AJNR

Periprocedural Morbidity and Mortality Associated with Endovascular Treatment of Intracranial Aneurysms

Hae-Kwan Park, Michael Horowitz, Charles Jungreis, Julie Genevro, Christopher Koebbe, Elad Levy and Amin Kassam

AJNR Am J Neuroradiol 2005, 26 (3) 506-514
http://www.ajnr.org/content/26/3/506

AJNR Am J Neuroradiol 26:506–514, March 2005

Periprocedural Morbidity and Mortality Associated with Endovascular Treatment of Intracranial Aneurysms

Hae-Kwan Park, Michael Horowitz, Charles Jungreis, Julie Genevro, Christopher Koebbe, Elad Levy, and Amin Kassam

BACKGROUND AND PURPOSE: **Despite experience and technological improvements, endovascular treatment of intracranial aneurysms still has inherent risks. We evaluated cerebral complications associated with this treatment.**

METHODS: **From October 1998 to October 2002, 180 consecutive patients underwent 131 procedures for 118 ruptured aneurysms and 79 procedures for 72 unruptured aneurysms. We retrospectively reviewed their records and images to evaluate their morbidity and mortality.**

RESULTS: **Thirty-seven (17.6%) procedure-related complications occurred: 27 and six with initial embolization of ruptured and unruptured aneurysms, respectively, and four with re-treatment. Complications included 22 cerebral thromboembolisms, nine intraprocedural aneurysm perforations, two coil migrations, two parent vessel injuries, one postprocedural aneurysm rupture, and one cranial nerve palsy. Fourteen complications had no neurologic consequence. Three caused transient neurologic morbidity; 10, persistent neurologic morbidity; and 10, death. Procedure-related neurologic morbidity and mortality rates, respectively, were as follows: overall, 4.8% and 4.8%; ruptured aneurysms, 5.9% and 7.6%; unruptured aneurysms, 1.4% and 1.4%; and re-treated aneurysms, 10% and 0%. Combined procedure-related morbidity and mortality rates for ruptured, unruptured, and re-treated aneurysms were 13.5%, 2.8%, and 10%, respectively. Nonprocedural complications attributable to subarachnoid hemorrhage in 118 patients with ruptured aneurysm were early rebleeding before coil placement (0.9%), symptomatic vasospasm (5.9%), and shunt-dependent hydrocephalus (5.9%); mortality from complications of subarachnoid hemorrhage itself was 11.9%.**

CONCLUSION: **Procedural morbidity and mortality rates were highest in ruptured aneurysms and lowest in unruptured aneurysms. Morbidity rates were highest in re-treated aneurysms and lowest in unruptured aneurysms. No procedural mortality occurred with re-treated aneurysms. The main cause of morbidity and mortality was thromboembolism.**

During the previous decade, the endovascular treatment of an intracranial aneurysm by using detachable coils has rapidly evolved. Despite increasing clinical experience and technological improvements, endovascular treatment still has inherent risks of morbidity and mortality (1–6). The purpose of this study was to retrospectively review our experience with periprocedural complications associated with endovascular coil embolization of intracranial aneurysms and to provide detailed data on the types and frequency of complications observed. This information is useful for advising patients about the general risks of endovascular treatment.

Methods

From October 1998 to October 2002, a total of 210 detachable coil embolization procedures were performed to treat 190 aneurysms (118 ruptured, 72 unruptured) in 180 consecutive patients at our institution. Two endovascular surgeons (M.H., C.J.) performed the procedures.

We retrospectively reviewed the medical records, radiographic studies, and endovascular procedure reports of 118 patients with 123 aneurysms who presented with subarachnoid hemorrhage (SAH) attributable to aneurysm rupture. Fifty patients (27.8%) were male and 130 (72.2%) female. Their ages ranged from 25 to 91 years (mean, 56.9 years).

Received February 24, 2004; accepted after revision May 19.

From the Department of Neurosurgery, St Mary's Hospital, Seoul, South Korea (H.-K.P.), and the Departments of Neurosurgery (M.H., C.J., A.K., C.K., E.L.), Radiology (M.H., C.J.), and Otolaryngology (A.K.), University of Pittsburgh Medical Center (J.G.), Pittsburgh, PA.

Address reprint requests to Michael Horowitz, MD, Department of Neurosurgery, Presbyterian University Hospital, Suite B400, University of Pittsburgh Medical Center, 200 Lothrop Street, Pittsburgh, PA.

TABLE 1: Locations of aneurysms

Location	Ruptured (n = 118)	Unruptured (n = 72)
Anterior circulation	88 (74.6)	53 (73.6)
Anterior choroidal artery	4	2
Posterior communicating artery	3	4
Paraclinoid ICA	7	32
ICA bifurcation	5	2
A1 segment of the ACA	1	1
Anterior communicating artery	45	6
Distal ACA	6	1
M1 segment of the MCA	1	0
MCA bifurcation	6	5
Posterior circulation	30 (25.4)	19 (26.4)
Basal artery tip	16	11
Distal posterior cerebral artery	3	1
Superior cerebellar artery	2	3
Basal artery trunk	1	1
Vertebrobasilar junction	1	0
Posterior inferior cerebellar artery	7	3

Note.—Data in parentheses are percentages. ACA is anterior cerebral artery; ICA, internal carotid artery; and MCA, middle cerebral artery.

The clinical status of patients with SAH was assessed by using the Hunt and Hess scale (7): 22 were grade I; 25, grade II; 36, grade III; 30, grade IV; and five, grade V. In 62 patients, 67 aneurysms were discovered incidentally after imaging for other unrelated medical conditions. In nine of 190 aneurysms (eight ruptured and one unruptured), an attempt at surgical clip placement was unsuccessful before coil embolization. Four (3.4%) of 118 patients with SAH had multiple aneurysms (two aneurysms in three patients each and three aneurysms in one patient). Five of (8%) 62 patients without SAH had multiple aneurysms (two aneurysms in each patient). In the four patients with multiple aneurysms and SAH, the ruptured aneurysm could be identified with a high degree of certainty on the basis of clinical, CT, and angiographic findings (8–10). Of 118 ruptured aneurysms, 114 were treated within 72 hours, and four were treated after 72 hours of SAH. In patients with multiple aneurysms, only one aneurysm was treated during a single procedure. Unruptured aneurysms associated with SAH from a ruptured aneurysm were treated electively after the patient clinically recovered from the ruptured lesion. There was no postoperative bleeding from any untreated aneurysm that was preoperatively thought to be asymptomatic.

A total of 210 procedures were performed to treat 190 aneurysms (131 procedures for 118 ruptured aneurysms and 79 for 72 unruptured aneurysms). A balloon remodeling technique was used in 12 procedures. Among 190 aneurysms treated with endovascular embolization, 16 (8.4%) required more than one session to complete the treatment, 14 aneurysms required two sessions, and two required four. Technical success was defined as the ability to superselectively catheterize and deploy more than one coil into the aneurysm. Technical failure occurred in three procedures: two for initial embolization of an unruptured aneurysm and one for re-treatment of a residual portion of a ruptured aneurysm. Of these failures, two (one for initial embolization of a small, unruptured paraclinoid aneurysm and one for the fourth treatment of a residual portion of a large ruptured basilar tip aneurysm) were aborted because of coil prolapse into the parent artery, and one (initial embolization of a small, unruptured posterior communicating artery aneurysm) was aborted after the intraprocedural development of a distal embolism.

Table 1 summarizes the locations of aneurysms treated with endovascular detachable coils. Eighty-eight (74.6%) ruptured aneurysms were in the anterior circulation, and 30 (25.4%), in the posterior circulation. The most common location was the anterior communicating artery (38.1%), followed by the basilar artery apex (13.6%), and the posterior communicating artery (11.0%). Fifty-three (73.6%) unruptured aneurysms were in the anterior circulation, and 19 (26.4%), the posterior circulation. The most common location was the paraclinoid internal carotid artery (44.4%), followed by the basilar artery apex (15.3%), and the anterior communicating artery (8.3%).

Aneurysms were measured according to their greatest diameter. Among ruptured aneurysms, 93 were small (<10 mm), 23 were large (11–24 mm), and two were giant (>25 mm); the respective distribution among unruptured aneurysms was 52, 20, and 0. Overall, 145 (76.3%) of all aneurysms were small, 43 (22.6%) were large, and two (1.1%) were giant. For ruptured aneurysms, fundus-to-neck ratios were favorable (>2) in 45 (38.1%) and unfavorable (<2) in 73 (61.9%). For unruptured aneurysms the ratios were favorable in 21 (29.2%) and unfavorable in 51 (70.8%).

More than 95% of all procedures were performed with the patients under general anesthesia. Heparin (3000–5000 U) was routinely infused before catheterization of both ruptured and unruptured aneurysms. Catheter-flushing solutions contained 2000 U/L of heparin. Activated clotting times were maintained at 250–400 seconds.

A 6F guiding catheter (Envoy; Cordis, Miami, FL) and a microcatheter (Rapid Transit; Cordis) were primarily used, although other systems were occasionally used (Fast Tracker 10 and 18, Target Therapeutics, Fremont, CA; Prowler 10 and 14, Cordis; Jetstream 10, MicroInterventional Systems, Sunnyvale, CA). The guidewires were sized for the microcatheter and included several types (Seeker, Target Therapeutics; QuickSilver, MicroInterventional Systems; GlideWire, Terumo Co., Tokyo, Japan). All coils, including soft and three-dimensional coils, were Guglielmi detachable coils (Target Therapeutics) and Micrus 3D coils (Micrus Co., Mountain View, CA). When the remodeling technique was performed (11), we used two types of angioplasty balloons (Endeavor, Target Therapeutics; Solstice, MicroInterventional Systems).

All coils were introduced into the aneurysm by using simultaneous biplane imaging with or without roadmapping. Coil placement proceeded until no additional coils could be placed in the aneurysm, until angiographically complete obliteration was achieved, or until the risk of occluding a normal arterial branch adjacent to the aneurysm seemed imminent. All patients received heparin for 12–24 hours after the procedure unless clear contraindications (e.g., intraprocedural rupture) were present. After the procedure, patients were transferred to the neurosurgical intensive care unit. All patients with SAH received oral nimodipine for 2 weeks. Hypervolemia was not routinely induced to prevent vasospasm, but systolic blood pressure was maintained above 120 mm Hg by using dopamine if necessary.

The degree of aneurysmal occlusion was classified into three categories: complete when the sac and the neck were densely packed in any projection, near-complete when the sac was occluded but a neck remnant was suspected or when an obvious, small (<2-mm) neck remnant was present, and partial when loose packing or persistent opacification of the sac or the neck remnant 2 mm was observed. Of 118 ruptured aneurysms, immediate postprocedural angiography showed complete occlusion in 74 (62.7%), near-complete occlusion in 25 (21.2%), and partial occlusion in 19 (16.6%). Of 72 unruptured aneurysms, complete occlusion was observed in 42 (58.3%), near-complete occlusion in 17 (23.6%), and partial occlusion in 11 (15.3%). Occlusion failed in 2 (2.8%) unruptured aneurysms.

Cases in which procedure-related cerebral complications occurred were selected. We analyzed their radiologic findings, clinical presentations, treatments, and clinical outcomes. Procedure-related neurologic deficits were classified as: transient deficits, which resolved within 7 days after examination, or persistent deficits, which persisted longer than 7 days. Proce-

TABLE 2: Procedure-related complications

Complication	Ruptured (n = 118)	Unruptured (n = 72)	Retreated (n = 20)	Incidence (%)
Thromboembolism (n = 22)	13	5	4	10.4
Intraprocedural rupture (n = 9)	9	0	0	4.2
Coil migration (n = 2)	2	0	0	1.0
Parent-vessel injury (n = 2)	2	0	0	1.0
Postprocedural rupture (n = 1)	1	0	0	0.5
Cranial nerve palsy (n = 1)	0	1	0	0.5
Total (n = 37)	27	6	4	17.6

TABLE 3: Procedural complications in 118 ruptured aneurysms

Complication	Neurologic Sequlae				Total	Incidence (%)
	None	Transient	Persistent	Fatal		
Intraprocedural rupture	6	0	0	3	9	7.6
Postprocedural rupture	0	0	0	1	1	0.8
Thromboembolism	1	1	7	4	13	11.0
Coil migration	1	0	0	1	2	1.7
Parent-vessel injury	2	0	0	0	2	1.7
Total	10	1	7	9	27	22.9

dure-related neurologic morbidity was defined as neurologic deficit lasting for more than 7 days that was attributable to coil embolization.

Results

Thirty-seven (17.6%) complications occurred. Among these, 27 were associated with initial embolization of ruptured aneurysms; six, with initial embolizations of unruptured aneurysms, and four with retreatment procedures. Complication rates for embolizations of ruptured, unruptured, and retreated aneurysms were 22.9% (27 of 118), 8.3% (six of 72), and 20% (four of 20), respectively. Complications included 22 cerebral thromboembolisms (10.4%), nine intraprocedural aneurysm perforations (4.2%), two coil migrations (1%), two parent-vessel injuries (1%), one postprocedural aneurysmal rupture (0.5%), and one cranial nerve palsy (0.5%) (Table 2). Fourteen complications had no neurologic consequences, three were associated with transient neurologic morbidity, 10 resulted in persistent neurologic morbidity on discharge, and 10 resulted in death. Only one complication (distal thromboembolism) was associated with the balloon remodeling technique; this event had no clinical consequence. Procedure-related neurologic morbidity and mortality rates for all 210 procedures were 4.8% and 4.8%, respectively.

Procedural Complications for Ruptured Aneurysms

Procedure-related complications for initial coil embolizations are summarized in Table 3. We recorded no technical failures. Twenty-seven (22.9%) procedural complications occurred with 118 procedures: 10 had no clinical consequences, one was associated with transient neurologic changes, seven resulted in persistent neurologic morbidity, and nine resulted in death. The procedure-related neurologic morbidity rate on discharge was 5.9%, and the mortality rate was 7.6% (13.5% combined).

Intraprocedural Aneurysmal Rupture

Intraprocedural aneurysmal rupture occurred in nine (7.6%) of 118 ruptured aneurysms due to protrusion of a tip of the coil (n = 6) or microcatheter (n = 3) outside the limit of the aneurysmal sac during the procedure. (Seven perforations were accompanied by angiographically visible extravasation of contrast agent.) Eight perforated aneurysms were small (3–8 mm), and one was large (12 mm). All ruptures occurred during the early stage of the procedure before detachment of the halfway coil. Coil-induced ruptures were caused by the first coil in three small (4–8 mm) aneurysms, the third coil in two small (6–8 mm) aneurysms, and the 11th coil in one large aneurysm (12 mm). Microcatheter-induced ruptures occurred in three small (4–5 mm) aneurysms during initial catheter placement in one case and during deployment of the second coil in two cases. All nine intraprocedural ruptures occurred during embolization of acutely ruptured aneurysms: four in the anterior communicating artery, one in the anterior choroidal artery, one in the middle cerebral artery bifurcation, one in the basilar tip, one in the basilar trunk, and one in the vertebrobasilar confluence. Preoperative clinical grades of the nine lesions were Hunt and Hess grade I in one, grade II in two, grade III in three, and grade IV in three.

All intraprocedural ruptures were managed with a systemic protamine injection for heparin reversal and further coil embolization. In three cases, one of the interventionalists (M.H.) inserted ventricular drain-

age catheters in the angiography suite immediately after aneurysmal perforation, and in five cases, a ventricular catheter had been placed before coil placement.

All three deaths were associated with intraprocedural ruptures that occurred before detachment of the first coil and with initial Hunt-Hess grades of III ($n = 1$) or IV ($n = 2$). Six intraprocedural ruptures had no clinical consequence, and three resulted in death. In 118 procedures, the morbidity rate from intraprocedural rupture of an already ruptured aneurysm was 0%, and the mortality rate was 2.5%. Overall morbidity and mortality rates at discharge from intraprocedural aneurysm rupture in 210 cases were 0% and 1.4%, respectively.

Periprocedural Thromboembolism

Thromboembolic complications occurred in 13 (11.0%) of 118 procedures; one resulted in no neurologic consequence, one resulted in transient neurologic deficit (expressive aphasia), seven resulted in persistent neurologic abnormalities on discharge, and four resulted in death. The morbidity rate on discharge due to thromboembolic complications was 5.9%, and the mortality rate was 3.4%. Seven thromboembolic complications were evident during the procedure, and six were documented on postembolization follow-up radiographic studies. Eight events were managed with local or systemic administration of fibrinolytic or antiplatelet agents. Fibrinolytic therapy consisted of intravenous tissue-type plasminogen activator (tPA) 10 mg along with 10 mg given intra-arterially at the occlusion site. When a distal multifocal occlusion was observed, patients were treated with intravenous abciximab or eptifibatide at the appropriate dose according to their weight.

Postembolization Rebleeding

One (0.8%) patient had fatal rebleeding the 6th day after partial embolization of a large acutely ruptured basilar-tip aneurysm. At the conclusion of the procedure, a few loops of a coil were projecting outside the limit of aneurysmal sac, and the lesion demonstrated residual filling of its base.

Coil Migration

Coil migration during treatment occurred in two (1.7%) of 118 aneurysms. Both cases were associated with coil embolization of small posterior communicating artery aneurysms with unfavorable fundus-to-neck ratios. Migrated coil could be retrieved successfully in one case with no clinical consequence. Another case experienced a fatal stroke after unsuccessful coil retrieval.

Parent-Vessel Injury

Parent-vessel injury occurred in two (1.7%) of 118 procedures, with no clinical consequence. Each involved extracranial dissection of a vertebral artery. The dissections occurred during catheter or wire manipulations. Both cases were treated with intravenous heparin for 24–48 hours after the procedure.

Nonprocedural Complications Attributable to SAH

Of 118 patients with SAH, one (0.9%) had early rebleeding just before coil embolization. Seven (5.9%) had symptomatic vasospasm: Five were treated with intra-arterial papaverine infusion with balloon angioplasty; one, with intra-arterial papaverine infusion only; and one, with triple-H therapy. Seven (5.9%) had hydrocephalus requiring shunt placement. Fourteen (11.9%) deaths occurred after SAH and were not related to direct complications of endovascular treatment. Twelve deaths were attributable to the initial effect of SAH; one death was due to early rebleeding in a patient not treated with coils and one death was due to vasospasm resistant to aggressive treatment.

Procedural Complications for Unruptured Aneurysms

Six (8.3%) procedural complications occurred after 72 procedures for unruptured aneurysms. Thromboembolic complications occurred in five (6.9%), and cranial nerve palsy (thought to be the result of the compressive effect of a coiled aneurysm) occurred in one (1.4%). We noted two technical failures: one due to coil prolapse into the parent artery and one due to intraprocedural distal thromboembolism. Two complications (thromboembolism) had no clinical consequence, two (one thromboembolism and one cranial nerve palsy) were associated with neurologic morbidity after the procedure, one (thromboembolism) resulted in persistent neurologic morbidity on discharge, and one (thromboembolism) resulted in death. Procedure-related neurologic morbidity and mortality rates at the time of discharge were 1.4% and 1.4%, respectively.

Procedural Complications for Re-embolization

Fourteen aneurysms were re-embolized once, and two were re-embolized three times. Additional procedures were necessary because of an inability to deposit coils during the initial attempt (one procedure), incomplete obliteration after initial embolization (14 procedures), or recurrent (or residual) aneurysms at follow-up angiography (five procedures). One technical failure occurred when a fourth embolization for a small residual of a previously ruptured, large basilar-tip aneurysm was aborted because of coil prolapse into the parent vessel. Of 20 re-embolization procedures, four (20%) had complications. All four complications were thromboembolic: two had no clinical consequence and two resulted in persistent neurologic morbidity on discharge. The neurologic morbidity rate related to re-embolization was 10%, and the mortality rate was 0%.

Discussion

Several groups have reported procedural complication rates related to endovascular aneurysm coil placement. Raymond and Roy (4) reported a 23% procedural complication rate in 75 patients, with procedure-related morbidity and mortality rates of 4% each. Roy et al (5) observed a 10.3% complication rate with 4.3% morbidity and 0% mortality in 130 coil embolization procedures for 125 unruptured aneurysms. In the series by Kuether et al (2) of 74 patients with 77 intracranial aneurysms (including 31 acutely ruptured aneurysms), 93 embolizations led to 13 technical complications (14%). Procedure-related morbidity and mortality rates were 9.1% and 7.8%, respectively. Ng et al (3) reported the results of endovascular treatment of 160 intracranial aneurysms (including 81 ruptured aneurysms) in 144 patients. The procedural complication rate was 21%, and procedure-related morbidity and mortality rates were 6.9% and 1.2%, respectively. In the ruptured group, procedure-related morbidity was 8.6%, and mortality was 2.5%; in the unruptured group, rates were 5.1% and 0%, respectively. Brilstra et al (1) reviewed 48 studies (1383 patients) on coil embolization, noting a 12% procedure-related complication rate. Procedure-related morbidity and mortality rates were 3.7% and 1.1%, respectively.

Our overall complication rate for all aneurysms was 17.6%, and the overall procedural morbidity and mortality rates were 4.8% each. The main cause of morbidity and mortality was thromboembolism, with all morbidity and half of all deaths secondary to thromboembolic complications. Overall procedure-related complication rates of embolization for ruptured, unruptured, and re-treated aneurysms were 22.9%, 8.3%, and 20%, respectively. In ruptured aneurysms, the procedure-related neurologic morbidity rate was 5.9%, and the mortality rate was 7.6% (13.5% combined). Two main causes of procedural morbidity and mortality in this group were thromboembolism and intraprocedural rupture. In unruptured aneurysms, procedure-related neurologic morbidity and mortality rates were 1.4% each (2.8% combined). Thromboembolism was the main cause of procedural morbidity and mortality in this group. Morbidity and mortality rates related to re-embolization were 10% and 0%, respectively (10% combined). Procedural morbidity related to re-embolization was entirely attributable to thromboembolism. For the series, complication rates were highest in ruptured aneurysms and lowest in unruptured ones. The procedural morbidity rate was highest in the re-treated group and lowest in the unruptured group. The procedural mortality rate was higher in the ruptured group than in the unruptured group.

Intraprocedural Aneurysmal Rupture

Rates of aneurysmal rupture during coil embolization are 1.9–16% for ruptured aneurysms and 0–1.3% for unruptured aneurysms (2–4, 6, 12–14). Many authors have found that iatrogenic rupture almost invariably involves previously ruptured lesions (2, 3, 13–15). Kuether et al (2) reported the result of 93 embolization procedures in 77 aneurysms with a 2.1% overall incidence of aneurysm perforation (6.5% in 31 ruptured aneurysms and 0% in 46 unruptured aneurysms). Valavanis et al (15) reported 128 endovascular cases, noting perforation only during treatment of previously ruptured lesions (4.2% in 69 ruptured aneurysms). Ng et al (3) also noted intraprocedural rupture more commonly during treatment of ruptured than treatment of unruptured ones (16% vs. 1.3%).

Small aneurysms are also associated with an increased incidence of intraprocedural rupture (6, 12, 13, 15). Ricolfi et al (12) observed four procedure-related perforations in small aneurysms only (4 mm or smaller in diameter). Vinuela et al (6) reported that nine of 11 perforated aneurysms measured 4–10 mm in diameter. Valavanis et al (15) reported that two of three perforated aneurysms measured 3–4 mm in diameter, and in the series by Sluzewski et al (13), six of the seven perforated aneurysms measured 2–10 mm.

In our series, intraprocedural rupture occurred in nine (4.2%) cases of ruptured aneurysms. The rate of aneurysm perforation was 7.6% in 118 ruptured aneurysms and 0% in 72 unruptured aneurysms. All ruptures occurred before or during the early phase of coil embolization. Anterior communicating artery aneurysms were most commonly perforated (four of nine perforations were interior communicating aneurysms), and all but one intraprocedural rupture occurred in small (3.5–8 mm) aneurysms. Of the nine ruptures, six had good outcomes with no clinical consequence, and three resulted in death. This seems to be consistent with other publications (2, 4, 16–21). Fatal outcomes were associated with intraprocedural ruptures that occurred before detachment of the first coil and poorer initial Hunt-Hess grades (grade III for one and grade IV for two). Morbidity and mortality rates attributed to intraprocedural aneurysm rupture were 0% and 1.5% respectively among a total of 210 procedures. Once an aneurysm ruptured, 33% of the patients died, while 66% did well.

Thromboembolism

Endovascular coil embolization of intracranial aneurysms is associated with a risk of thromboembolic and ischemic complications. Despite routine use of heparin in conjunction with this procedure, complications that related to thromboembolic events occurred in 2.5–28% of patients treated (6, 14, 18, 22). In our study, thromboembolic complications were observed in 22 (10.4%) of 210 procedures; 13 (11%) of 118 ruptured aneurysms, five (6.9%) of 72 unruptured aneurysms, and four (20%) of 20 re-treated aneurysms. Thromboembolic complications accounted for 59.5% of all complications. All thromboembolic complications observed occurred during (n = 12) or within 24 hours (n = 10) of the procedures.

Periprocedural thromboembolism can be treated with selective intra-arterial administration of throm-

bolytic agents (urokinase or tPA). Cronqvist et al (23) reported the results of superselective intra-arterial fibrinolytic therapy in 19 patients to treat thromboembolic complications during endovascular aneurysm treatment. Complete recanalization was achieved in 10, and partial recanalization, in nine. Fourteen patients had a good clinical recovery, and one died of a large intracerebral hematoma. Aneurysm rupture with SAH occurred in two patients. We previously reported five cases in which intra-arterial thrombolytic agents were used to treat acute vascular occlusion associated with endovascular coil placement of intracranial aneurysms (24). Mechanical clot disruption was performed before intra-arterial thrombolytics were delivered. Angiographic recanalization was observed in four patients, with clinical improvement in two. Two patients experienced hemorrhage, which caused severe morbidity or death.

In view of the modest results and limitations of thrombolytic therapy, several authors (25–28) have proposed the use of abciximab—a chimeric monoclonal antibody fragment against the platelet glycoprotein IIb/IIIa receptor complex—to manage acute thromboembolism during endovascular coil placement in intracranial aneurysms. This drug, or others like it, may be more effective and logical for intraprocedural thromboembolism because most patients have already received full heparinization, making it unlikely that a fibrin clot is present. Platelet clumps, however, are known to quickly form on intravascular foreign bodies, even with full heparin anticoagulation. Lempert et al (27) reported a case of successful abciximab treatment for an acute thrombosis during coil embolization of a basilar apex aneurysm. They observed complete thrombus dissolution after 30 minutes of systemic drug infusion. Ng et al (28) also reported successful thromboembolic treatment with systemic abciximab during endovascular coil placement of a ruptured intracranial aneurysm after superselective infusion of a fibrinolytic agent was unsuccessful. Alexander et al (25) described a similar experience with intravenous abciximab for the treatment of intraprocedural arterial thrombus. Duncan and Fourie (26) described their experience with catheter-directed intra-arterial abciximab in five cases of acute intracranial arterial occlusion during neurointerventional procedures. Rapid thrombus dissolution was observed in four cases, and partial dissolution, in one. Two patients had no neurologic deficit, one had a pre-existing neurologic deficit, one had mild residual thumb paresis, and one had a severe neurologic deficit. No abciximab-related complication occurred. The authors concluded that the intra-arterial administration of abciximab could result in rapid clot lysis.

Of 22 thromboembolic complications in our series, eight were treated by using superselective intra-arterial or intravenous abciximab, and one was treated by using local tPA. Of the eight cases treated with abciximab, we observed complete recanalization in six and partial recanalization in two. One case treated with tPA showed partial recanalization. Two cases with complete recanalization had no neurologic consequence, two had transient neurologic deficit, and two had persistent neurologic deficit. Two of three partially recanalized cases had persistent neurologic deficit, and one resulted in death. Overall morbidity and mortality rates from thromboembolic complications were 4.8% (10 of 210) and 2.4% (five of 210), respectively.

Thromboembolic complication was the major cause of morbidity and mortality in our series. All morbidity from our 210 embolization procedures was associated with thromboembolic complications, which also accounted for one-half of all procedure-related deaths. Once a thromboembolic event occurred, morbidity was 45% and mortality was 23%. With successful experiences in the use of IIb/IIIa inhibitor for these events, acute platelet aggregation is implicated as an important constituent (22, 25, 27, 29).

In view of these findings, our present approach (since November 2002) to decrease the incidence of thromboembolic complications includes the prophylactic use of intravenous eptifibatide (Integrilin; CGL Therapeutics, San Francisco, CA) at the conclusion of the procedure. The effects of eptifibatide, a synthetic heptapeptide with high specificity and affinity for glycoprotein IIb/IIIa receptors, rapidly reverse (within 2–4 hours) after its discontinuation (30–32). This effect may be beneficial in the event of serious bleeding (including aneurysmal rebleeding), in the routine removal of a femoral arterial sheath, and in consideration of early ambulation and discharge after a successful procedure. Preventive use of eptifibatide during coil embolization of an aneurysm poses a substantial risk if iatrogenic rupture should necessitate emergent neurosurgical intervention to evacuate a hematoma. To avoid this quandary, we currently use eptifibatide only at the completion of embolization to prevent or reduce the incidence of postoperative thromboembolic complications.

Nonprocedural Complications Attributable to SAH

Hydrocephalus.—The incidence of SAH-associated hydrocephalus is reported to range from 6% to 67% (33–39). In the International Cooperative Study on the Timing of Aneurysm Surgery (40), 8.0% of patients underwent CSF shunt surgery. In terms of the effect of the type of procedure performed on the incidence of shunt surgery, a number of reports indicate no difference between endovascular and exovascular therapy. In a series of 242 patients with aneurysmal SAH treated with early surgery or early endovascular treatment, Gruber et al (41) reported incidences of 23.2% in the shunt-dependent hydrocephalus in the surgical group and 17.7% in the endovascular group. Sethi et al (42) retrospectively studied 100 matched patients with aneurysmal SAH to determine the association between treatment method and the development of chronic hydrocephalus. They

TABLE 4: Published complication rates for coil embolization of cerebral aneurysms

Reference	Rate
Johnston et al[62]	10% procedure-related adverse outcome rate in coiled unruptured aneurysms (adverse outcome not defined)
Duke et al[63]	2.5% procedure-related neurologic deficit rate
Johnston et al[64]	11% procedure-related adverse outcome rate
Vanninen et al[65]	4% technique-related mortality rate
Bavinzski et al[66]	2.2% procedure-related mortality, 4.4% procedure-related morbidity
Solander et al[21]	13% procedure-related temporary neurologic complication rate
Klein et al[67]	24% inadvertent vessel occlusion secondary to coiling, 10% stroke/TIA rate secondary to coiling procedure
Eskridge et al[68]	23% procedure-related embolus rate
Guglielmi et al[69]	4.8% procedure-related morbidity, 2.4% procedure-related mortality
Murayama et al[70]	4.3% procedure-related neurologic morbidity for unruptured aneurysms
Kuether et al[2]	9.1% procedure-related morbidity, 7.8% procedure-related mortality
Raymond et al[71]	22% procedure-related neurologic complications, 3% procedure-related mortality
McDougall et al[72]	10% procedure-related neurologic complications
Byrne et al[73]	18% procedure-related neurologic complications, 4% procedure-related mortality
Casasco et al[74]	4.2% procedure-related strokes, 7% procedure-related deaths
Brilstra et al[1]	4% procedure-related permanent neurologic complications, 8.5% procedure-related temporary neurologic ischemic complications, 1.1% procedure-related mortality
Soeda et al[75]	20% procedure-related ischemic event rate in coiling or unruptured aneurysms
Vinuela et al[6]	8.9% procedure-related morbidity, 1.8% procedure-related mortality
Klotzsch et al[76]	20% procedure-related neurologic complications
Holley et al[77]	7.1% procedure-related neurologic morbidity
Graves et al[78]	8% procedure-related stroke rate
Pelz et al[22]	28% procedure-related neurologic thromboembolic rate (12% TIA rate, 17% stroke rate)

also concluded that the technical procedure does not significantly affect the incidence of shunted hydrocephalus (18% for surgical clip placement and 16% for coil embolization). In our study, the incidence of shunt-dependent hydrocephalus was 5.9% in patients with aneurysmal SAH.

Vasospasm.—Delayed ischemic neurologic deficit (symptomatic vasospasm) is a major cause of morbidity and mortality in patients with aneurysmal SAH. Symptomatic vasospasm is reported in 22–40% of patients with SAH, resulting in 34% morbidity and 30% mortality rates (31, 40, 43–46). Early aneurysmal surgery followed by proper postoperative management, including preventive use of intravenous nimodipine, is reported to reduce the incidence of symptomatic vasospasm to 10% or less (47–49). Although some have suggested that the cisternal removal of blood may reduce the incidence of cerebral vasospasm, only partial physical removal of subarachnoid blood is possible during early aneurysmal surgery (50–53). The International Cooperative Study on the Timing of Aneurysm Surgery (40, 54) did not demonstrate a major influence of early surgery on morbidity and mortality due to chronic cerebral vasospasm. The difficulty in removing tenacious subarachnoid blood clots, the effects of blood breakdown products, or the surgical-mechanical manipulation of vessels may explain this failure of early surgery to substantially alter the incidence of vasospasm (40, 46, 55, 56). Murayama et al (57) reported a 23% incidence of symptomatic vasospasm after endovascular coil occlusion of acutely ruptured; this rate compares favorably with that found in conventional surgical series. Gruber et al (58), however, noted an increased incidence of vasospasm-related infarctions in patients treated endovascularly (37.7% vs. 21.6% with surgery). However, when patients with Fisher grade 4 and Hunt and Hess grade V lesions were excluded, the difference between the treatment groups was no longer significant.

Other authors (57, 59, 60) have not found an increased risk of vasospasm with endovascular therapy. Yalamanchili et al (60) retrospectively compared 19 patients treated by surgical clip placement with 18 patients treated by endovascular coil embolization after aneurysmal SAH, excluding patients with Hunt and Hess grade IV or V SAH. Symptomatic vasospasm was more frequent and more severe in the surgical group (74% vs. 22%). Charpentier et al (59) performed a multivariate analysis to determine the role of treatment technique on cerebral vasospasm after aneurysmal SAH. Symptomatic vasospasm occurred in 25 (22.2%) of 145 surgical patients compared with 22 (17.2%) of 99 endovascular patients. They concluded that the type of treatment was not associated with an increased risk of cerebral vasospasm. Rabinstein et al (61) studied 415 consecutive patients with aneurysmal SAH. Symptomatic vasospasm occurred in 39% treated with surgical clip placement and 30% treated with endovascular coil occlusion. In a univariate analysis, the incidence of vasospasm did not differ between the groups.

In our study, the incidence of symptomatic vasospasm among 118 patients with ruptured aneurysms was 5.9% ($n = 7$). Excluding 35 patients with Hunt and Hess grades of IV and V, in whom it is difficult to accurately detect a vasospastic neurologic deterioration, the incidence was 4.8%. Our rate tended to be lower than those previously reported, even when we did not make the exclusion just described.

Conclusion

Our review indicates that endovascular coil embolization of an intracranial aneurysm is a safe technique with low morbidity and mortality rates. Our results are consistent with those reported in the literature (Table 4): 1) The overall procedure-related complication rate was 17.6%, and morbidity and mortality rates were 4.8% each; 2) The procedural complication rate was highest (22.9%) in ruptured aneurysms and lowest (8.3%) in unruptured aneurysms; 3) The procedural morbidity rate was highest (10%) in the re-treated aneurysms and lowest (1.4%) in unruptured aneurysms; 4) The procedural mortality rate was higher in ruptured aneurysms (7.6%) than in unruptured aneurysms (1.4%); 5) No procedural mortality occurred in patients with re-treated aneurysms; 6) Combined procedure-related morbidity and mortality rates for ruptured, unruptured, and re-treated aneurysms were 13.5%, 2.8%, and 10%, respectively; and 7) The main cause of morbidity and mortality was thromboembolism (60% of all complications were thromboembolic). The thromboembolism rate was 10.4% with a disproportionate number of events occurring during re-embolization of previously treated lesions. A thromboembolic complication was associated with 45% morbidity and 23% mortality.

While we report on clinically identifiable complications and procedure-related morbidity and mortality, subclinical events were not reported because most go unrecognized. Only by performing preprocedural and postprocedural MR imaging studies is it possible to truly quantify all untoward cerebral events and injuries, even those without clinical sequelae.

References

1. Brilstra EH, Rinkel GJ, van der Graaf Y, van Rooij WJ, Algra A. **Treatment of intracranial aneurysms by embolization with coils: a systematic review.** *Stroke* 1999;30:470–476
2. Kuether TA, Nesbit GM, Barnwell SL. **Clinical and angiographic outcomes, with treatment data, for patients with cerebral aneurysms treated with Guglielmi detachable coils: a single-center experience.** *Neurosurgery* 1998;43:1016–1025
3. Ng P, Khangure MS, Phatouros CC, Bynevelt M, ApSimon H, McAuliffe W. **Endovascular treatment of intracranial aneurysms with Guglielmi detachable coils: Analysis of midterm angiographic and clinical outcomes.** *Stroke* 2002;33:210–217
4. Raymond J, Roy D. **Safety and efficacy of endovascular treatment of acutely ruptured aneurysms.** *Neurosurgery* 1997;41:1235–1246
5. Roy D, Milot G, Raymond J. **Endovascular treatment of unruptured aneurysms.** *Stroke* 2001;32:1998–2004
6. Vinuela F, Duckwiler G, Mawad M. **Guglielmi detachable coil embolization of acute intracranial aneurysm: perioperative anatomical and clinical outcome in 403 patients.** *J Neurosurg* 1997;86:475–482
7. Hunt WE, Hess RM. **Surgical risk as related to time of intervention in the repair of intracranial aneurysms.** *J Neurosurg* 1968;28:14–19
8. Almaani WS, Richardson AE. **Multiple intracranial aneurysms: identifying the ruptured lesion.** *Surg Neurol* 1978;9:303–305
9. Nehls DG, Flom RA, Carter LP, Spetzler RF. **Multiple intracranial aneurysms: determining the site of rupture.** *J Neurosurg* 1985;63:342–348
10. Sengupta RP, Lassman LP. **Identification of the source of bleeding in multiple intracranial aneurysms.** *Vasc Surg* 1974;8:177–183
11. Moret J, Cognard C, Weill A, Castaings L, Rey A. **The "remodeling technique" in the treatment of wide neck intracranial aneurysms.** *Intervent Neuroradiol* 1997;3:21–35
12. Ricolfi F, Le Guerinel C, Blustajn J, et al. **Rupture during treatment of recently ruptured aneurysms with Guglielmi electrodetachable coils.** *AJNR Am J Neuroradiol* 1998;19:1653–1658
13. Sluzewski M, Bosch JA, van Rooij WJ, Nijssen PC, Wijnalda D. **Rupture of intracranial aneurysms during treatment with Guglielmi detachable coils: incidence, outcome, and risk factors.** *J Neurosurg* 2001;94:238–240
14. Tummala RP, Chu RM, Madison MT, Myers M, Tubman D, Nussbaum ES. **Outcomes after aneurysm rupture during endovascular coil embolization.** *Neurosurgery* 2001;49:1059–1067
15. Valavanis A, Machado E, Chen JJ. **Aneurysm rupture during GDC treatment: incidence, management and outcome.** *Neuroradiology* 1996;38:45
16. Byrne JV, Molyneux AJ, Brennan RP. **Embolisation of recently ruptured intracranial aneurysms.** *J Neurol Neurosurg Psychiatry* 1995;59:616–620
17. Cognard C, Weill A, Castaings L, Rey A, Moret J. **Intracranial berry aneurysms: Angiographic and clinical results after endovascular treatment.** *Radiology* 1998;206:499–510
18. Debrun GM, Aletich VA, Kehrli P, Misra M, Ausman JI, Charbel F. **Selection of cerebral aneurysms for treatment using Guglielmi detachable coils: the preliminary University of Illinois at Chicago experience.** *Neurosurgery* 1998;43:1281–1297
19. Malisch TW, Guglielmi G, Vinuela F. **Intracranial aneurysms treated with the Guglielmi detachable coil: midterm clinical results in a consecutive series of 100 patients.** *J Neurosurg* 1997;87:176–183
20. McDougall C, Halbach V, Dowd C, Higashida R, Larsen D, Hieshima G. **Causes and management of aneurysmal hemorrhage occurring during embolization with Guglielmi detachable coils.** *J Neurosurg* 1998;89:87–92
21. Solander S, Ulhoa A, Vinuela F. **Endovascular treatment of multiple intracranial aneurysms by using Guglielmi detachable coils.** *J Neurosurg* 1999;90:857–864
22. Pelz DM, Lownie SP, Fox AJ. **Thromboembolic events associated with the treatment of cerebral aneurysms with Guglielmi detachable coils.** *AJNR Am J Neuroradiol* 1998;19:1541–1547
23. Cronqvist M, Pierot L, Boulin A, Cognard C, Castaings L, Moret J. **Local intraarterial fibrinolysis of thromboemboli occurring during endovascular treatment of intracerebral aneurysm: a comparison of anatomic results and clinical outcome.** *AJNR Am J Neuroradiol* 1998;19:157–165
24. Koebbe CJ, Horowitz MB, Levy EI, Dutton K, Jungries CC, Purdy PD. **Intraarterial thrombolysis for thromboemboli associated with endovascular aneurysm coiling: report of five cases.** *Intervent Neuroradiol* 2002;8:151–158
25. Alexander MJ, Duckwiler GR, Gobin YP, Vinuela F. **Management of intraprocedural arterial thrombus in cerebral aneurysm embolization with abciximab: technical case report.** *Neurosurgery* 2002;50:899–902
26. Duncan IC, Fourie PA. **Catheter-directed intra-arterial abciximab administration for acute thrombotic occlusions during neurointerventional procedures.** *Intervent Neuroradiol* 2002;8:159–168
27. Lempert TE, Malek AM, Halbach VV, Phatouros CC, Dowd CF, Higashida RT. **Rescue treatment of acute parent vessel thrombosis with glycoprotein IIb/IIIa inhibitor during GDC coil embolization.** *Stroke* 1999;30:693–695
28. Ng PP, Phatouros CC, Khangure MS. **Use of glycoprotein IIb-IIIa inhibitor for a thromboembolic complication during Guglielmi detachable coil treatment of an acutely ruptured aneurysm.** *AJNR Am J Neuroradiol* 2001;22:1761–1763
29. Workman MJ, Cloft HJ, Tong FC, et al. **Thrombus formation at the neck of cerebral aneurysms during treatment with Guglielmi detachable coils.** *AJNR Am J Neuroradiol* 2002;23:1568–1576
30. Harrington RA, Kleiman NS, Kottke-Marchant K, et al. **Immediate and reversible platelet inhibition after intravenous administration of a peptide glycoprotein IIb/IIIa inhibitor during percutaneous coronary intervention.** *Am J Cardiol* 1995;76:1222–1227
31. Ljunggren B, Saveland H, Brandt L. **Causes of unfavorable outcome after early aneurysm operation.** *Neurosurgery* 1983;13:629–633
32. Scarborough RM. **Development of eptifibatide.** *Am Heart J* 1999; 138: 1093–1104
33. Black PMcL. **Hydrocephalus and vasospasm after subarachnoid hemorrhage from ruptured intracranial aneurysms.** *Neurosurgery* 1986;18:12–16
34. Galera RC, Greitz T. **Hydrocephalus in the adult secondary to the rupture of intracranial arterial aneurysms.** *J Neurosurg* 1970;32: 634–641

35. Kolluri VR, Sengupta RP. **Symptomatic hydrocephalus following aneurysmal subarachnoid hemorrhage.** *Surg Neurol* 1984;21: 402–404
36. Milhorat TH. **Acute hydrocephalus after aneurysmal subarachnoid hemorrhage.** *Neurosurgery* 1987;20:15–20
37. Steinke D, Weir B, Disney L. **Hydrocephalus following aneurysmal subarachnoid haemorrhage.** *Neurol Res* 1987;9:3–9
38. van Gijn J, Hijdra A, Wijdicks EF, Vermeulen M, van Crevel H. **Acute hydrocephalus after aneurysmal subarachnoid hemorrhage.** *J Neurosurg* 1985;63:355–362
39. Vassilouthis J, Richardson AE. **Ventricular dilatation and communicating hydrocephalus following spontaneous subarachnoid hemorrhage.** *J Neurosurg* 1979;51:341–351
40. Kassell NF, Torner JC, Haley EC, Jane JA, Adams HP, Kongable G. **The International Cooperative Study on the Timing of Aneurysm Surgery, I: overall management results.** *J Neurosurg* 1990;73:18–36
41. Gruber A, Reinprecht A, Bavinzski G, Czech T, Richling B. **Chronic shunt-dependent hydrocephalus after early surgical and early endovascular treatment of ruptured intracranial aneurysms.** *Neurosurgery* 1999;44:503–512
42. Sethi H, Moore A, Dervin J, Clifton A, MacSweeney JE. **Hydrocephalus: comparison of clipping and embolization in aneurysm treatment.** *J Neurosurg* 2000;92:991–994
43. Adams HP Jr, Kassell NF, Torner JC, Haley EC Jr. **Predicting cerebral ischemia after aneurysmal subarachnoid hemorrhage: Influences of clinical condition, CT results, and antifibrinolytic therapy—a report of the Cooperative Aneurysm Study.** *Neurology* 1987;37:1586–1591
44. Dorsch NWC, King MT. **A review of cerebral vasospasm in aneurysmal subarachnoid hemorrhage, I: incidence and effects.** *J Clin Neurosci* 1994;1:19–26
45. Ljunggren B, Brandt L, Sundbarg G, Saveland H, Cronqvist S, Stridbeck H. **Early management of aneurysmal subarachnoid hemorrhage.** *Neurosurgery* 1982;11:412–418
46. Taneda M. **Effect of early operation for ruptured aneurysms on prevention of delayed ischemic symptoms.** *J Neurosurg* 1982;57: 622–628
47. Auer LM. **Acute operation and preventive nimodipine improve outcome in patients with ruptured cerebral aneurysms.** *Neurosurgery* 1984;15:57–66
48. Gilsbach J, Harders A. **Morbidity and mortality after early aneurysm surgery: A prospective study with nimodipine prevention.** *Acta Neurochir (Wien)* 1989;96:1–7
49. Ljunggren B, Brandt L, Saveland H, et al. **Outcome in 60 consecutive patients treated with early aneurysm operation and intravenous nimodipine.** *J Neurosurg* 1984;61:864–873
50. Inagawa T, Kamiya K, Matsuda Y. **Effect of continuous cisternal drainage on cerebral vasospasm.** *Acta Neurochir (Wien)* 1991;112:28–36
51. Kawakami Y, Shimamura Y. **Cisternal drainage after early operation of ruptured intracranial aneurysm.** *Neurosurgery* 1987;20:8–14
52. Mizukami M, Kawase T, Usami T, Tazawa T. **Prevention of vasospasm by early operation with removal of subarachnoid blood.** *Neurosurgery* 1982;10:301–307
53. Ogura K, Hara M, Tosaki F, Hirai N. **Effect of cisternal drainage after early operation for ruptured intracranial aneurysms.** *Surg Neurol* 1988;30:441–444
54. Kassell NF, Torner JC, Jane JA, Haley EC Jr, Adams HP. **The International Cooperative Study on the Timing of Aneurysm Surgery, II: surgical results.** *J Neurosurg* 1990;73:37–47
55. Miyaoka M, Sato K, Ishii S. **A clinical study of the relationship of timing to outcome of surgery for ruptured cerebral aneurysms: a retrospective analysis of 1622 cases.** *J Neurosurg* 1993;79:373–378
56. Ohman J, Servo A, Heiskanen O. **Risks factors for cerebral infarction in good-grade patients after aneurysmal subarachnoid hemorrhage and surgery: a prospective study.** *J Neurosurg* 1991;74: 14–20
57. Murayama Y, Malisch T, Guglielmi G, et al. **Incidence of cerebral vasospasm after endovascular treatment of acutely ruptured aneurysms: report on 69 cases.** *J Neurosurg* 1997;87:830–835
58. Gruber A, Ungersböck K, Reinprecht A, et al. **Evaluation of cerebral vasospasm after early surgical and endovascular treatment of ruptured intracranial aneurysms.** *Neurosurgery* 1998;42:258–268
59. Charpentier C, Audibert G, Guillemin Civit T, et al. **Multivariate analysis of predictors of cerebral vasospasm occurrence after aneurysmal subarachnoid hemorrhage.** *Stroke* 1999;30:1402–1408
60. Yalamanchili K, Rosenwasser RH, Thomas JE, Liebman K, McMorrow C, Gannon P. **Frequency of cerebral vasospasm in patients treated with endovascular occlusion of intracranial aneurysms.** *AJNR Am J Neuroradiol* 1998;19:553–558
61. Rabinstein AA, Pichelmann MA, Friedman JA, et al. **Symptomatic vasospasm and outcomes following aneurysmal subarachnoid hemorrhage: A comparison between surgical repair and endovascular coil occlusion.** *J Neurosurg* 2003;98:319–325
62. Johnston SC, Zhao S, Dudley RA, Berman MF, Gress DR. **Treatment of unruptured cerebral aneurysms in California.** *Stroke* 2001;32:597–605
63. Duke DA, Lynch JJ, Harner SG, Faust RJ, Ebersold MJ. **Venous air embolism in sitting and supine patients undergoing vestibular schwannoma resection.** *Neurosurgery* 1998;42:1282–1286
64. Johnston SC, Dudley RA, Gress DR, Ono L. **Surgical and endovascular treatment of unruptured cerebral aneurysms at university hospitals.** *Neurology* 1999;52:1799–1805
65. Vanninen R, Koivisto T, Saari T, Hernesniemi J, Vapalahti M. **Ruptured intracranial aneurysms: acute endovascular treatment with electrolytically detachable coils—a prospective randomized study.** *Radiology* 1999;211:325–336
66. Bavinzski G, Killer M, Gruber A, Reinprecht A, Gross CE, Richling B. **Treatment of basilar artery bifurication aneurysms by using Guglielmi detachable coils: a 6-year experience.** *J Neurosurg* 1999;90:843–852
67. Klein GE, Szolar DH, Leber KA, Karaic R, Hausegger KA. **Basilar tip aneurysms: endovascular treatment with Guglielmi detachable coils—midterm results.** *Radiology* 1997;205:191–196
68. Eskridge JM, Song JK. **Endovascular embolization of 150 basilar tip aneurysms with Guglielmi detachable coils: results of the Food and Drug Administration multicenter clinical trial.** *J Neurosurg* 1998;89:81–86
69. Guglielmi G, Vinuela F, Duckwiler G, et al. **Endovascular treatment of posterior circulation aneurysms by electrothrombosis using electrically detachable coils.** *J Neurosurg* 1992;77:515–524
70. Murayama Y, Vinuela F, Duckwiler GR, Gobin YP, Guglielmi G. **Embolization of incidental cerebral aneurysms by using the Guglielmi detachable system.** *J Neurosurg* 1999;90:207–214
71. Raymond J, Roy D, Bojanowski M, Moumdjian R, L'Esperance G. **Endovascular treatment of acutely ruptured and Unruptured aneurysms of the basilar bifurcation.** *J Neurosurg* 1997;86:211–219
72. McDougall CG, Halbach VV, Dowd CF, Higashida RT, Larsen DW, Hieshima GB. **Endovascular treatment of basilar tip aneurysms using electrolytically detachable coils.** *J Neurosurg* 1996;84:393–399
73. Byrne JV, Adams CB, Kerr RS, Molyneux AJ. **Endosaccular treatment of inoperable intracranial aneurysms with platinum coils.** *Br J Neurosurg* 1995;9:585–592
74. Casasco AE, Aymard A, Gobin YP, et al. **Selective endovascular treatment of 71 intracranial aneurysms with platinum coils.** *J Neurosurg* 1993;79:3–10
75. Soeda A, Sakai N, Sakai H, et al. **Thromboembolic events associated with Guglielmi detachable coil embolization of asymptomatic cerebral aneurysms: evaluation of 66 consecutive cases with use of diffusion-weighted MR imaging.** *AJNR Am J Neuroradiol* 2003;24:127–132
76. Klotzsch C, Nahser HC, Henkes H, Kuhne D, Berlit P. **Detection of microemboli distal to cerebral aneurysms before and after therapeutic embolization.** *AJNR Am J Neuroradiol* 1998;19:1315–1318
77. Holley P, Bonafe A, Cha F, et al. **Complications of the intravascular treatment of intracranial aneurysms using metal microcoils. Embolization using coils in intracranial aneurysms.** *J Neuroradiol* 1994;21:205–212
78. Graves VB, Strother CM, Duff TA, Perl J 2nd. **Early treatment of ruptured aneurysms with Guglielmi detachable coils: effect on subsequent bleeding.** *Neurosurgery* 1995;37:647–668