Treatment of traumatic aneurysms and arteriovenous fistulas of the skull base by using endovascular stents

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Object. The authors describe their preliminary clinical experience with the use of endovascular stents in the treatment of traumatic vascular lesions of the skull base region. Because adequate distal exposure and direct surgical repair of these lesions are not often possible, conventional treatment has been deliberate arterial occlusion. The purpose of this report is to demonstrate the safety and efficacy as well as limitations of endovascular stent placement in the management of craniofacial arterial injuries.

Methods. Six patients with vascular injuries were treated using endovascular stents. There were two arteriovenous fistulas and two pseudoaneurysms of the distal extracranial internal carotid or vertebral arteries resulting from penetrating trauma, and two petrous carotid pseudoaneurysms associated with basal skull fractures. In one patient a porous stent placement procedure was undertaken as well as coil occlusion of an aneurysm, whereas in the remaining five patients covered stent grafts were used as definitive treatment.

There were no procedural complications. One patient in whom there was extensive traumatic arterial dissection was found to have asymptomatic stent thrombosis when angiography was repeated 1 week postoperatively. This was the only patient whose associated injuries precluded routine antithrombotic or antiplatelet therapy. Follow-up examinations in the remaining five patients included standard angiography (four patients) or computerized tomography angiography (one patient), which were performed 3 to 6 months postoperatively, and clinical assessments ranging from 3 months to 1 year in duration (mean 9 months). In all five cases the vascular injury was successfully treated and the parent artery remained widely patent. No patient experienced aneurysm recurrence or hemorrhage, and there were no thromboembolic complications.

Conclusions. The authors’ experience demonstrates that endovascular treatment of traumatic vascular lesions of the skull base region is both feasible and safe. The advantages of minimally invasive stent placement and parent artery preservation make this procedure for repair of neurovascular injuries a potentially important addition to existing methods.

Key Words • internal carotid artery • vertebral artery • aneurysm • arteriovenous fistula • stent • intracranial stent

ARTERIAL aneurysms or pseudoaneurysms resulting from trauma may appear in isolation or be associated with AVFs. Those lesions located near the skull base are particularly hazardous to approach and difficult to repair surgically. Extensive exposures necessary to achieve adequate proximal and distal vessel control may result in significant cranial nerve damage. If the injured vessel segment is inaccessible, proximal occlusion or segmental isolation are the most common approaches. When the collateral supply to the affected intracranial circulation is insufficient, extracranial–intracranial bypass may be required. Management is frequently complicated by associated injuries or delayed focal cerebral ischemia due to thromboembolism.

With the development of detachable balloon catheters, endovascular therapy in which balloons are used to occlude the injured artery has largely supplanted direct surgical approaches for vascular injuries to the ICA and VA in the region of the skull base. Recently, several case reports have contained descriptions of endovascular procedures in which stents and coils have been used to treat symptomatic dissections of the extracranial vessels associated with pseudoaneurysms, with the goal of parent artery preservation. There has been considerable interest in the application of covered endovascular stent grafts for the treatment of peripheral traumatic arterial lesions. These devices permit minimally invasive arterial repairs to be performed from easily accessible sites, remote from the area of arterial trauma. Inherent to this approach is occlusion of the injury achieved from within the arterial lumen without compromising arterial flow. These factors make such a therapeutic strategy extremely attractive for arterial injuries of the skull base region. In this report we describe our preliminary clinical experience with traumatic aneurysms and AVFs located at or near the skull base, which were treated using intravascular stent placement.

Abbreviations used in this paper: AVF = arteriovenous fistula; CCA = common carotid artery; CT = computerized tomography; GDC = Guglielmi detachable coil; ICA = internal carotid artery; MCA = middle cerebral artery; PTFE = polytetrafluoroethylene; VA = vertebral artery; VV = vertebral vein.
Treatment of skull base vascular lesions by using stents

Clinical Material and Methods

Patient Population

Between January 1997 and July 2000, six consecutive patients with traumatic pseudoaneurysms or AVFs were treated using endovascular stent placement. There were four men and two women with a mean age of 27.5 years (range 16–60 years). All patients were symptomatic. Four of the lesions were the result of penetrating injuries, two affecting the distal extracranial ICA and two the VA. There were two pseudoaneurysms located on the petrous segment of the ICA, resulting from closed head injuries with basal skull fractures.

Surgical Procedures

One patient with a pseudoaneurysm of the VA was initially treated using a porous stent. Because of persistence of the pseudoaneurysm, a second procedure was required to occlude the aneurysm by inserting GDCs. All other patients were treated by placement of a covered stent. In two cases a Palmaz stent covered with a segment of autologous saphenous vein was used. A detailed case report on the first patient who was treated using this procedure (Case 2) has been published elsewhere. In three patients a PTFE-covered stent was inserted; this device consists of two coaxially aligned stainless-steel stents that encompass a microporous PTFE membrane between them in a sandwich-like configuration.

In anticipation of complications that might arise during stent placement, which could require immediate balloon occlusion of the parent artery, a balloon occlusion tolerance test of the injured vessel was performed before undertaking the placement procedure. This test was performed in all cases except for Case 6, which required emergency treatment because of massive hemorrhage. These procedures were performed during a separate diagnostic session or before the induction of general anesthesia for the treatment session. Symptoms of cerebral ischemia did not develop in any patient. Control injections were made into the opposite ICA or VA during the period of balloon inflation to assess the extent of collateral blood flow on angiograms. In addition, 99mTc hexamethylpropyleneamine oxime single-photon emission CT scans were obtained in those cases in which the carotid artery was involved, to confirm symmetrical hemispheric perfusion.

All stent placement procedures were performed via a transfemoral approach while the patient was in a state of general anesthesia in a dedicated biplane neuroangiography suite. Electroencephalographic monitoring was not used while anesthesia was induced because adequate collateral blood flow had previously been demonstrated. Systemic heparinization was initiated immediately after the femoral puncture, with intermittent bolus administrations throughout the procedure to maintain the activated clotting time at 2 to 2.5 times normal. The vein-covered stents were introduced directly over a guidewire, to avoid stripping the vein from the stent construct. The porous stent and PTFE-covered stents were delivered through a No. 8 French guiding catheter positioned proximally in the affected vessel. A 300-cm moderately stiff exchange length of 0.014-in guidewire with a soft distal tip was introduced coaxially through a microcatheter and positioned across the level of the pseudoaneurysm or fistula with its tip in the distal intracranial ICA or VA. The microcatheter was then withdrawn and exchanged for a 150-cm-long balloon catheter to which the stent had been hand crimped. The mounted stent was then advanced and centered over the lesion by using digital roadmap fluoroscopy. Stent delivery was accomplished using a single brief dilation of the balloon to 10 atm. The balloon catheter was withdrawn after deflation, with care taken to maintain the position of the guidewire across the lesion. The guidewire was not withdrawn until control angiography demonstrated exclusion of the lesion and proper seating of the stent against the vessel wall. On occasion, a second balloon inflation was necessary to dilate areas of mild narrowing further.

Following completion of the stenting procedure, control angiograms of the intracranial circulation were obtained to exclude thromboembolic branch occlusion. Heparinization was continued for 12 to 24 hours and then allowed to taper physiologically. Oral administration of ticlopidine (250 mg twice a day) or clopidogrel (75 mg daily) was continued for 6 weeks, and oral administration of enteric-coated aspirin (325 mg daily) was continued for 3 months.

Sources of Supplies

The ACS Multi-Link porous stent was purchased from Guidant Corp. (Indianapolis, IN); the Palmaz stent from Johnson and Johnson Interventional Systems (Warren, NJ); and the PTFE-covered JoStent from JoMed (Helsingborg, Sweden). The GDCs were obtained from Target Therapeutics (Fremont, CA). The ACS Hi-Torque guidewire was acquired from Guidant Corp.; the Prowler-14 microcatheter from Cordis Endovascular (Miami Lakes, FL); and the UltraThin Diamond balloon catheter from Medi-Tech/Boston Scientific (Natick, MA).

Results

Stents were successfully placed in all six patients. The first patient in this series, who was treated with a porous stent, required a second procedure 6 weeks later to pack a persistent pseudoaneurysm with GDCs. There were no infections, episodes of distal embolization, vessel ruptures, or puncture site complications. One patient (Case 4) in whom there was extensive associated ICA dissection was found to have an asymptomatic stent thrombosis when angiography was repeated 1 week postoperatively. This was the only patient whose associated injuries precluded routine antithrombotic or antiplatelet therapy. Follow-up examinations in the remaining five patients included standard angiography (four patients) or CT angiography (one patient) performed 3 to 6 months postoperatively, and clinical assessment ranging from 3 months to 1 year in duration (mean 9 months). In all five cases the vascular injury was successfully treated and the parent artery remained widely patent. There were no delayed neurological or vascular complications and no lesions recurred. No remedial procedures were required. The clinical characteristics and outcome of each patient are summarized in Table 1.

Illustrative Cases

Case 1
This 30-year-old woman sustained a deep stab wound
Complications. Angiography performed 6 months after the left VA pseudoaneurysm (stab wound) complete occlusion. There were no thromboembolic stent struts into the pseudoaneurysm, resulting in near-total occlusion. It was believed that an attempt at definitive repair, involving the parent vessel, was warranted. A postoperative angiogram demonstrated patency of the VA and complete occlusion at the termination of the procedure. Because of the potential for hemorrhage from the dissection, there were no procedural complications and the patient demonstrated gradual neurological recovery. One week after stent placement angiography was repeated.

Repeated angiography performed 6 weeks later revealed no change in the appearance of the pseudoaneurysm. Given the previous left ICA occlusion, it was believed that an attempt at definitive repair of the pseudoaneurysm, with preservation of the parent vessel, was warranted. A 3.5 × 35-mm porous stent was positioned across the level of the aneurysm and dilated with a 4-mm angioplasty balloon. Control angiography demonstrated excellent flow through the VA and stasis of flow within the pseudoaneurysm (Fig. 1). The patient was maintained on aspirin (325 mg daily) and ticlopidine (250 mg twice a day).

Repeated angiography performed 6 weeks later revealed no change in the appearance of the pseudoaneurysm. Because of the persistent aneurysm filling, we elected to perform secondary coil placement in the aneurysm. Four GDCs of various sizes were delivered through the stent struts into the pseudoaneurysm, resulting in nearly complete occlusion. There were no thromboembolic complications. Angiography performed 6 months after the procedure exhibited patent flow through the VA and complete occlusion of the aneurysm (Fig. 1). The patient’s suboccipital pain had resolved.

Case 4
This 20-year-old man suffered a severe closed head injury as a result of a high-speed motor vehicle accident. No lateralizing abnormalities were apparent on examination, but a CT scan revealed generalized cerebral edema as well as a minimally depressed right temporoparietal fracture and a basal skull fracture. The patient was treated aggressively for raised intracranial pressure. Three weeks after the injury, a right cavernous sinus syndrome abruptly developed. Angiography demonstrated a large pseudoaneurysm of the petro cavernous segment of the right ICA. In addition, there was a small pseudoaneurysm of the angular branch of the right MCA beneath the skull fracture (Fig. 2).

The petro cavernous pseudoaneurysm was treated using a 16-mm PTFE-covered coronary stent graft. The aneurysm was satisfactorily occluded; however, because of vessel tortuosity the distal aspect of the arterial dissection could not be fully dilated and there was moderate stenosis of the ICA immediately beyond the stent. Control angiography performed at the termination of the procedure demonstrated patency of the ICA and normal filling of the intracranial branches, with minimal extravasation of contrast material at the site of the pseudoaneurysm (Fig. 3). Because of the potential for hemorrhage from the distal MCA pseudoaneurysm, heparin therapy was discontinued following the procedure, and single-agent antiplatelet therapy consisting of aspirin (325 mg daily) was initiated. Two days later the MCA pseudoaneurysm was repaired surgically. There were no procedural complications and the patient demonstrated gradual neurological recovery. One week after stent placement angiography was repeated.

### TABLE 1

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs)</th>
<th>Sex</th>
<th>Vascular Lesion (injury)</th>
<th>Clinical Presentation</th>
<th>Treatment</th>
<th>Antithrombotic Therapy</th>
<th>Result on Angiogram (timing postop)</th>
<th>Clinical Outcome (timing postop)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30, F</td>
<td>It VA pseudoaneurysm (stab wound)</td>
<td>suboccipital pain embolic stroke, demonstrated enlargement</td>
<td>porous stent &amp; 4 GDCs vein- covered Pal- maz stent</td>
<td>aspirin &amp; ticlopidine</td>
<td>aneurysm occluded, parent artery preserved (6 mos)</td>
<td>resolution of pain (6 mos)</td>
<td>good recovery (12 mos)</td>
</tr>
<tr>
<td>2</td>
<td>20, M</td>
<td>It cervical ICA pseudoaneurysm (gunshot wound)</td>
<td>bruit, central cord syndrome</td>
<td>vein-covered Pal- maz stent</td>
<td>aspirin &amp; ticlopidine</td>
<td>fistula closed, parent artery preserved (6 mos)</td>
<td>elimination of bruit, improvement in myelopathy (12 mos)</td>
<td>resolution of cavernous sinus syndrome, no new neurological symptoms, moderate recovery from head injury (12 mos)</td>
</tr>
<tr>
<td>3</td>
<td>60, F</td>
<td>It VA–VV fistula (direct puncture on angiogram 25 yrs earlier)</td>
<td>cavernous sinus syndrome</td>
<td>PTFE-covered stent</td>
<td>aspirin</td>
<td>aneurysm excluded, ICA patent (at termination of procedure); ICA occluded (1 wk)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>20, M</td>
<td>Enlarging rt petro- cavernous ICA pseudoaneurysm (severe head injury, basal skull fracture)</td>
<td>embolic stroke, subdural hematoma massive hemorrhage</td>
<td>PTFE-covered stent ×3</td>
<td>aspirin &amp; clopidogrel</td>
<td>aneurysm excluded, parent artery preserved (3 mos)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>19, M</td>
<td>It petrous ICA pseudoaneurysm (head injury, basal skull fracture)</td>
<td>embolic stroke, subdural hematoma</td>
<td>PTFE-covered stent</td>
<td>aspirin &amp; clopidogrel</td>
<td>fistula closed, parent artery preserved (3 mos)*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>16, M</td>
<td>Rt cervical ICA–jugular vein fistula (gunshot wound)</td>
<td></td>
<td></td>
<td>aspirin &amp; clopidogrel</td>
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* Results of CT angiograms.
ed. The stent had thrombosed, but there was good collateral blood flow to the right hemisphere (Fig. 3). There was no thromboembolic or hemodynamic sequela and the patient eventually made a moderate recovery from his head injury.

Case 5

This 19-year-old man sustained a closed head injury as a result of a motor vehicle accident. On examination he was alert and cooperative. There was a left sixth nerve palsy and right hemiparesis. A CT scan demonstrated a subdural hematoma along the left tentorial margin and a fracture of the left petrous bone. Angiograms revealed a dissection of the left ICA in the petrous segment, as well as embolic occlusion of multiple branches of the left MCA (Fig. 4). The patient received anticoagulation therapy with heparin, and the right hemiparesis improved rapidly. Six days after the injury severe headache, chemosis of the left eye, and paresthesia in the left trigeminal nerve distribution developed. A repeated CT scan was obtained and demonstrated new intracranial hemorrhage above the petrous temporal bone and along the left cavernous sinus. Repeated angiography revealed a pseudoaneurysm at the site of the previous dissection. The pseudoaneurysm was treated using a 16-mm PTFE-covered stent graft, with complete elimination of aneurysm filling and no stenosis of the ICA (Fig. 4). Antiplatelet therapy with aspirin and clopidogrel was initiated. The ocular and cranial nerve symptoms gradually diminished. Angiographic assessment performed 3 months later confirmed stable occlusion of the pseudoaneurysm and normal patency of the ICA.

Case 6

This 16-year-old man sustained a gunshot injury with an entry wound medial to the left eye. The bullet was lodged adjacent to the right ICA near the skull base. Massive hemorrhage resulted, requiring intubation and packing of the oropharynx. Following fluid resuscitation and blood volume replacement, the patient was found to be neurologically intact. Angiography revealed a fistula extending from the ICA to the jugular vein (Fig. 5). Because of the large size of the fistulous communication and a limited inventory of covered stents, the fistula was closed using a series of three overlapping 12-mm PTFE-covered stent grafts, which were placed in tandem. Immediate postoperative control angiography demonstrated occlusion of the fistula but minor filling of a pseudoaneurysm. Antiplatelet therapy with aspirin and clopidogrel was maintained. Repeated angiography performed 2 days later confirmed complete occlusion of the pseudoaneurysm and normal flow through the ICA (Fig. 5). The patient recovered uneventfully and was well at the time of follow-up examination 3 months later.

Fig. 1. Case 1. A: Left VA angiogram, anteroposterior view, demonstrating a posttraumatic pseudoaneurysm of the distal extracranial VA. The surgical clips relate to a previous ligation of the ICA. B: Control angiogram obtained 6 weeks after endovascular placement of a porous stent. Arrows indicate the upper and lower stent margins. There has been mild straightening of the vessel, but the pseudoaneurysm remains unchanged. C and D: Angiograms, anteroposterior (C) and lateral (D) views, obtained 6 months after the pseudoaneurysm was packed with GDCs. The VA is patent and the aneurysm has been occluded.

Fig. 2. Case 4. Left: Right CCA angiogram, early arterial phase, revealing a large pseudoaneurysm extending anterior and posterior to the petrocavernous segment of the ICA. Tapered narrowing of the ICA lumen indicates the extent of arterial dissection. Right: Right ICA angiogram, midarterial phase, demonstrating a small pseudoaneurysm (arrow) of the angular branch of the MCA.
Discussion

Traumatic arterial aneurysms and AVFs resulting from penetrating craniocervical injuries or basal skull fractures are difficult lesions to manage. Most commonly, adequate distal exposure and direct repair are not safely possible. These lesions are distinct from dissecting aneurysms arising spontaneously or in association with blunt trauma, which frequently have a benign natural history and are best treated conservatively. Penetrating injuries may cause complete or partial arterial transection, false aneurysms (paravascular encapsulated hematomas that communicate with the lumen of the artery), arteriovenous connections, mural arterial dissections, or arterial thrombosis. Aggressive management is generally warranted to prevent life-threatening hemorrhage or thromboembolic cerebral ischemia.

The mechanism of vascular injury has significant bear-
Direct trauma results when the vessel is in the path of a penetrating object or in proximity to an adjacent fracture. Patients with aneurysms resulting from traumatic dissections or penetrating injuries are more likely than those with spontaneous dissections to display significant neurological deficits. Traumatic dissections are more often associated with aneurysms or stenosis and are less likely to resolve without intervention. With spontaneous ICA dissections, angiographically evident improvement occurs in 60% of aneurysms and 80 to 90% of stenoses. Traumatic ICA dissections, however, angiographically demonstrated resolution occurs in only 20% of aneurysms and 50% of stenoses. All patients in this series harbored symptomatic vascular lesions resulting from penetrating trauma or adjacent fractures, which we believed justified aggressive therapy.

Beginning with the pioneering work of Dotter and associates and Cragg, et al., who demonstrated the feasibility of transcatheter arterial grafting, there has been remarkable progress in the development of porous and covered stents, which have been used primarily in the coronary and peripheral circulations. Neurovascular applications for stent use have more recently emerged. The results of some experimental studies have indicated that placement of a porous stent within the parent artery across an aneurysm neck may sufficiently change the hemodynamic flow pattern within the aneurysm so that thrombosis may ensue. Clinical experience has been disappointing in this regard, however, as in Case 1 of this series, and many broad-based aneurysms for which conventional endovascular occlusion with GDCs is not feasible have re-
quired a combination of stents and coils for definitive aneurysm occlusion. 17,18,21,31,32

The use of covered stents was studied in a dog model of side-wall CCA aneurysms by Iwakoshi, et al. 16 An “intra-arterial bypass” was created by placing an autologous vein-covered stent across the aneurysm neck in tandem with self-expanding porous stents placed proximally and distally to fix the vein graft in place. Of 13 aneurysms, seven were completely occluded, with preservation of the parent artery. The remaining six procedures resulted in parent artery occlusion because of failures in stent placement. Histological examination of specimens obtained in the successfully treated cases 1 week following stent placement showed smooth intima with slight endothelial hypertrophy.

There have been several case reports and small series of patients with spontaneous or traumatic carotid artery dissections that have been successfully treated using either self-expanding or balloon-expandable porous stents. 2,9,14,33 Little has been published, however, regarding covered stent placement for neurovascular disease. Singer, et al. 16 reported on two cases of deliberate arterial occlusion accomplished using balloon-expandable stents covered with a closed-end PTFE tube graft as an alternative to detachable balloon occlusion. We previously described our first experience with the use of a vein-covered stent (Case 2) in a technical case report. 24 Waldman and colleagues 37 reported on a single patient with a penetrating VA injury that was treated with a polycarbonate urethane-covered stent graft. Experience in the coronary10 and peripheral4,22,29,34 circulations with the use of PTFE-covered stents has been particularly favorable, with extremely low rates of neointimal hyperplasia, indicating a potential antiproliferative effect of sealing the vessel wall. 22,28 Laboratory studies with PTFE-covered stents have confirmed these clinical observations, 7 whereas dacron- and silicone-covered stents have been shown to have poor short-term patency rates due to acute inflammation and exuberant ingrowth of fibrous connective tissue. 12,20

A rare but important complication associated with stent use is the development of subacute thrombotic occlusion shortly after implantation. A number of variables appear to correlate with a higher probability of stent thrombosis, including small vessel size, proximal or distal dissection, and underdilation of the stent. The only occurrence of stent thrombosis in our series was in a patient (Case 4) in whom tapered narrowing resulted because of dissection extending beyond the segment in which the stent was placed; in this patient, combination antiplatelet therapy was contraindicated. Clinical trials comparing various antithrombotic regimens following coronary artery stenting after angioplasty have demonstrated that treatment with either ticlopidine and aspirin or clopidogrel and aspirin is more effective in reducing stent thrombosis than treatment with aspirin alone or aspirin and warfarin. 19,27,30 Clopidogrel has fewer side effects than ticlopidine and may convey a specific benefit when used with covered stent grafts. 19,27

Conclusions

This report contains a description of a series of traumatic neurovascular lesions that were treated with endovascu-
aneurysm of the internal carotid artery: combined endovascular treatment with coils and stents. AJNR 18:1261–1264, 1997

Manuscript received October 19, 2000.
Accepted in final form May 7, 2001.
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