novel approach is both feasible and safe with the use of flexible intravascular stents. However, persistent problems while using this method arise from difficulties in achieving complete coil packing and permanent thrombosis in irregularly shaped, complex aneurysms. In addition, the long-term effects of intracranially placed stents are currently unknown. Despite these limitations, we believe that this combined approach holds great practical promise, especially in lieu of the potential for device improvements.

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