ORIGINALARTICLE

Microstent-Assisted Coiling for Wide-Necked Intracranial Aneurysms

Marlise Peruzzo dos Santos Souza, Ronit Agid, Robert A. Willinsky, Michael Cusimano, Walter Montanera, M. Christopher Wallace, Karel G. terBrugge, Thomas R. Marotta

ABSTRACT: ***Objective:*** To describe the results, technical feasibility, efficacy and challenges encountered in our preliminary experience using a self-expandable microstent, optimized for intracranial use, as an adjunct in the endovascular treatment of wide-necked aneurysms. ***Methods:*** Only broad-necked aneurysms (dome-to-neck ratio ≤2, or an isolated neck size > 4.5 mm) were treated with Neuroform microstent from July 2003 to May 2004. The techniques used for stent deployment were either parallel or sequential. Angiographic results were recorded immediately for all patients and classified as Class 1 (complete occlusion), Class 2 (neck remnant) or Class 3 (sac remnant) by three interventional neuroradiologists not involved in the procedure. Follow-up angiography at six months was obtained for one case. Modified Rankin Score scale was assessed for all patients. ***Results:*** Seventeen intracranial aneurysms in a total of 18 patients were treated (mean age, 52.2 yr). Eight patients (44.4%) presented with acute subarachnoid hemorrhage. Eleven aneurysms (61.1%) were in the posterior circulation. Average dome size was 10.2 mm (range, 3.7-19.8 mm) and average neck size was 5.36 mm (range, 3.0-10.0 mm). Six out of seven aneurysms of the anterior circulation were approached with parallel technique. Eight aneurysms of the posterior circulation were approached with sequential technique. Average number of coils deployed was 9.64 (range, 4-23 coils). Eleven aneurysms (64.8%) resulted in Class 1 and/or Class 2. One technical failure was observed. Technical complications were recognized in four patients (23.5%), all of them with unruptured aneurysms in the anterior circulation. Two patients (11.7%) presented transient immediate clinical complications. One patient (5.8%) had minor permanent neurological complication. Neither major clinical complications nor death were encountered. Favorable clinical outcome (Modified Rankin Scale score 0-2) was observed in 88.2% of the patients (average follow-up time, 4.72 months). ***Conclusions:*** Absence of major permanent complications and satisfactory immediate obliteration degree in our preliminary experience indicates that microstent-assisted coiling technique is useful for the minimally invasive treatment of broad-necked complex aneurysms that are not ideal for conventional endovascular treatment and are at a high risk for conventional surgical treatment.

RÉSUMÉ: Rapport préliminaire sur une technique d'embolisation avec microstent d'anévrismes intracrâniens à large collet. ***Objectif:*** Décrire les résultats, la faisabilité technique, l'efficacité et les défis rencontrés au cours de nos premières expériences d'utilisation d'un microstent autodéployant adapté pour utilisation intracrânienne dans le traitement endovasculaire des anévrismes à large collet. ***Méthodes:*** Le microstent Neuroform a été utilisé de juillet 2003 à mai 2004 pour traiter uniquement les anévrismes à large collet (rapport sommet/collet ≤2, ou un collet >4,5 mm). La technique utilisée pour le déploiement du sent était soit parallèle ou séquentielle. Les résultats angiographiques étaient enregistrés immédiatement pour tous les patients et classifiés par trois neuroradiologistes interventionnels indépendants de l'étude comme suit: classe 1 quand l'occlusion était complète; classe 2 quand il y avait un collet résiduel et classe 3 quand il y avait un sac résiduel. Une angiographie a été faite chez un cas 6 mois après l'intervention. Tous les patients ont été évalués au moyen de l'échelle modifiée de Rankin. ***Résultats:*** Dix-sept anévrismes chez 18 patients dont l'âge moyen était de 52,2 ans ont été traités. Huit patients, soit 44,4%, avaient consulté pour une hémorragie sous-arachnoïdienne aiguë. Onze anévrismes, soit 61,1% étaient situés au niveau de la circulation postérieure. La taille moyenne du sommet de l'anévrisme était de 10,2 mm (écart de 3,7 à 19,8 mm) et la taille moyenne du collet était de 5,36 mm (écart de 3,0 à 10,0 mm). La technique parallèle a été utilisée pour traiter six des sept anévrismes situés au niveau de la circulation antérieure et la technique séquentielle pour 8 anévrismes situés au niveau de la circulation postérieure. Le nombre moyen de coils déployés était de 9,64 (écart de 4 à 23 coils). Le résultat du traitement de onze anévrismes (64,8%) a été classifié comme étant de classe 1 et/ou de classe 2. Il y a eu un échec technique et des complications techniques sont survenues chez quatre patients (23,5%), tous des patients qui avaient des anévrismes sans rupture au niveau de la circulation antérieure. Deux patients (11,7%) ont eu des complications cliniques passagères immédiates. Un patient (5,8%) a eu une complication neurologique permanente mineure. Aucune complication clinique majeure ou décès n'ont été observés. 88,2% des patients ont eu une issue favorable (score de 0 à 2, à l'échelle modifiée de Rankin) au cours d'un suivi moyen de 4,72 mois. ***Conclusions:*** Chez ces patients, nous n'avons pas observé de complications permanentes majeures et nous avons obtenu un degré satisfaisant d'oblitération immédiate. Nos résultats préliminaires indiquent que la technique du coiling avec microstent est utile dans le traitement non effractif des anévrismes complexes à large collet pour lesquels le traitement endovasculaire conventionnel n'est pas idéal et la chirurgie conventionnelle présente un risque élevé.

Can. J. Neurol. Sci. 2005; 32: 71-81

In the past years, the concepts of treatment of intracranial aneurysms have changed and evolved. New technologies have contributed to expand the options for endovascular management of both ruptured and unruptured intracranial aneurysm.[1-4] The

From the Department of Medical Imaging, St. Michael's Hospital and Toronto Western Hospital, University Health Network, Toronto, Ontario, Canada

RECEIVED MAY 18, 2004. ACCEPTEDINFINALFORM OCTOBER 7, 2004.

Reprint requests to: Thomas R. Marotta, St. Michael's Hospital, Department of Medical Imaging, 3 Cardinal Carter, 30 Bond Street, Toronto, ON, M5B 1W8 Canada.

"ideal" aneurysm treatment should prevent subsequent hemorrhage by mechanical and hemodynamic effects on intra-aneurysmal flow. This goal is more readily achieved in aneurysms with a favorable dome-to-neck ratio. The geometry of wide-necked aneurysms sometimes makes it most challenging to treat the aneurysm by an endovascular approach. The microstent-assisted coiling technique has been used to provide an adjunct treatment option for patients with wide-necked aneurysms in whom direct surgical clipping or conventional endovascular therapy would be difficult or impossible, and in whom parent artery occlusion is a less favorable option. We describe the results, technical feasibility, efficacy and challenges encountered in our preliminary experience using a self-expandable microstent, optimized for intracranial use, as an adjunct in the endovascular treatment of wide-necked intracranial aneurysms.

Patients and Methods

Patients

The patients enrolled in this clinical study were registered in a prospectively maintained database. Patient selection for treatment with intracranial stenting and coiling was based on the clinical status and on the anatomic characteristics of each aneurysm. All patients were evaluated by at least one vascular neurosurgeon and two interventional neuroradiologists before being selected for endovascular treatment. Two interventionists were the main operators in the two hospitals involved in the study. All physicians involved in the care of each patient agreed that endovascular technique was preferred over surgical clipping. All patients and/or their direct relatives had signed a written informed consent before starting the procedure. The Neuroform microstent (Boston Scientific Target, Fremont, CA) was approved for use in our institutions through a Special Access Authorization obtained from the Medical Devices Bureau, Therapeutic Products Directorate, Health Canada.

Indication for Treatment

Indication for treatment using the Neuroform microstent as opposed to other endovascular or exovascular techniques was based on anatomical characteristics of each aneurysm. Only aneurysms with "broad neck" were considered for this treatment. The definition of broad neck in our series was a dome-to-neck ratio ≤ 2, or an isolated neck size > 4.5 mm.

Intracranial Stenting Technique

With one exception, patients with unruptured cerebral aneurysms were pretreated with 325 mg aspirin and 75 mg clopidogrel (Plavix; Bristol-Myers Squibb/Sanofi Pharmaceuticals, New York, NY) for three to five days prior to stenting. One of the patients with an unruptured aneurysm (Patient 5) was pretreated with aspirin only because the initial treatment plan did not include the use of a microstent. Three patients with ruptured aneurysms (Patients 12, 13 and 16) were pretreated with these antiplatelet agents, which were loaded through a nasogastric tube immediately before the femoral puncture (usually 325 mg of aspirin and 300 mg of clopidogrel). All procedures were performed under general anesthesia. Femoral arterial access was achieved using single-wall methods in all patients. A bilateral femoral approach was chosen for parallel technique. Five and 6-F Envoy guiding catheters (Cordis Neurovascular, Miami Lakes, FL) or 6-F Shuttle sheaths (Cook Corp. Bloomington, IN) were used. Full anticoagulation with intravenous heparin (USP, Wyeth-Ayers & Co., Philadelphia, PA) was started immediately after arterial puncture. The activating clotting time was maintained between 250-350 seconds. After diagnostic angiography had been performed, appropriate working angles were registered for microstent delivery and aneurysm coiling.

The Neuroform Microdelivery Stent System has become available for use in United States in September 2002 (U.S. Food and Drug Administration, Humanitarian Device Exemption, H020002). It is a flexible, self-expanding, microcatheter-delivered nitinol (nickel-titanium) stent, designed specifically for the treatment of patients with intracranial aneurysms.[5] The first Neuroform system available consisted of the self-expanding Neuroform stent preloaded into an unbraided 3-F microdelivery catheter containing a 2-F over-the-wire stabilizer catheter ("pusher"). The second generation Neuroform Stent (Neuroform 2) has four "more radiopaque" and "more rounded" platinum markers on each end of the stent (to reduce friction) and comes preloaded in a 3-F microdelivery catheter with a braided distal portion (which reduces the force necessary to deploy the stent in comparison to previous generation).

The dimensions of the parent vessel in the region targeted as the landing zone for the microstent were defined with 3-D reconstruction, to select the appropriately sized Neuroform stent. Available sizes for first generation Neuroform stent were 3.0-, 3.5-, 4.0- and 4.5 mm nominal diameters with 15- and 20 mm nominal lengths. Available sizes for Neuroform 2 stent were 2.5-, 3.0-, 3.5-, 4.0- and 4.5 mm nominal diameters with 10-, 15- and 20 mm nominal lengths. The microstent interstices size range from 2-F to 2.5-F. Stents were sized to a nominal diameter 0.5 to 1.0 mm wider than the targeted landing zone's diameter. The ideal microstent's length was calculated to provide a minimum of 4 mm landing zone on either side of the aneurysm neck.

Two types of microstent-assisted aneurysm coiling techniques were employed in our patients: either parallel or sequential. The choice of technique was made according to the anatomy of the affected vessel following diagnostic angiography, including rotational views of the target vessel and 3-D reconstruction. The parallel technique consists of positioning a microcathether within the aneurysm as a first step and afterwards deploying the microstent over the microcatheter. This technique was chosen for side wall aneurysms, for aneurysms that could be approached through two vessels (for instance, posterior circulation), or whenever we suspected it would be difficult to reach the interior of the aneurysm sac through the microstent interstices, due to anatomical limitations. The sequential technique consists of deploying the microstent within the target vessel first, followed by positioning a microcatheter within the aneurysm through the interstices of the microstent. This technique requires a single guiding catheter and was chosen whenever we predicted it would be feasible to negotiate the microcatheter through the microstent (favorable anatomical angles). Bare platinum coils of multiple shapes and lengths were used in our patients for both techniques.

Heparinization was not reversed at the end of the coiling procedures and the common femoral artery sheath(s) was removed 24 hours after the procedure. Hemostasis was

https://doi.org/10.1017/S0317167100016917 Published online by Cambridge University Press

Table 1. Clinical presentation and aneurysm characteristics of 18 patients enrolled fortreatment with microstent-assisted coiling technique

Patient no.	Age (yr)	Sex (M/F)	Main symptoms	Aneurysm location	Aneurysm type	Aneurysm size (mm)	Neck size (mm)	Dome-to-neck ratio
1	59	F	Progressive Rt III CN palsy	Basilar artery, apex, incorporating Rt P1-PCA	Broad-necked, large dome	19.8	5	3.96
2	55	F	Progressive Rt III CN palsy	Basilar artery, apex, incorporating both P1-PCAs	Broad-necked	11.7	6.5	1.78
3	60	F	SAH (WFNS V)	Basilar artery, unfused, incorporating both vertebral arteries	Broad-necked, bilobulated	11	10	1.1
4	56	F	SAH (WFNS I)	Basilar artery, apex, incorporating both P1-PCAs	Broad-necked, previous incomp. coiling	7.8	7	1.11
5	48	F	Remote Lt MCA stroke	Lt ICA, ophthalmic segment	Broad-necked	12	5	2.4
6	37	F	SAH (WFNS IV)	Basilar artery, partially unfused	Broad-necked, bilobulated	3.7	3	1.23
7	55	F	Headaches, progressive diplopia	Basilar artery, apex, incorporating Lt P1-PCA	Broad-necked, bilobulated	7	4	1.75
8	50	M	Headaches	Lt ICA, terminus	Broad-necked, multilobulated	12	6	2
9	55	F	Headaches	Lt ICA, incorporating fetal-type origin P Comm	Broad-necked, large dome	10.5	7.2	1.45
10	37	F	Remote SAH, partially coiled	Basilar artery, apex, incorporating Lt P1-PCA	Broad-necked, remote incomplete coiling	5	4	1.25
11	47	F	Headaches	Basilar artery, apex, incorporating both P1-PCAs	Broad-necked, large dome	13.6	5.1	2.66
12	57	M	SAH (WFNS III)	A Comm artery, incorporating Rt A2-ACA	Broad-necked, large dome	13.1	4.5	2.94
13	66	F	SAH (WFNS III)	Basilar artery, apex, incorporating both P1-PCAs	Broad-necked	10	7	1.42
14	45	M	SAH (WFNS I)	Basilar artery, apex, incorporating Rt P1-PCA	Broad-necked	7.9	4	1.97
15	48	M	SAH (WFNS I)	Rt ICA, P Comm	Broad-necked	6.3	3.6	1.75
16	58	F	SAH (WFNS II)	Lt ICA, incorporating P Comm	Broad-necked, multilobulated	8	5	1.6
17	64	F	Dizziness	Lt ICA, ophthalmic segment	Broad-necked	13	5	2.6
18	44	M	Remote SAH, completely coiled, recurrence	Basilar artery, apex, incorporating both P1-PCAs	Broad-necked, coils compaction and recurrence	4.6	4.6	1

CN: cranial nerve, P1-PCA: first segment of the posterior cerebral artery, SAH: subarachnoid hemorrhage, WFNS: World Federation of Neurological Surgeons SAH Clinical Grading System, ICA: internal carotid artery, P Comm: posterior communicating artery, A Comm: anterior communicatingartery, A2-ACA: second segment of the anterior cerebral artery , Rt: right, Lt: left, MCA: middle cerebral artery

accomplished by direct manual compression over the puncture site. Patients with both unruptured and ruptured aneurysms were maintained on 325 mg of aspirin and 75 mg of clopidogrel for six to eight weeks, followed by aspirin alone, which was continued indefinitely.

Angiographic Results

Angiographic findings were recorded immediately post coiling for all patients and in a delayed fashion for Patient 1. Multiple projections with selective contrast injections and rotational angiography with 3-D reconstruction were used to define any residual. The angiographic obliteration results were classified according to a method described by Roy et al.[6] Three interventional neuroradiologists not involved in the coiling procedure classified the anatomical results. Class 1 was equivalent to complete (or 100%) obliteration. Class 2 was defined as the persistence of any portion of the original defect of the arterial wall as seen on any single projection but without opacification of the aneurysm sac (nearly complete occlusion or more then 95%). Any opacification of the aneurysm sac was classified as Class 3 and considered partial obliteration (or less then 95%).

https://doi.org/10.1017/S0317167100016917 Published online by Cambridge University Press

Follow-up

Telephone assessment of the Modified Ranking Scale score (MRS)[7,8] was obtained for all patients.

Results

Patients

From July 2003 to May 2004, 18 intracranial aneurysms in 18 patients (13 women and five men) were considered for treatment using microstent-assisted coiling technique (Table 1). These patients ranged in age from 37 to 66 years at the time of treatment (mean age, 52.2 yr). Eight patients presented with acute subarachnoid hemorrhage (44.4%), two had remote subarachnoid hemorrhage (11.1%), three had subacute progressive neurological deficit (16.6%), four had an unruptured, incidentally-discovered aneurysm (22.2%), and one had remote neurological deficit (5.5%). Eleven patients had either high blood pressure on treatment or smoking as co-morbidities, whereas six of them were previously healthy. Patient 13 had Factor V deficiency and four patients had multiple intracranial aneurysms. Eleven aneurysms (61.1%) were located in the posterior circulation, nine of them in the apex of the basilar artery and two in a partially unfused basilar artery. Seven patients (38.8%) were treated for aneurysms located in the anterior circulation, including one aneurysm in the anterior communicating complex (Patient 12, Figure 1).

Aneurysms Characteristics and Technical Decisions

All aneurysms considered for this treatment had a broad neck. Five of them were bilobulated or multilobulated, and two were treated after remote incomplete coiling (Patient 4, incomplete obliteration after conventional coiling technique using bare platinum coils (Figure 2), and Patient 10, incomplete obliteration after attempting balloon assisted-coiling technique). One patient (Patient 18) had his aneurysm completely coiled using balloon-assisted technique and bare platinum coils in June 2003, however follow-up magnetic resonance angiography at five months showed coil compaction and recurrence of the aneurysm.

The average dome size was 10.2 mm (range, 3.7-19.8 mm). The average neck size was 5.36 mm (range, 3.0-10.0 mm). All aneurysms stented were coiled during the same session. Five aneurysms had neck sizes equal or smaller than 4 mm. All of these had an unfavorable dome-to-neck ratio, two were either multilobulated or bilobutated (Patients 6 and 7) and one had previous attempt at standard and balloon remodeled techniques, neither of which achieved satisfactory results (Patient 10).

In one patient (Patient 6), the microstent was not deployed due to anatomical difficulties in a partially unfused basilar artery (arterial tortuosity and kinking, lack of flexibility in the delivery system of the microstent despite using a “buddy wire” maneuver). This patient was treated surgically and was not included in the analysis.

The system used in 16 out of 17 cases was Neuroform 2. In one patient (Patient 1), the microstent was transferred from the original microcatheter into the newer delivery catheter (Renegade HIGH-FLO,.027”, Boston Scientific Target, Fremont, CA). As mentioned above, the deployment technique chosen depended on the characteristics of the vascular access to the target aneurysm (Table 2). In most cases where the aneurysm was at a bifurcation, the sequential technique was preferred (n = 8). In side wall aneurysms the parallel technique was chosen (n = 7). Six out of seven patients treated for aneurysms in the anterior circulation were approached with parallel technique. Eight out of 11 patients treated for aneurysms in the posterior circulation were approached with sequential technique. The average number of coils deployed per aneurysm was 9.64 (range, 4-23 coils) and the average minutes of fluoroscopy per aneurysm treated was 72.9 min (range, 37.8-198 min).

Aneurysm Obliteration

The anatomical results for each case are summarized in Table 2. Class 2 result was achieved in almost half of the aneurysms treated (47%, 8/17). Of those, six were located in the posterior circulation. The next most prevalent result was Class 3 in 35.2% (6/17) of the aneurysms. Three of those were located in the posterior circulation. The least common result was Class 1 in 17.6% of aneurysms (3/17), two of which were located in the anterior circulation (Figure 1, Patient 12 and Figure 3, Patient 15).

In two patients (Patients 5 and 17), coiling was interrupted after clot formation developed within the microstent and a Class 3 result was achieved. In Patient 16 the presumed point of rupture of the aneurysm was adjacent to the neck and it had residual filling despite all attempts to enter coils into it. Therefore this patient was felt to be unprotected after coiling and proceeded to successful surgical repair with a clip without the need to reverse antiplatelet therapy (aspirin and clopidogrel).

Complications

Technical complications were encountered in four patients (23.5%), two of them related to the thrombogenicity of the microstent (11.7%), (Table 2, Patients 2, 3, 5 and 17). In Patient 2 an iatrogenic dissection in the proximal cervical segment of the left vertebral artery occurred during manipulation of a 0.35 inch Terumo Glide Wire, under road map guidance, for positioning an Envoy Guiding catheter. The coiling procedure was carried out uneventfully through the contralateral vertebral artery, which had a good caliber. This patient remained asymptomatic after the procedure and one month follow-up magnetic resonance angiography showed healing of the left vertebral artery dissection. In Patient 3, an unexpected “detachment” of the distal segment of the exchange micro guidewire (Xceleretor-10, 300-cm, Micro Therapeutics Inc., Irvine, CA) occurred. We believe it occurred due to “sympathetic detachment” of the distal platinum component of the micro guidewire related to transmission of current through the coil mass into the stent that was then transmitted along the “security” wire as it remained in contact with the stent. This caused dissolution of the solder point releasing the distal 10-cm of platinum wire tip. The wire fragment could not be removed despite all attempts and the patient remains asymptomatic five months after the procedure. In both patients (Patients 2 and 3), nearly complete occlusion of the aneurysms was achieved. In Patient 5 (an unruptured para-ophthalmic carotid artery aneurysm), clot formation within the microstent led to interruption of the coiling procedure. This patient was not preloaded with clopidogrel (aspirin only) before the coiling because we believed that a complete packing of the aneurysm could be obtained using only a balloon-assisted technique. However after deploying a few coils, we had

https://doi.org/10.1017/S0317167100016917 Published online by Cambridge University Press

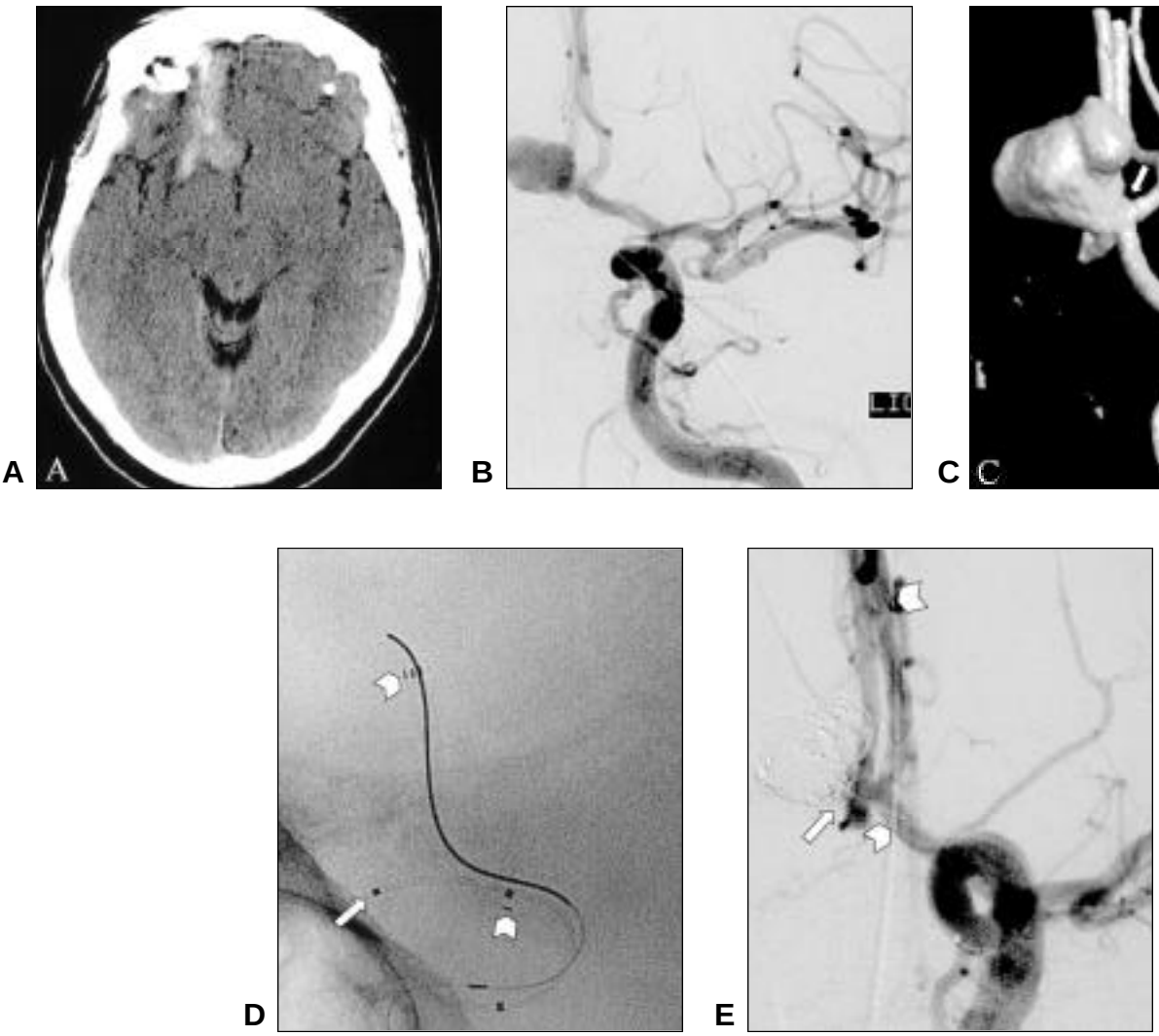

Figure 1 (*Patient* ***12):*** *(A) Unenhanced CT head shows a right frontal intra-parenchymal hemorrhage with ipsilateral subdural layering. (B) Left internal carotid angiogram revealed an aneurysm from the anterior communicating complex with both A2s filling from this side. There was a hypoplastic right first segment of the anterior cerebral artery. (C) 3-D angiographic reconstruction shows a multilobulated dome as well as a wide neck (arrow) incorporating the origin of the left second segment of the anterior cerebral artery. (D) Parallel technique was chosen. The long arrow indicates the tip of the microcatheter within the aneurysm sac. The short arrows indicate the markers of the microstent within the first and second segments of the left anterior cerebral artery. (E) Complete packing of the aneurysm was achieved at the end of the procedure (Class 1 result). The long arrow shows the tip of the microcatheter at the neck of the aneurysm at the end of coiling. The short arrows indicate the markers of the microstent.*

difficulty stabilizing the tip of the microcatheter within the aneurysm. We therefore decided to deploy a microstent using the parallel technique. Formation of clot was noticed adjacent to the distal marker points of the microstent. The clot was dissolved completely with intra-arterial abciximab (ReoPro, Centocor, Inc.) and the patient awakened without neurological symptoms. The dome of the aneurysm was well-protected by the coil mass and the patient will be reevaluated on follow-up angiogram. In one patient (Patient 17), clot formation within the microstent associated with coil stretching was observed. Partial thrombosis of both anterior and middle cerebral arteries on the left was observed and intravenous abciximab was immediately initiated. The clot was dissolved after 20 minutes, however, a small branch of the left middle cerebral artery remained distally occluded. The patient developed a mild distal upper limb weakness and an ischemic stroke was noticed within the left fronto-temporal region (“water-shed” areas) on MRI. Repeated transient ischemic attacks characterized by right-sided weakness were observed for one week after the procedure.

Technical failure was observed in one patient (5.5%, Patient 6), when the microstent could not be navigated and deployed into the appropriate position across the two aneurysms along the partially unfused basilar artery.

Two patients (11.7%) had minor immediate clinical events, represented by transient neurological deficits: Patient 8 had a transient ischemic attack six hours after the procedure and

https://doi.org/10.1017/S0317167100016917 Published online by Cambridge University Press

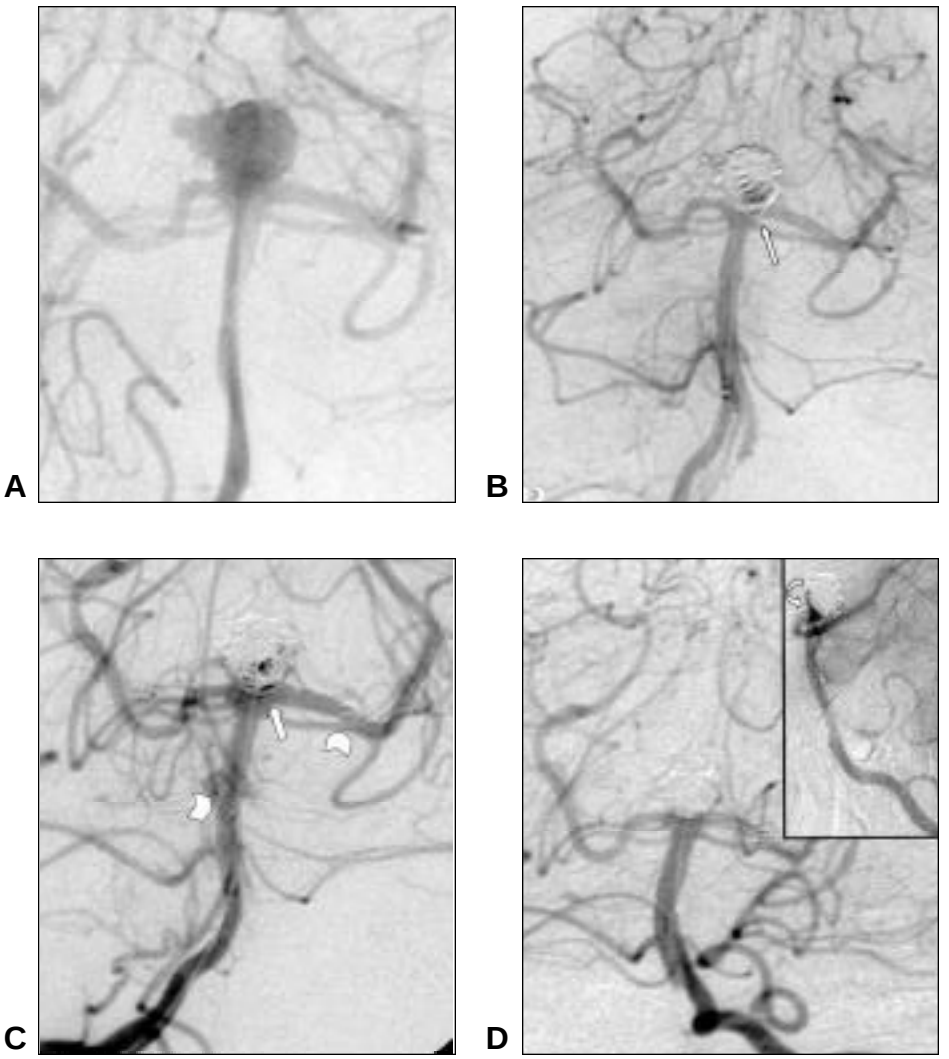

Figure 2 (*Patient* ***4):*** *(A) Right vertebral angiogram revealed a wide-necked aneurysm at the basilar apex. (B) Conventional coiling was attempted and a loop of a coil herniated within the proximal left P1-PCA segment (arrow). The procedure was interrupted and the patient was pretreated with anti-platelet agents for microstent neck remodeling and further coiling in a subsequent procedure. (C) 48 hours later, a microstent was deployed (short arrows) and the coil loop was pushed back into the limits of the aneurysm neck (long arrow). (D) Final result after coiling shows patency of both posterior cerebral arteries with a Class 3 result. The frontal view looks complete but the lateral view shows aneurysm remnant (curved arrow).*

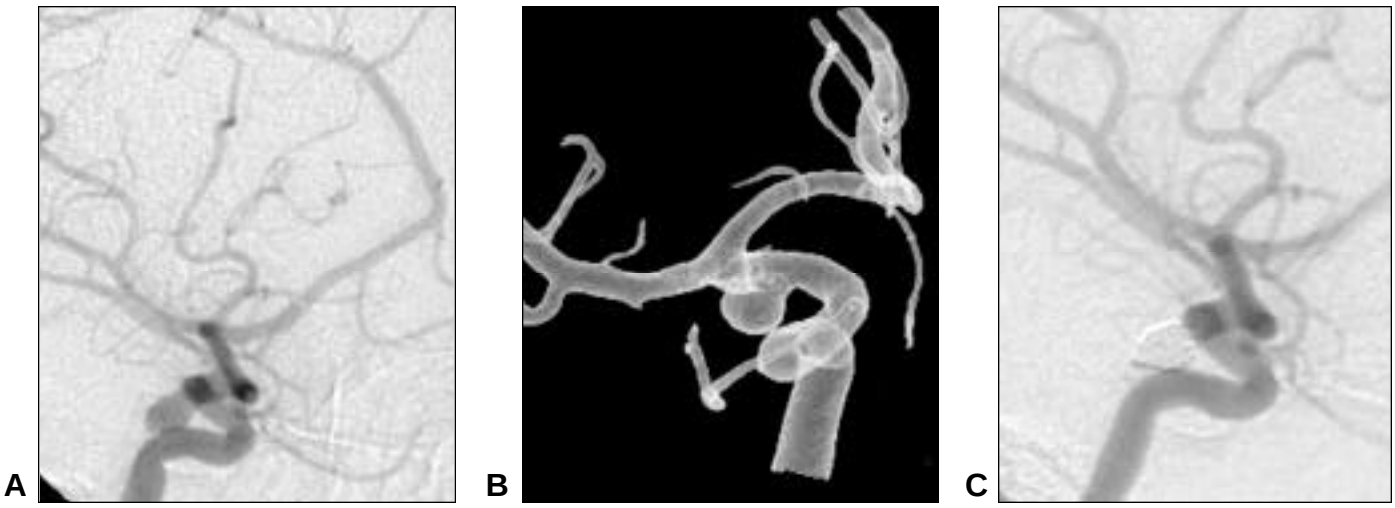

Figure 3 (*Patient* ***15):*** *(A) Right carotid angiogram revealed a wide-necked aneurysm at the origin of the right posterior communicating artery. (B) Angiographic 3-D reconstruction demonstrates widening of the supraclinoid internal carotid artery at the level of the neck of the aneurysm. (C) Class 1 result was obtained after microstent-assisted coiling with the parallel technique.*

https://doi.org/10.1017/S0317167100016917 Published online by Cambridge University Press

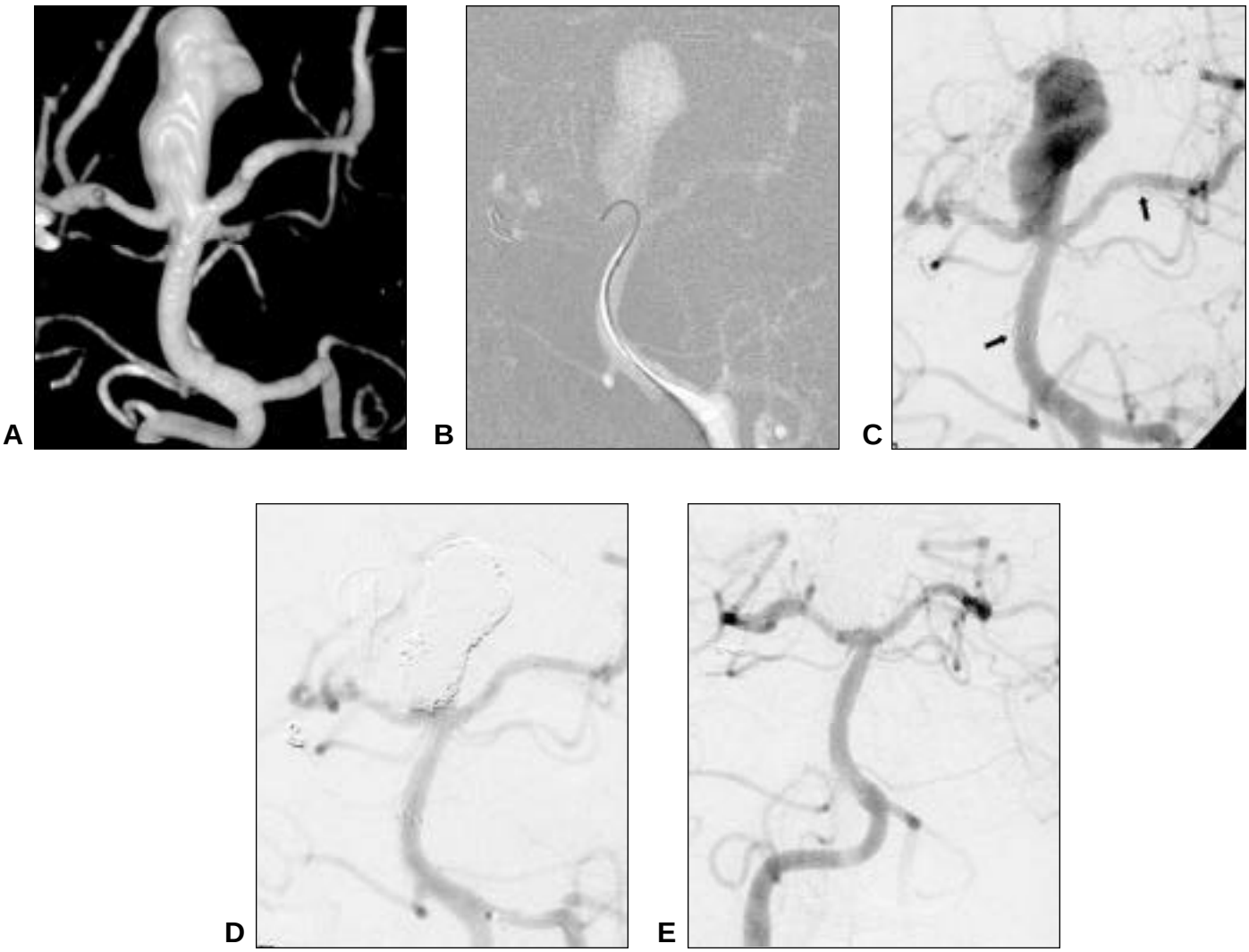

Figure 4 (*Patient* ***1):*** *(A) 3-D angiographic reconstruction shows an aneurysm in the basilar apex on anterior-posterior view, incorporating the first segment of the posterior cerebral arteries bilaterally, particularly on the right. (B) Selective catheterization of the right posterior cerebral artery was attempted to deploy the microstent across a broader segment of the aneurysm neck but this was not possible. (C) The stent was successfully deployed within the left posterior cerebral artery (arrows indicate the markers of the microstent). Note that the microstent bridges the superior cerebellar arteries bilaterally without interfering with their flow. (D) The microstent prevented coil herniation into the parent vessels throughout the procedure. A Class 2 result was obtained at the end. Note the indentation towards the neck of the aneurysm, probably representing the location of the expanded mesh portion of the stent. (E) Six-month follow-up cerebral angiography demonstrates the same result (persisting neck remnant maybe in part related to indentation from the microstent).*

Patient 9 had a transient ischemic attack three hours after the procedure. Both patients were treated with heparin for 24 to 48 hours after the procedure. Neither of these patients had any further events. Permanent minor clinical complication occurred in one patient (5.8%, Patient 17), with persistent grade 4+ out of 5 distal right upper limb weakness at one month and documented stroke on MRI. Major clinical complications and death did not occur in our series.

Follow-up

Follow-up has ranged from 0.5 to 10 months (average, 4.72 months; Table 2). Fifteen of the 17 patients (88.2%) treated using microstent had a favorable clinical outcome, considered as a MRS score between 0-2. One patient (Patient 6), had MRS score equal to 4 at six months and another patient (Patient 13) had a MRS score equal to 5 at three months. Both of them were in the group of patients with acute subarachnoid hemorrhage and had poor clinical grade at admission (see Table 1). Seven out of eight patients with MRS equal to 0 (87.5%) had no acute subarachnoid hemorrhage at the time of the treatment. One patient (Patient 5) had previous neurological deficit of a remote stroke at the time of treatment (Table 1), was discharged clinically unchanged after microstent-assisted coiling and had a MRS score equal to 3 at six months. Chart 1 compares the MRS scores obtained in the

https://doi.org/10.1017/S0317167100016917 Published online by Cambridge University Press

Table 2. Technical aspects and immediate results of 18 patients enrolled for treatment with microstent-assisted coiling technique

Patient no.	Technique (Seq. X Par.)	Stent size (mm)	Stent position	No. of coils	Fluoroscopy Time (min.)	Oblit. Result (Class)	Complications	Follow-up (Months)	MRS score
1	Seq	4.0 X 20	Mid BA, Lt PCA	23	123.2	Class 2	None	10	0
2	Seq	3.5 X 20	Mid BA, Rt PCA	10	54.1	Class 2	Asymptomatic Lt. VA dissection (diagnostic part)	8	0
3	Par	3.5 X 20	Proximal BA, distal Rt VA	18	198	Class 2	Rupture of micro-guidewire within Rt VA. Asymptomatic	6	2
4	Seq	3.0 X 20	Mid BAto Lt PCA	15	136.1	Class 3	None	6	1
5	Seq	4.5 X 20	Lt ICA, supraclinoid	12	53	Class 3	Clot formation within stent during packing. Dissolved with ReoPro. Asymptomatic	6	3
6	Par	3.5 X 20	Not deployed	0	45	Not coiled	Stent not deployed due to anatomical difficulties. Surgical treatment.	6	4
7	Seq	3.0 X 20	Mid basilar, Lt PCA	11	55.6	Class 2	None	5.5	0
8	Par	4.5 X 20	Proximal Lt MCA, supraclinoid Lt ICA	7	45	Class 2	TIA6 hours after the procedure. Complete recovery.	5.5	0
9	Par	4.0 X 20	Lt ICA, ophthalmic and supraclinoid	6	79.2	Class 2	TIA3 hours after the procedure. Complete recovery.	5.5	0
10	Seq	3.5 X 20	Distal BA, Lt PCA	8	37.8	Class 1	None	5.5	2
11	Seq	3.0 X 20	Mid basilar, Rt PCA	15	44.9	Class 2	None	5.5	0
12	Par	3.0 X 20	Distal Lt A1-ACA, proximal Lt A2-ACA	8	67	Class 1	None	5	2
13	Seq	3.5 X 20	Mid basilar, Lt PCA	9	61.4	Class 3	None	3	5
14	Par	3.5 X 20	Mid basilar, Rt PCA	8	70.5	Class 3	None	2	0
15	Par	3.5 X 20	Rt ICA, ophthalmic and supraclinoid	6	45	Class 1	None	2	1
16	Par	4.5 X 20	Lt ICAophthalmic to proximal M1-MCA	4	101	Class 3	None, but aneurysm surgically clipped (see text)	2	1
17	Par	4.5 X 20	Lt ICAophthalmic segment, jailing ophthalmic artery	7	110	Class 3	Clot formation within stent during packing. TIAs for 1 week. Ischemic stroke.	1	1
18	Seq	3.5 X 20	Mid basilar, Rt PCA	4	42	Class 2	None	0.5	0

Oblit: obliteration, Par: parallel technique, Seq: sequential technique, MRS: Modified Rankin Scale, Un: unilateral, Bil: bilateral, BA: basilar artery, PCA: posterior cerebral artery, VA: vertebral artery, ICA: internal carotid artery, MCA: middle cerebral artery, TIA: transient ischemic attack, A1-ACA: first segment of the anterior cerebral artery, A2-ACA: second segment of the anterior cerebral artery, M1-MCA: first segment of the middle cerebral artery, Rt: right, Lt: left.

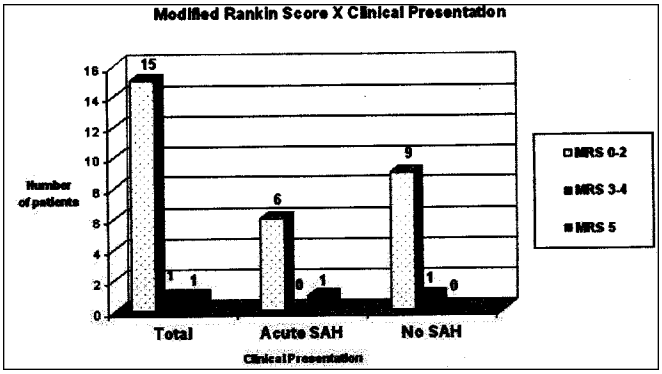

Chart 1: Comparison of early Modifed Rankin Scale score considering initial clinical presentation for 17 patients treated with microstent-assisted coiling technique (Patient 6 is not included).

https://doi.org/10.1017/S0317167100016917 Published online by Cambridge University Press

groups of patients with and without acute subarachnoid hemorrhage.

Patient 1 had a six-month follow-up cerebral angiogram (Figure 4) which confirmed the patency of the stented parent vessel and stability of the nearly complete packing of the basilar artery aneurysm.

Discussion

Since the publication of the International Subarachnoid Aneurysm Trial in 2002,[9] in our institution there has been a shift towards endovascular treatment of ruptured aneurysms. New technologies have contributed to better results from endovascular treatment of both ruptured and unruptured intracranial aneurysms.[1-4] There have been many modifications and advances in the coil and imaging technology designed to manage wide-necked aneurysms, which also represent a challenge for conventional surgical clipping. One of the main predictors of complete aneurysm occlusion by coil embolization is the size of the neck relative to the size of the aneurysm. In this instance, a higher dome-to-neck ratio indicates a better immediate result after endovascular treatment with detachable coils.[10-13]

The application of an endovascular stent as an adjunctive technique to the coil embolization has evolved quickly in the past three years. The first microstents used were coronary stents.[14-16] Only limited types of these balloon-expandable microstents are flexible enough to navigate the tortuous intracranial circulation. These more rigid microstents potentially have more risk of damaging the artery or causing vessel rupture. The Neuroform microstent, on the other hand, is very flexible and easy to navigate through the intracranial vessels. Only in one patient (Patient 6) could we not deploy the microstent along the neck of an aneurysm located in a rather tortuous, partially unfused basilar artery. Even after trying a stiffer coronary wire (Balance Middle Weight 0.014", 190-cm, Guidant Corp., Indianapolis) and a "buddy" technique, it was impossible to negotiate the stent within the parent vessel. This patient was treated surgically thereafter.

Microstent-assisted endovascular coiling provides important technical advantages. By providing secure and durable protection of the parent vessel, a broad-necked aneurysm theoretically could be more completely packed with coils with less risk of dissecting, rupturing, occluding or deforming the parent vessel. After the coils are deployed, the microstent (unlike a balloon) continues to support the coils within the aneurysm. A microstent can be used as a salvage procedure when a coil loop prolapses through the aneurysm neck (Patient 4, Figures 2-B and 2-C). In this instance, the microstent can be positioned across the loop in order to pin the coil against the wall of the vessel or push the loop back into the aneurysm. Furthermore, the Neuroform microstent can bridge or "jail" vessels arising from the parent vessel without interfering with the flow in these vessels (Patient 1, Figure 4-C). Ischemic events related to these vessels did not occur in our series.

Theoretically, microstents may produce flow redirection and disruption of the aneurysm inflow and outflow zones resulting in hemodynamic uncoupling of the parent vessel-aneurysm complex.[17,18] This hemodynamic advantage may help to reduce coil compaction in the region of the inflow zone and prevent subsequent growth of the aneurysm. The longer term follow-up of our patients will confirm whether this hypothesis is supported. The microstent also represents a helpful adjunctive tool to occlude small neck remnants in aneurysms that have been incompletely treated (Patient 4, Figure 2).[19-20] In addition, the microstent potentially provides a physical matrix for endothelial growth and allows appropriate remodeling of the parent vessel along the aneurysm neck.[21] A microstent might also be used to reconstruct a diseased parent vessel as in cases of dissecting of fusiform aneurysms.[2,22,23]

In our series, the microstent prevented coil herniation into the parent vessel throughout all procedures. For this purpose, it was crucial to use 3-D tools to obtain measurements of at least two axes of the aneurysm neck to choose an adequately oversized microstent. The relatively larger number of Class 2 immediate results in our series could be related to the microstent oversizing. It could theoretically represent a slight "herniation" of the microstent towards the aneurysm dome that could have caused the "pseudo-neck remnant" effect seen on angiography (Figure 4-D). Since the mesh of the microstent is radiolucent, it is so far impossible to prove this hypothesis *in vivo*.

In our practice, as in most of other series of intracranial

Table 3. Clinical studies of Neuroform-assisted aneurysm treatment

Investigators	No. of aneurysms	No. of stents	No. of transient complications	No. of permanent complications	No. of deaths	Technical failure	Complete occlusion	Nearly complete occlusion
Henkes et al., 2002	18	18	7	0	0	2	8	8
Wanke et al., 2003	4	4	0	1	0	0	3	1
Fiorella et al., 2004	22	25	6	2	2	2	2	4
Alfke et al, 2004	9	6	0	0	0	3	3	3
Chow et al., 2004	1	2	0	0	0	0	1	0
Benitez et al., 2004	49	48	2	1	4	8	28	7
Souza et al., 2004	17	17	2	1	0	1	3	8
Total*	120	120	17 (14.1%)	5 (4.1%)	6 (5%)	16 (13.3%)	48 (40%)	31 (25.8%)

* Percentages are based on the total number of aneurysms treated.

https://doi.org/10.1017/S0317167100016917 Published online by Cambridge University Press

stenting, clopidogrel (Plavix) was predominantly used in association with aspirin after intracranial stenting.[24-27] It was initiated three to five days before stenting in elective cases, or immediately before coiling in patients with subarachnoid hemorrhage, differing from Fiorella et al's[2] experience (where pretreatment was not applicable yet in patients with acute subarachnoid hemorrhage) though similar to Wanke et al's[22] series. In Henke's[28] series, 12% of patients had their aneurysms coiled without systemic anticoagulation (heparin or acetylsalicylic acid), and the regimen applied for microstent-assisted coiling was not described. Interestingly, all our four patients who had thrombogenic complications during or after the procedure (Patients 5, 8, 9 and 17) were treated for unruptured aneurysms in the internal carotid artery, considered the most problematic for microstent positioning and deployment.[2] With the exception of Patient 5 (see Methods), all three other patients were preloaded with both aspirin and clopidogrel. We believe that all patients considered for using an intracranial microstent should be pretreated with aspirin and clopidogrel. Resistance to antiplatelet therapy has been investigated in patients treated for coronary disease and may represent another reason for following this strategy.[29-30] Postprocedural heparinization for 24-48 hours should also be considered for unruptured aneurysms treated with a microstent and coils.

A few investigators have published their experience with the Neuroform microstent for aneurysm coiling (Table 3).[1,2,22,31-33] Including our series, a total of 120 aneurysms have been reported using a total of 120 microstents. So far, 17 immediate transient neurological complications were detected, representing a 14.1% transient complication rate. Five permanent complications (4.1%) and six deaths (5%) were documented. In total, these combined series show an overall complication rate of 23.3%, with a combined complete/nearly complete occlusion rate of 65.8% and complete occlusion rate of 40%. Regardless of the low number of cases, our results compare favorably to the other series, with a transient complication rate of 11.7%, permanent complication rate of 5.8%, no deaths, and a 5.8% rate of technical failure. A complete and nearly complete occlusion (Class 1 + Class 2) was obtained in 64.7% of the aneurysms in our series.

A recent retrospective analysis of 1811 intracranial aneurysms treated with multiple techniques of coil embolization,[28] demonstrated an increased complication rate in patients treated with microstent deployment (35.9%), whereas the overall complication rate in that series was 17.7%. The kind of microstents used in this clinical study was not described in detail; however one can deduce that most of their cases were treated with coronary microstents rather than Neuroform. The use of other modified techniques in that study, including three-dimensional coils, dual-catheter techniques, balloon remodeling, parent artery occlusion and trispan coils were also associated with higher complication rates in comparison with standard endovascular coiling.

Microstents are an important addition to the armamentarium used in the endovascular treatment of intracranial aneurysms. In our series, the morphology of the aneurysms was unfavorable for a safe and effective treatment using conventional endovascular techniques. We do not believe that microstents should be used for aneurysms that are suitable for coiling without assisted techniques. More clinical data with long term follow-up is needed to help establish the role of microstents in aneurysm treatment.

The recent advances created in the Neuroform 2 system allowed an overall easier and accurate deployment, especially in the anterior circulation. Systemic anticoagulation and combined antiplatelet therapy are important to avoid thromboembolic complications, including patients presenting acute subarachnoid hemorrhage. Even though this is a small series with limited clinical and angiographic follow-up, no deaths and a low permanent complication rate indicate that the Neuroform microstent is a useful tool for the minimally invasive treatment of selected patients with wide-neck aneurysms that are not ideal for conventional endovascular treatment and are at a high risk for conventional surgical treatment.

Conflict of Interest

The authors do not have nonscientific or nonacademic interest to disclose.

Acknowledgments

The authors thank Nurse Coordinator Gail Reintamm, Technologists Mary Lou Montanera, Rory Stamina and Mike Ball, and Dr. Thorsteinn Gunnarsson for their helpful assistance.

References

1. Henkes H, Bose A, Felber S, et al. Endovascular coil occlusion of intracranial aneurysms assisted by a novel self-expandable nitinol microstent (Neuroform). Intervent Neuroradiol 2002;8(2):107-119.
2. Fiorella D, Albuquerque FC, Han P, McDougall CG. Preliminary experience using the Neuroform stent for the treatment of cerebral aneurysms. Neurosurgery 2004;54(1):6-16; discussion 16-17.
3. Murayama Y, Vinuela F, Tateshima S, et al. Cellular Responses of Bioabsorbable Polymeric Material and Guglielmi Detachable Coil in Experimental Aneurysms. Stroke 2002;33(4):1120-1128.
4. Johnston SC, Higashida RT, Barrow DL, et al. Recommendations for the endovascular treatment of intracranial aneurysms: a statement for healthcare professionals from the Committee on Cerebrovascular Imaging of the American Heart Association Council on Cardiovascular Radiology. Stroke 2002;33(10):2536-2544.
5. Howington JU, Hanel RA, Harrigan MR, et al. The Neuroform stent, the first microcatheter-delivered stent for use in the intracranial circulation. Neurosurgery 2004;54(1):2-5.
6. Roy D, Milot G, Raymond J. Endovascular treatment of unruptured aneurysms. Stroke 2001;32(9):1998-2004.
7. van Swieten JC, Koudstaal PJ, Visser MC, Schouten HJ, van Gijn J. Interobserver agreement for the assessment of handicap in stroke patients. Stroke 1988;19(5):604-607.
8. Newcommon NJ, Green TL, Haley E, Cooke T, Hill MD. Improving the assessment of outcomes in stroke: use of a structured interview to assign grades on the Modified Rankin Scale. Stroke 2003;34(2):377-378.
9. Molyneux A, Kerr R, Stratton I, et al. International Subarachnoid Aneurysm Trial (ISAT) of neurosurgical clipping versus endovascular coiling in 2143 patients with ruptured intracranial aneurysms: a randomised trial. Lancet 2002;360(9342):1267-1274.
10. Hademenos GJ, Massoud TF, Turjman F, Sayre JW. Anatomical and morphological factors correlating with rupture of intracranial aneurysms in patients referred for endovascular treatment. Neuroradiology 1998;40(11):755-760.
11. Turjman F, Massoud TF, Sayre J, Vinuela F. Predictors of aneurysmal occlusion in the period immediately after

endovascular treatment with detachable coils: a multivariate analysis. AJNR Am J Neuroradiol 1998;19(9):1645-1651.
12. Debrun GM, Aletich VA, Kehrli P, et al. Selection of cerebral aneurysms for treatment using Guglielmi detachable coils: the preliminary University of Illinois at Chicago experience. Neurosurgery 1998;43(6):1281-1295; discussion 1296-1287.
13. Hope JK, Byrne JV, Molyneux AJ. Factors influencing successful angiographic occlusion of aneurysms treated by coil embolization. AJNR Am J Neuroradiol 1999;20(3):391-399.
14. Szikora I, Guterman LR, Wells KM, Hopkins LN. Combined use of stents and coils to treat experimental wide-necked carotid aneurysms: preliminary results. AJNR Am J Neuroradiol 1994;15(6):1091-1102.
15. Turjman F, Massoud TF, Ji C, et al. Combined stent implantation and endosaccular coil placement for treatment of experimental wide-necked aneurysms: a feasibility study in swine. AJNR Am J Neuroradiol 1994;15(6):1087-1090.
16. Higashida RT, Smith W, Gress D, et al. Intravascular stent and endovascular coil placement for a ruptured fusiform aneurysm of the basilar artery. Patient report and review of the literature. J Neurosurg 1997;87(6):944-949.
17. Lieber BB, Gounis MJ. The physics of endoluminal stenting in the treatment of cerebrovascular aneurysms. Neurol Res 2002;24 (Suppl 1):S33-S42.
18. Rhee K, Han MH, Cha SH. Changes of flow characteristics by stenting in aneurysm models: influence of aneurysm geometry and stent porosity. Ann Biomed Eng 2002;30(7):894-904.
19. Lylyk P, Cohen J, Ceratto R, Ferrario A, Miranda C. [Endovascular treatment of partially clipped aneurysms]. Medicina (B Aires) 2001;61(1):57-62.
20. Lylyk P, Cohen JE, Ferrario A, Ceratto R, Miranda C. Partially clipped intracranial aneurysm obliterated with combined stent and coil implantation. J Endovasc Ther 2002;9(2):160-164.
21. Lopes DK, Ringer AJ, Boulos AS, et al. Fate of branch arteries after intracranial stenting. Neurosurgery 2003;52(6):1275-1278; discussion 1278-1279.
22. Wanke I, Doerfler A, Schoch B, Stolke D, Forsting M. Treatment of wide-necked intracranial aneurysms with a self-expanding stent system: initial clinical experience. AJNR Am J Neuroradiol 2003;24(6):1192-1199.
23. Phatouros CC, Sasaki TY, Higashida RT, et al. Stent-supported coil embolization: the treatment of fusiform and wide-neck aneurysms and pseudoaneurysms. Neurosurgery 2000;47(1):107-113; discussion 113-105.
24. Leon MB, Baim DS, Popma JJ, et al. A clinical trial comparing three antithrombotic-drug regimens after coronary-artery stenting. Stent Anticoagulation Restenosis Study Investigators. N Engl J Med 1998;339(23):1665-1671.
25. A randomised, blinded, trial of clopidogrel versus aspirin in patients at risk of ischaemic events (CAPRIE). CAPRIE Steering Committee. Lancet 1996;348(9038):1329-1339.
26. Bhatt DL, Bertrand ME, Berger PB, et al. Meta-analysis of randomized and registry comparisons of ticlopidine with clopidogrel after stenting. J Am Coll Cardiol 2002;39(1):9-14.
27. Gurbel PA, Cummings CC, Bell CR, et al. Onset and extent of platelet inhibition by clopidogrel loading in patients undergoing elective coronary stenting: the Plavix Reduction Of New Thrombus Occurrence (PRONTO) trial. Am Heart J 2003;145(2): 239-247.
28. Henkes H, Fischer S, Weber W, et al. Endovascular coil occlusion of 1811 intracranial aneurysms: early angiographic and clinical results. Neurosurgery 2004;54(2):268-280; discussion 280-265.
29. Gum PA, Kottke-Marchant K, Welsh PA, White J, Topol EJ. A prospective, blinded determination of the natural history of aspirin resistance among stable patients with cardiovascular disease. J Am Coll Cardiol 2003;41(6):961-965.
30. Gurbel PA, Bliden KP, Hiatt BL, O'Connor CM. Clopidogrel for coronary stenting: response variability, drug resistance, and the effect of pretreatment platelet reactivity. Circulation 2003; 107(23):2908-2913.
31. Alfke K, Straube T, Dorner L, Mehdorn HM, Jansen O. Treatment of intracranial broad-neck aneurysms with a new self-expanding stent and coil embolization. AJNR Am J Neuroradiol 2004; 25(4):584-591.
32. Chow MM, Woo HH, Masaryk TJ, Rasmussen PA. A novel endovascular treatment of a wide-necked basilar apex aneurysm by using a Y-configuration, double-stent technique. AJNR Am J Neuroradiol 2004;25(3):509-512.
33. Benitez RP, Silva MT, Klem J, Veznedaroglu E, Rosenwasser R. Endovascular occlusion of wide-necked aneurysms with a new intracranial microstent (Neuroform) and detachable coils. Neurosurgery 2004;54(6):In Press.