The purpose of this paper is to present the experience of eight initial centers participating in a United States Food and Drug Administration–approved Guglielmi detachable coil (GDC) clinical study for the treatment of aneurysms. This report summarizes the perioperative results from eight initial interventional neuroradiology centers in the United States. The report focuses on 403 patients who presented with acute subarachnoid hemorrhage from a ruptured intracranial aneurysm. These patients were treated within 15 days of the primary intracranial hemorrhage and were followed until they were discharged from the hospital or died.

Seventy percent of the patients were female and 30% were male. The patients’ mean age was 58 years old. Aneurysm size was categorized as small (60.8%), large (34.7%), and giant (4.5%); and neck size was categorized as small (53.6%), wide (36.2%), fusiform (6%), and undetermined (4.2%). Fifty-seven percent of the aneurysms were located in the posterior circulation and 43% in the anterior circulation.

Eighty-two patients were classified as Hunt and Hess Grade I (20.3%), 105 Grade II (26.1%), 121 Grade III (30%), 69 Grade IV (17.1%), and 26 Grade V (6.5%). All patients in this study were excluded from surgical treatment either because of anticipated surgical difficulty (69.2%), attempted and failed surgery (12.7%), the patient’s poor neurological (12.2%) or medical (4.7%) status, and/or refusal of surgery (1.2%).

The GDC embolization was performed within 48 hours of primary hemorrhage in 147 patients (36.5%), within 3 to 6 days in 156 patients (38.7%), 7 to 10 days in 71 patients (17.6%), and 11 to 15 days in 29 patients (7.2%). Complete aneurysm occlusion was observed in 70.8% of small aneurysms with a small neck, 35% of large aneurysms, and 50% of giant aneurysms. A small neck remnant was observed in 21.4% of small aneurysms with a small neck, 57.1% of large aneurysms, and 50% of giant aneurysms. Technical complications included aneurysm perforation (2.7%), unintentional parent artery occlusion (3%), and untoward cerebral embolization (2.4%). There was an 8.9% immediate morbidity rate related to the GDC technique. Seven deaths were related to technical complications (1.7%) and 18 (4.4%) to the severity of the primary hemorrhage.

The findings of this study demonstrate the safety of the GDC system for the treatment of ruptured intracranial aneurysms in anterior and posterior circulations. The authors believe additional randomized studies will further identify the role of this technique in the management of acutely ruptured intracranial aneurysms.

KEY WORDS • Guglielmi detachable coil embolization • acute subarachnoid hemorrhage • aneurysm occlusion • aneurysm perforation • morbidity • mortality • outcome
Prospective randomized trials are needed to identify more fully the role of this technique in the management of these patients. The involved endovascular therapists used a similar, reproducible endovascular GDC technique with limited individual variations and followed a Food and Drug Administration–approved protocol. Ongoing technical developments in the GDC system will continue to affect the morphological and clinical outcome of GDC embolization of intracranial aneurysms. Prospective randomized trials are needed to identify more fully the role of this technique in the management of acutely ruptured intracranial aneurysms.

Clinical Material and Methods

Patient Population

From December 1990 to July 1995, 403 patients presenting with an acute ruptured intracranial aneurysm were treated using the GDC technique in eight hospitals designated Interventional Neuroradiology Centers in the United States. All aneurysms were treated within 15 days of rupture. All endovascular therapists had received preclinical laboratory training with the GDC system.

Patients’ clinical presentation, technical data on GDC performance, and immediate clinical outcomes were documented using a Food and Drug Administration–approved protocol. The two most important factors that influenced the selection of the participating centers were the recognized expertise of the endovascular team and the availability of an experienced vascular neurosurgical unit. This study group consisted of patients initially managed at the university centers or referred by neurosurgeons from outside institutions.

Two hundred eighty-three patients were female (70.2%) and 120 were male (29.8%). Twenty-one patients (5.2%) were 30 years old or younger, 161 (40%) were between 31 and 50, 165 (40.9%) were between 51 and 70, and 56 (13.9%) were between 71 and 90 years of age.

The GDC Procedure

A complete cerebral angiographic series was performed as soon as the patient was clinically stable and able to be moved to the neuroangiography suite. This series included anterior and posterior fossa circulation, morphological evaluation of the ruptured aneurysm, presence of arterial vasospasm, and angiographic evidence of an intracranial hematoma or acute hydrocephalus.

In most cases, GDC embolization of the ruptured aneurysm was performed immediately after the diagnostic cerebral angiogram had been reviewed to protect the patient from aneurysm rerupture and/or to treat aggressively present or potential delayed cerebral ischemia due to symptomatic arterial vasospasm.

The endovascular procedures were all performed in the neuroangiography suite and the type of anesthesia was selected according to the patient’s cooperation and clinical condition. In the late phases of our experience, we favored general over neuroleptic analgesia because it provided better control of the patient’s clinical condition and potential technical complications (aneurysm perforation, untoward cerebral ischemia, and so forth) and increased the quality of roadmapping. At most clinical sites, the microcatheter was positioned in the aneurysm by means of high-quality fluoroscopy and roadmapping, thus decreasing the chances of aneurysm perforation. The GDC coils were sequentially delivered using the roadmapping and the procedure was considered terminated when a solid cast of the aneurysm was achieved or when herniation of the last GDC coil in the parent artery was observed.

The GDC Tracker-10 catheter and GDC-10 coils, because of their small size and suppleness, were used in most acute aneurysms. The GDC-18 system was selectively chosen for use in ruptured large or giant aneurysms, in which the possibility of touching the wall of the aneurysm with the microcatheter or GDC coils was small in the initial phases of the embolization.

In patients having aneurysms with a wide neck and/or in patients with poor neurological status, the procedure was sometimes discontinued when the dome, body, and identified ruptured site of the aneurysm were occluded, in

F. Viñuela, G. Duckwiler, and M. Mawad

TABLE 1

Aneurysm location in 403 patients with acute aneurysmal SAH

<table>
<thead>
<tr>
<th>Location</th>
<th>No. of Patients</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>posterior circulation (230 aneurysms [57%])</td>
<td>127</td>
<td>31.5</td>
</tr>
<tr>
<td>basilar tip</td>
<td>25</td>
<td>6.2</td>
</tr>
<tr>
<td>vertebral</td>
<td>23</td>
<td>5.7</td>
</tr>
<tr>
<td>posterior cerebral</td>
<td>21</td>
<td>5.2</td>
</tr>
<tr>
<td>anterior inferior cerebellar</td>
<td>16</td>
<td>4.0</td>
</tr>
<tr>
<td>superior cerebellar</td>
<td>15</td>
<td>3.7</td>
</tr>
<tr>
<td>basilar trunk</td>
<td>7</td>
<td>1.7</td>
</tr>
<tr>
<td>anterior circulation (173 aneurysms [43%])</td>
<td>47</td>
<td>11.7</td>
</tr>
<tr>
<td>carotid/periophthalmic</td>
<td>54</td>
<td>13.4</td>
</tr>
<tr>
<td>anterior communicating</td>
<td>53</td>
<td>13.2</td>
</tr>
<tr>
<td>posterior communicating/anterior choroidal</td>
<td>11</td>
<td>2.7</td>
</tr>
<tr>
<td>middle cerebral artery bifurcation</td>
<td>8</td>
<td>2.0</td>
</tr>
<tr>
<td>internal carotid artery bifurcation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
spite of leaving a discernible neck remnant. Often this emergency embolization was then complemented with a second GDC embolization or postembolization surgical clipping after the patient recovered from the primary intracerebral hemorrhage. Some patients did not receive any coils because of technical difficulties such as vessel tortuosity, wide neck, and instability of coil placement. In patients with ruptured dissecting or fusiform vertebral or posterior cerebral aneurysms the parent artery was purposely occluded at the same time the aneurysm was packed with GDCs. After the emergency aneurysm embolization, the patients were returned to the neurological intensive care unit or neurosurgical ward, where they remained under neurosurgical care until they were discharged or died.

**Description of the Aneurysms**

**Size of the Aneurysm.** Two hundred forty-five aneurysms (60.8%) were small (4–10 mm in their largest diameter); 140 (34.7%) were large (11–25 mm); and 18 (4.5%) were giant (>25 mm). Four of the giant aneurysms were partially thrombosed.

**Size of the Neck.** Two hundred sixteen aneurysms (53.6%) had a small neck (≤4 mm); 146 aneurysms (36.2%) had a wide neck (>4 mm); 24 aneurysms (6%) were fusiform; and in 17 aneurysms it was not possible to identify the neck on cerebral angiography.

**Location of the Aneurysm.** Fifty-seven percent of the aneurysms were in the posterior circulation (Fig. 1) and 43% were located in the anterior circulation. The most common location was the basilar artery bifurcation (31.5%), followed by the anterior communicating (13.4%), and posterior communicating (13.2%) arteries (Table 1).

**Hunt and Hess Grading**

Eighty-two patients (20.3%) were classified as Grade I, 105 (26.1%) as Grade II, 121 (30%) as Grade III, 69 (17.1%) as Grade IV, and 26 patients (6.5%) as Grade V.

**Timing of Treatment**

One hundred forty-seven patients (36.5%) underwent GDC aneurysm occlusion within 48 hours after the primary hemorrhage; 156 (38.7%) underwent GDC aneurysm occlusion between 3 and 6 days posthemorrhage; 71 (17.6%) underwent GDC aneurysm occlusion 7 to 10 days posthemorrhage; and 29 (7.2%) were treated between 11 and 15 days posthemorrhage. All patients were treated immediately on their referral to the participating centers. Delay in treatment was due only to referral patterns and not to any decision or randomization on the part of the investigators.

**Patient Selection**

Surgical exclusion of the 403 patients was the primary factor considered in the selection of the GDC technique as the therapeutic alternative. The causes for surgical exclusion in this group included: anticipated surgical difficulty because of aneurysm size or location in 279 patients (69.2%); attempted surgical exploration in 51 patients (12.7%) (Fig. 2); poor neurological grade in 49 patients (12.2%); poor medical status in 19 patients (4.7%); and refusal of surgery by five patients (1.2%).

**Results**

The GDC embolization of the ruptured aneurysm was preceded by cerebral angiography, which was performed as described previously to determine the view that best delineated the neck of the aneurysm from the surrounding arteries. The same angiographic view was used to assess postembolization anatomical results (Fig. 3).

**Morphological Results**

Immediate postembolization angiographic results varied widely among institutions. For example, complete occlusion of small aneurysms with a small neck ranged between 57% and 85%, with an average of 70.8%. These morphological results are as follows.

**Small Aneurysms With a Small Neck (168 Aneurysms).** Complete aneurysm occlusion was observed in 119 cases (70.8%); a neck remnant was observed in 36 cases (21.4%) (Fig. 4); the body of the aneurysm was visualized in seven cases (4.2%); and an attempted embolization (inability to place coils due to technical difficulties such as vessel tortuosity, wide neck, or instability of coil placement) was documented in six cases (3.6%).
Small Aneurysms With a Wide Neck (77 Aneurysms). Complete aneurysm occlusion was shown in 24 cases (31.2%); a neck remnant was identified in 32 cases (41.6%); the body of the aneurysm was shown in eight cases (10.4%); and an attempted embolization was observed in 13 cases (16.9%).

Large Aneurysms (140 Aneurysms). Complete occlusion was shown in 49 cases (35%); a neck remnant was seen in 80 cases (57.1%); the aneurysm body filling was seen in seven cases (5%); and an attempted embolization was described in four cases (2.9%).

Giant Aneurysms (18 Aneurysms). Complete aneurysm occlusion was shown in nine cases (50%) and a neck remnant was observed in nine other cases (50%).

Postembolization Surgical Procedures

Postembolization neurosurgical procedures were performed in 33 patients (8.19%). These procedures included: surgical clipping of the ruptured aneurysm in 21 patients (5.2%); surgical trapping of the aneurysm with an external carotid–internal carotid artery bypass in three patients (0.74%); evacuation of cerebral hematoma in six patients (1.49%); and postembolization surgical removal of a brain arteriovenous malformation in one patient (0.25%).

Technical Complications

Thirty-seven technical complications (9.18%) were observed during the GDC occlusion of these 403 acute aneurysms. The complications included: 11 aneurysm perforations (2.73%); 10 cerebral embolizations (2.48%); 12 unintentional parent artery occlusions (2.98%); two coil migrations (0.50%); and two cases of arterial vasospasm (0.50%). The time of these technical complications relative to the time of rupture is depicted in Table 2. Thirteen technical complications were observed in aneurysms embolized within 48 hours of rupture; 10 in aneurysms treated within 3 to 6 days; nine in the group treated between 7 and 10 days posthemorrhage; and five in the group treated 11 to 15 days posthemorrhage.

Immediate Clinical Outcome

All patients were evaluated prior to their discharge from the hospital. Three hundred forty-two patients (84.9%) improved or remained neurologically unchanged, 36 (8.9%) experienced postembolization clinical deterioration, and 25 (6.2%) died within 1 week of the GDC procedure.

As categorized by physicians participating in this study, the neurological deterioration was mild in 10 (2.48%), moderate in 15 (3.72%), and severe in 11 (2.73%) patients.

Seven (1.74%) of the deaths were related to GDC technical complications and 18 (4.47%) were associated with the severity of the primary intracranial hemorrhage.

Table 3 outlines the immediate clinical outcomes as they related to the patients’ Hunt and Hess clinical grades. There were 6.1% morbidity and 1.2% mortality rates in Grade I patients, 8.6% morbidity and 0% mortality rates in Grade II, 10.7% morbidity and 5.8% mortality rates in Grade III, 8.7% morbidity and 11.6% mortality rates in Grade IV, and 11.5% morbidity and 34.6% mortality rates in Grade V patients.

Table 4 reviews morbidity and mortality rates by aneurysm location. There were 8.1% morbidity and 6.4% mortality rates in anterior circulation aneurysms and 9.6% morbidity and 6.1% mortality rates in posterior circulation aneurysms.

Discussion

Acute SAH from a ruptured intracranial aneurysm remains a catastrophic event in spite of the early timing of surgical clipping, development of microsurgical techniques, and aggressive medical and/or intravascular management of acute complications. No more than one of three patients having a ruptured intracranial aneurysm will make a satisfactory recovery.17,18

The most important factors that determine the patient’s clinical outcome are brain damage from the primary hemorrhage, aneurysm rebleeding, and delayed cerebral ischemia related to arterial vasospasm and hydrocephalus. In 1975, Norlén (unpublished data) pioneered the use of early surgical clipping of the aneurysm. The neurosurgical community has come to recognize the benefits of early surgical intervention and it is now the standard of care.

The literature favoring emergency surgical clipping of the aneurysm emphasizes the significant mortality and morbidity rates from aneurysm rebleeding and delayed cerebral ischemia caused by vasospasm that occurs during the waiting period.
Guglielmi detachable coil embolization of acute intracranial aneurysm

We incorporated the principle of early intravascular occlusion of ruptured intracranial aneurysms with GDC coils to eliminate the risk of aneurysm rebleeding and to treat delayed cerebral ischemia that is caused by symptomatic arterial vasospasm aggressively.

Other methods of treatment reported in the literature include the use of detachable balloons,3,7,12 pushable microcoils,3,11 and liquid embolic agents20 to occlude intracranial aneurysms with preservation of the parent artery. In 1991 and 1992, Guglielmi and colleagues9,10 reported the use of detachable platinum microcoils to occlude intracranial aneurysms. These microcoils are deposited in the aneurysm and detached by means of electrolysis and electrothrombosis. This endovascular technique offers a controllable and delicate occlusion of the aneurysm that appears to be appropriate for ruptured aneurysms in the acute phase of SAH. It is in this type of clinical setting that we expected the GDC technique to be exposed to its highest technical and clinical challenges.

The GDC technique was used in patients who had previously undergone surgical exploration or who were found to harbor aneurysms with potentially high rates of surgical morbidity or mortality. This specific form of patient selection explains why 57% of the 403 ruptured aneurysms were in the posterior circulation and why the basilar bifurcation aneurysm was the most common one (31.5%).

The frequency of vertebrobasilar aneurysms in surgical series ranges between 8% and 12%, and they classically present more challenging surgical problems when compared with aneurysms situated in the anterior circulation. The geometry of the major arteries in the posterior circulation is particularly beneficial for intravascular navigation, selective catheterization, and GDC occlusion of aneurysms. The basilar artery courses in a straight line and the curvature of the supraclinoid internal carotid artery and the angle of origin of supraclinoid aneurysms (superior hypophyseal, carotidopthalmic, posterior communicating, and anterior choroidal aneurysms) are more challenging; however, the shape of the present generation of microcatheters can be tailored to the geometry of the aneurysm to be catheterized.

Clinical Results

We observed 37 technical complications (9.18%) that were related to GDC embolization of these 403 acute ruptured aneurysms. They included aneurysm perforation, cerebral clot embolization, and parent artery occlusion.

Aneurysm perforation was documented in 11 (2.73%) of 403 patients. It was observed in three (2.04%) of 147 aneurysms embolized in the first 2 days after SAH, in three (1.92%) of 156 aneurysms treated between 3 and 6 days, in four (5.6%) of 71 aneurysms treated between 7 and 10 days, and in one (3.5%) of 29 aneurysms embolized between 11 and 15 days after the primary intracranial hemorrhage. This technical complication precipitated the patient’s death in six patients (1.49%) and it was controlled by further coil embolization in five patients. The six deaths occurred in patients who had been classified as Hunt and Hess Grade IV or V. Patients who survived the aneurysm perforation were classified as Hunt and Hess Grade I or II and the perforation occurred with coils already deposited in the dome and body of the aneurysm. Even when aneurysm perforation was noted, GDC delivery continued until a complete aneurysm occlusion was observed on cerebral angiography. In the five surviving patients an immediate head computerized tomography scan showed that the intracranial hemorrhage mainly involved the subarachnoid space or ventricles without intraparenchymal blood dissection.

Batjer and Samson1 reported an intraoperative aneurysm rupture in 58 (19%) of 307 patients. This rupture occurred before aneurysm dissection in 7%, during aneurysm dissection in 48%, and during clip application in 45% of cases. This surgical technical complication added a 16% morbidity to the 22% overall morbidity rate observed in those patients who had an uneventful aneurysm surgical clipping.

Nine of the 11 aneurysm perforations in this report occurred in small aneurysms. In one case the perforation occurred after delivery of five coils to a small basilar tip aneurysm. The tip of the microcatheter was in the neck of the aneurysm. The perforation occurred at the dome and not at the base of the aneurysm, as observed on a control angiogram. We believe the coils’ mesh was forced through the fresh clot while we were trying to achieve complete aneurysm obliteration. In selected cases, it may be safer to leave a small neck remnant in the first embolization than to achieve a complete aneurysm obliteration because of the increased risk of aneurysm perforation. The neck remnant may be occluded later by a second embolization or by surgical clipping with a better brain condition and clinical status. Our long-term angiographic and clinical follow-up evaluation in patients with stabilized neck remnants demonstrated no repeated aneurysm.

TABLE 3

<table>
<thead>
<tr>
<th>Grade</th>
<th>No. of Patients</th>
<th>Outcome (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>82</td>
<td>76 (92.7)</td>
</tr>
<tr>
<td>II</td>
<td>105</td>
<td>96 (91.4)</td>
</tr>
<tr>
<td>III</td>
<td>121</td>
<td>101 (83.5)</td>
</tr>
<tr>
<td>IV</td>
<td>69</td>
<td>55 (79.7)</td>
</tr>
<tr>
<td>V</td>
<td>26</td>
<td>14 (53.8)</td>
</tr>
<tr>
<td>total</td>
<td>403</td>
<td>342 (84.9)</td>
</tr>
</tbody>
</table>

TABLE 4

<table>
<thead>
<tr>
<th>Location of Aneurysm</th>
<th>No. of Patients</th>
<th>Outcome (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>anterior circulation</td>
<td>173</td>
<td>148 (85.5)</td>
</tr>
<tr>
<td>posterior circulation</td>
<td>230</td>
<td>194 (84.3)</td>
</tr>
<tr>
<td>total</td>
<td>403</td>
<td>342 (84.9)</td>
</tr>
</tbody>
</table>

TABLE 4 Morbidity and mortality in 403 patients with acute aneurysmal SAH by location of aneurysm
Vertebral angiogram obtained after. 5. Angiograms documenting postembolization angioplasty IG. Lateral right in-

Upper Left: Postembolization angiogram demonstrates GDC occlusion of the supraclinoid internal carotid artery (white arrows). Lower Right: Vertebral angiogram obtained after mechanical angioplasty demonstrates successful dilation of spastic arteries. The patient exhibited significant clinical improvement after the angioplasty.

Fig. 5. Angiograms documenting postembolization angioplasty of severe symptomatic vasospasm. Upper Left: Lateral right internal carotid angiogram shows a small sacular posterior communicating artery aneurysm (black arrow) with severe vasospasm of the supraclinoid internal carotid artery (white arrows). Upper Right: Postembolization angiogram demonstrates GDC occlusion of the aneurysm (straight arrow) and mechanical angioplasty of the supraclinoid internal carotid artery (curved arrow). Lower Left: Right vertebral angiogram shows severe, diffuse vasospasm involving the distal basilar artery and the proximal posterior cerebral arteries. Lower Right: Vertebral angiogram obtained after mechanical angioplasty demonstrates successful dilation of spastic arteries. The patient exhibited significant clinical improvement after the angioplasty.

rapture up to 3 years after the initial rupture and treatment (data not published).

Cerebral clot embolization was observed in 10 patients (2.48%). It was seen more commonly within 48 hours after the procedure and particularly in wide-necked aneurysms with a small residual neck. It appears to be related to the development of further thrombosis in the residual neck and migration of a fresh clot intracranially. The migrating clot is usually small and it tends to occlude small cerebral arteries, producing confined, small cerebral infaracts easily seen on magnetic resonance imaging.

Our present approach to decrease this complication includes the recognition of its potential development on the final cerebral angiogram and the use of temporary heparinization (up to 48 hours) and long-term aspirin therapy.

This complication may also be observed after surgical clipping of an aneurysm. It is more frequently observed in large aneurysms with a wide, calcified neck that require placement of a surgical clip more than once and/or the use of multiple clips. Sometimes, it is difficult to differentiate the acute cerebral ischemia related to cerebral clot embolization from ischemia related to surgical brain retraction or arterial vasospasm.

Unintentional parent artery occlusion occurred in 12 patients (2.98%). It was produced by migration of GDC coils into the parent artery, by the development of a late clot in the neck of the aneurysm, or by a combination of the two.

In some cases the parent artery occlusion was well tolerated by the patient because of the presence of sufficient arterial collateral vessels distal to the arterial occlusion. In cases without appropriate arterial collateral vessels or in occlusion of perforating arteries (lenticulostriate, thalamoperforators, and so forth) it is mandatory to reopen the occluded artery by endovascular (balloon angioplasty or intraarterial thrombolysis) or surgical (surgical removal of coil and clipping) techniques.

In patients with ruptured dissecting or fusiform vertebral or posterior cerebral aneurysms, the parent artery was purposefully occluded at the same time the aneurysm was packed with GDCs. The occlusion of the parent artery was performed after evaluating the presence of arterial collateral vessels to eliminate the possibility of postembolization brain infarction or ischemia. The GDC packing of the ruptured aneurysm with concomitant endovascular trapping of the parent artery has been particularly useful in treating ruptured dissecting aneurysms of the distal vertebral artery. This potentially lethal ruptured aneurysm may reach the vertebrobasilar junction and in those circumstances it can be difficult to trap. Endovascular GDC embolization allows the delivery of coils to the most distal part of the aneurysm while checking the blood flow through the contralateral vertebral artery. It is important not to leave a distal portion of the aneurysm exposed to the blood circulation because the aneurysm can rupture again, with fatal consequences.

Table 3 details the technical complications in this series of patients as they relate to the day of the hemorrhage. In this series, we have not demonstrated a significantly increased incidence of complications in GDC embolizations performed within 2 days of the SAH (13 [8.8%] technical complications in 147 patients) when compared with technical complications observed in the other groups. These data are very reassuring because they show that GDC embolization of an acutely ruptured aneurysm is safe to perform when it is most needed, without increasing the chances of aneurysm rerupture. It appears to provide a substantial benefit to the management of patients with an acute SAH in whom surgery could not be performed to protect them from a frequently severe rehemorrhage or symptomatic vasospasm (Fig. 5).

Morphological Results

All patients underwent immediate postembolization angiography using a radiographic projection that cleared the neck of the aneurysm from surrounding arteries. This approach identified numerous small residual necks that would have been missed if only standard views had been used. The percentage of complete anatomical occlusions was highest in small aneurysms with small necks.

The relatively limited number of complete aneurysm occlusions in this series of acute aneurysms also shows an appropriately conservative approach in the use of this new technology. In some complex aneurysms it was decided to perform an incomplete aneurysm occlusion to decrease the chances of rehemorrhage. A more aggressive endovascular and/or surgical approach was later performed when
the patient recovered from the acute phase of subarachnoid hemorrhage.

Most patients had at least a 6-month clinical follow-up period and, in some cases, the patients had postembolization clinical evaluations up to 56 months later. During this period, nine incompletely embolized aneurysms rebled (2.2%).

Juvela\textsuperscript{5} reported a 22.5\% incidence of aneurysm rebleeding in 236 untreated patients within 6 months of the primary hemorrhage. He described peaks of rebleeding at 24 hours (4.1\%) and at 7 days posthemorrhage, with a rebleeding mortality rate of 74\%. The cumulative rate of rebleeding at 14 days was 27.7\%. Forty percent of patients died at 6 months and 17\% died within the first 48 hours.

A comparison of Juvela’s\textsuperscript{15} results and those of others\textsuperscript{13,14} describing the natural history of the disease with the results achieved in this series allows us to conclude that the GDC embolization performed in these 403 patients presenting with acute SAH helped to improve their natural clinical course. These positive results were achieved not only in aneurysms that were completely occluded, but also in aneurysms in which a residual neck was observed. We recommend 1-, 6-, and 12-month angiographic follow-up evaluations and complete endovascular or surgical obliteration of the residual neck of the aneurysm, when technically feasible and clinically indicated.

\textbf{Morbidity and Mortality Rates}

The sample of this population of patients with acute SAH treated with GDC coils is unique and does not represent the normal population of patients with ruptured aneurysm. These patients underwent GDC embolization of their aneurysms after having been excluded from surgical alternatives for reasons previously described. In spite of this, we believe that these data offer a realistic review of the advantages and limitations of the GDC system for the treatment of all acute aneurysms.

We observed overall rates of 8.9\% morbidity and 6.2\% mortality in these 403 acute ruptured aneurysms embolized with the GDC technique.

Säveland, et al.,\textsuperscript{22} in 1992 reported data on management outcome of patients with acute SAH from a prospective study of neurosurgical units in Sweden spanning a 1-year period. In their admission protocol, these researchers emphasized ultrathin referral, earliest possible surgery, and aggressive antithrombotic surgery. Sixty nine percent of their patients had surgery within 1 day of SAH. Thirty percent were classified as Hunt and Hess Grade I, 37\% as Grade II, 16\% as Grade III, 23\% as Grade IV, and 11\% as Grade V. Fifty-two percent of patients underwent surgery within 3 days of SAH, 8.9\% underwent surgery between 4 and 6 days posthemorrhage, and 14.4\% had the aneurysm clipped 7 days after hemorrhage; in 15\% of patients surgery was not performed. The authors reported overall rates of 23\% morbidity and 21\% mortality.

Seiler, et al.,\textsuperscript{23} in 1988 reported overall rates of 14\% morbidity and 27\% mortality in 153 patients with acute SAH due to aneurysm rupture treated with early surgery, a course of intravenous nimodipine, and use of transcerebral Doppler ultrasound. Gilbsbach and Harders\textsuperscript{8} in 1989 reported an overall 16\% mortality rate in 116 consecutive patients with acute SAH treated with early surgery and nimodipine. The two most important determinants of this mortality rate were the primary brain damage produced by the SAH and surgical complications (8\%).

Guglielmi detachable coil embolization may have some advantages over the surgical clipping of acute aneurysms. The procedure is performed without the need of mechanical retraction on a brain potentially edematous and/or ischemic. Brain surgical resection or occlusion of major cortical veins is not required to reach the aneurysm. Säveland, et al.,\textsuperscript{22} on the other hand, stated that the morbidity rate related to the surgical clipping of an acute aneurysm is similar to the one related to a “cold” aneurysm if an appropriate surgical technique is applied. Ljunggren, et al.,\textsuperscript{17} believe that the “tight brain” observed in acute SAH is almost always found to be related to an acute stagnation of bloody cerebrospinal fluid and that it can be well controlled by cautious opening of the cisterns and intraoperative evacuation of hemorrhagic cerebrospinal fluid.

Arterial perforating vessels may be accidentally occluded with either technique, but the endovascular approach appears to be more advantageous in the identification and protection of deep-seated perforating vessels such as those related to vertebrobasilar aneurysms. These perforating vessels may be occluded by the GDC system if there is untoward coil migration into the parent artery or clot progression in the neck of the aneurysm.

Additionally, the GDC embolization of an acute aneurysm may be performed after induction of neuroleptic analgesia in the patient. This alternative is very useful in patients suffering from severe cardiovascular and/or respiratory failures. Staging of GDC embolization may also be advantageous in very sick patients with complex intracranial aneurysms. This technique is particularly useful in ruptured large or giant aneurysms with a wide neck. In those cases, it may be advisable to perform an incomplete embolization of the aneurysm in the acute phase of SAH, wait for the GDC coils to be repacked by the blood flow, and perform a definitive second embolization or final surgical clipping when the acute morbidity of the SAH has been overcome.

\textbf{Conclusions}

In conclusion, we present morphological and clinical data related to the GDC embolization of 403 patients presenting with an acute aneurysmal SAH. The selection of this group of patients was mainly determined by relatively high risks of morbidity or mortality linked to the neurosurgical clipping of the ruptured aneurysm. This selection process explains the relatively high number of large and giant aneurysms as well as the higher incidence of vertebrobasilar aneurysms.

The morphological results obtained in this series show that the GDC technique is particularly effective in small aneurysms with a small neck and less effective in large or giant aneurysms or in small aneurysms with a wide neck. The angiographic depiction of a small neck remnant was enhanced by using special radiological projections that cleared the aneurysm neck from the surrounding arteries. The authors predict a progressive improvement in the final anatomical results with increasing experience of the
endovascular therapist as well as technical refinements of the delivery systems and GDC coils.

The rebleeding rate during the 6-month clinical follow-up period allows us to conclude that GDC embolization of acute aneurysms improves the natural history of the disease, even in those cases in which an incomplete GDC embolization of the aneurysm was achieved. We do not believe that these patients are completely cured but they may have a more successful second embolization or final surgical clipping of the residual neck, after overcoming the acute critical period of the SAH.

The morbidity and mortality rates related to GDC embolization of an acute aneurysm are lower than those associated with an untreated acute ruptured aneurysm. This technique may be safely applied within hours of the aneurysm rupture with a low probability of aneurysm perforation.

The results of this study indicate that GDC obliteration of a nonsurgical acute aneurysm decreases the possibility of a repeated aneurysm rupture and allows an aggressive medical and/or endovascular therapy of delayed cerebral ischemia due to symptomatic vasospasm. Randomized, prospective, multicenter studies are needed to define more clearly the role of the GDC embolization of acute intracranial aneurysm.

Appendix

The following investigators participated in this study and provided data for this publication:

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