



Coil embolization in 481 ruptured intracranial aneurysms: angiographic and clinical results

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PURPOSE

We aimed to report our 13-year experience with the embolization of ruptured cerebral aneurysms using detachable coils and postembolization angiographic and clinical results.

MATERIALS AND METHODS

Between June 1998 and September 2011, 481 patients with ruptured aneurysms were referred for endovascular treatment with detachable coils at our center. The technical feasibility, procedural complications, morbidity, mortality, and initial angiographic and clinical results were evaluated.

RESULTS

Endovascular treatment was successful in 95.6% of the patients. Postembolization angiography showed complete occlusion in 63.4%, a neck remnant in 30.8%, and incomplete occlusion in 5.8% of the aneurysms. A total of 331 patients were followed up. The overall angiographic results showed stable occlusion in 234 aneurysms (70.7%) and recurrence in 97 aneurysms (29.3%). During the follow-up period, stable angiographic occlusion was evident in 75% of the small, 61% of the large, and 38.5% of the giant aneurysms. Complications during the coiling procedure occurred in 75 procedures (15.6%). Ischemic complications were observed in 33 procedures (6.9%), and perforation of the aneurysm during the coiling occurred in 12 cases (2.5%). Five (41.7%) of 12 patients who had perforation during coiling died. The overall procedure-related morbidity and mortality were 5.6% and 2%, respectively. During the follow-up period, two patients (0.4%) had early rebleeding. None of the patients showed late rebleeding. In the follow-up, the retreatment rate was 12.6%.

CONCLUSION

Our data confirm the feasibility, safety, and efficacy of endovascular coil embolization in patients with ruptured cerebral aneurysms.

Cerebral aneurysm treatment experienced a revolution after the introduction of Guglielmi detachable coils in 1991 (1, 2). Initially, endovascular treatment was preferred for patients with higher surgical morbidity, those with poor medical conditions for surgery and those who refused surgery (3). The first randomized controlled study was the International Subarachnoid Aneurysm Trial (ISAT), which compared clipping and endovascular treatment in patients with intracranial aneurysms. It demonstrated better outcomes for ruptured aneurysms that were treated with coiling (4, 5). This study led to a substantial change in the treatment of cerebral aneurysms despite continued controversy regarding the durability and long-term efficacy of coil treatment for preventing rebleeding (6). In the last decade, endovascular coil embolization has become the treatment of choice for most ruptured cerebral aneurysms (7, 8).

The purpose of this study was to report our 13-year experience with endovascular coil embolization for treating ruptured intracranial aneurysms and to describe the technical feasibility, procedural complications, morbidity, mortality, and initial angiographic and clinical results of our endovascular treatment.

Materials and methods

Patient population

Between June 1998 and September 2011, a total of 481 patients with 527 cerebral aneurysms were referred to endovascular treatment at our hospital. Thirty-nine (8.1%) of the 481 patients had multiple aneurysms; 442 patients had one aneurysm, 33 patients had two aneurysms, five patients had three aneurysms, and one patient had four aneurysms. In patients with multiple aneurysms, the aneurysms responsible for subarachnoid hemorrhage (SAH) were assessed by computed tomography (CT) and angiographic findings such as blood distribution on CT, aneurysm appearance (presence of a nipple or lobulation) and vasospasm distribution on digital subtraction angiography (DSA). According to these criteria, 481 patients with 481 ruptured aneurysms were included in the study. The unruptured aneurysms were either treated during the same session or later.

The 481 patients consisted of 274 females (57%) and 207 males (43%). The mean age was 52.5 years (range, 11–85 years). Prior to treatment, the clinical grades of the patients were assessed using the World Federation of Neurosurgical Societies (WFNS) grading scale (9). Most of the patients (58%) were grade I, 25% were grade II, 11% were grade III, and only 5.9% were grades IV and V (Table 1).

The decision to treat with coil

The patients were referred by the neurosurgical department. The decision to treat each patient was made after the patient had consulted

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Table 1. The clinical grading of the patients before treatment, using the WFNS grading scale (9)

WFNS grade	Glasgow coma score	Number of patients (%)
I	15	279 (58)
II	13–14	121 (25)
III	13–14	53 (11)
IV	7–12	19 (4)
V	3–6	9 (1.9)

with a neurosurgeon (K.K.) and a neurointerventionalist (H.D., M.H.Ö., A.S.) about the clinical and radiological findings, such as patient's age, clinical grade of the patient, aneurysm location, aneurysm size, neck to dome ratio or neck size, and whether the parent artery arose from the sac.

Endovascular technique

Between June 1998 and August 2000, 42 of the 481 patients were treated under deep sedation. After August 2000, all of the patients were treated under general anesthesia. Systemic heparin was used after placing the introducer sheath. A baseline activated clotting time was obtained for each patient prior to embolization. The activated coagulation time was maintained at two to three times the normal value during the procedure and for 24–36 hours afterwards.

The treatment consisted of navigating a 6 F introducer sheath Arrow-Flex 6 F, 7 F (Arrow International Inc., Reading, Pennsylvania, USA) or a Destination 6 F, 7 F (Terumo Medical Corporation, Elkton, Maryland, USA) through the femoral artery to the common carotid artery and subsequently introducing a 5 F or 6 F Envoy guiding catheter (Cordis Corporation, Miami Lakes, Florida, USA; Codman & Shurtleff, Inc., Raynham, Massachusetts, USA), a Fargo-Fargomax 6 F (Balt Extrusion, Montmorency, France) or Guider 6 F (Boston Scientific/Target, Natick, Massachusetts, USA) to the proximal segment of the internal carotid artery (ICA) under fluoroscopic or road mapping guidance, using a monoplane until 2009 (Advantex, GE Medical Systems, Milwaukee, Wisconsin, USA) or biplane with three-dimensional reconstruction after 2009 (Neurostar, Siemens Medical Solutions, Erlangen, Germany). Different types

of microcatheters, including a Rapid Transit microcatheter (Cordis Corporation; Codman & Shurtleff, Inc.), were used, depending on the aneurysm size and location; an Exel-10 microcatheter (Boston Scientific/Target) and an Echelon™ 10 (ev3 Micro Therapeutics Inc., Irvine, California, USA) were used both in the early and more recent cases. Under road mapping and magnified-fluoroscopy guidance, the microcatheter was navigated into the aneurysm sac using a Fas-Dasher microguidewire (Boston Scientific/Target), a Radifocus Glidewire (Terumo Corporation, Tokyo, Japan), or an X-Pedion (ev3 Micro Therapeutics Inc.). The balloon-assisted technique, using compliant balloons such as the Hyper form or Hyper glide (ev3 Micro Therapeutics Inc.) was employed in patients with wide-necked aneurysms. The vast majority of the deployed coils were bare platinum, including the Micrus coil (Micrus Endovascular, San Jose, California, USA), Guglielmi Detachable Coils (Boston Scientific, Fremont, California, USA), MicroVention/Terumo coils (MicroVention Inc., Tustin, California, USA), and Axium coils (ev3 Micro Therapeutics Inc.). A small number of coated bioactive Cerecyte coils (Micrus Endovascular) were also used.

In patients with vasospasm or who were prone to vasospasm, a nimodipine or papaverine infusion into the carotid or vertebral artery was maintained through the guiding catheter. The aneurysm coiling was repeated until the aneurysm sac was occluded as densely as possible. The coil size, coil type, and number of coils used were recorded for each case. Large aneurysms were treated with both 0.010 and 0.018 inch coils, whereas in acute stage (within 0–3 days after hemorrhage) and small aneurysms, only 0.010 inch coils were used. After 2006,

in 305 patients (63.5%), Angio-Seal (St. Jude Medical, Minnetonka, Minnesota, USA), a vascular closure device, was used to seal the femoral artery puncture site following the embolization procedure.

Clinical and radiological follow-up

The clinical condition of the patients prior to treatment was determined with the Glasgow Coma Scale and the WFNS grading scale (9). Following treatment, the clinical outcome was assessed using the Glasgow outcome scale (10).

Each patient was scheduled for follow-up DSA or contrast-enhanced magnetic resonance angiography (MRA) at 6 months, 12 months, and yearly thereafter. When an aneurysm recurrence could not be excluded on MRA, a formal DSA was performed. Endovascular retreatment was performed if the recurrence was found to be morphologically significant. We attempted to evaluate the clinical outcomes of the patients who refused any imaging studies, including magnetic resonance imaging and DSA, through a telephone interview. The postembolization and follow-up angiograms were evaluated by three experienced neuro-interventionalists (H.D., M.H.Ö., A.S.). The degree of aneurysm occlusion was evaluated from the immediate postembolization angiograms with multiple angiographic projections. We evaluated the angiographic results of the coil embolization using the classification scale established by Roy et al. (11). This scale classifies aneurysms as follows: class 1, complete aneurysm occlusion without any contrast filling of the aneurysm neck and sac; class 2, residual neck without contrast filling of the aneurysm sac; class 3, aneurysm sac opacification (residue aneurysms).

Results

Aneurysm characteristics and locations

The most common aneurysm location (45.9%) was at the anterior communicating artery (AcomA) (Table 2). Three patients had proximal cervical ICA aneurysms accompanied by intracranial aneurysms. One had an AcomA aneurysm and a left cervical ICA aneurysm, one had a right middle cerebral artery (MCA) bifurcation aneurysm and a right cervical ICA aneurysm, and one had a right posterior communicating artery (PcomA) aneurysm and a

right cervical ICA aneurysm. Two patients with SAH were pregnant. One of the pregnant patients had an AcomA aneurysm, and the other patient had a right proximal posterior inferior cerebellar artery aneurysm.

Using angiographic data obtained prior to embolization, the neck, size, and width of the aneurysms were evaluated. Of the total, 358 aneurysms (74.4%) were small (<10 mm in diameter), 102 aneurysms (21.2%) were between 11 and 24 mm, and 21 (4.3%) were giant (>25 mm in diameter) (Table 3). The aneurysm neck size was small (≤ 4 mm) in 283 aneurysms (58.8%) and large (>4 mm) in 198 aneurysms (41.2%).

Feasibility and efficacy of treatment

In 22 patients (4.4%), treatment was unsuccessful due to access problems, such as tortuosity, occlusion of the carotid (n=4) and iliac arteries (n=11), and severe vasospasm (n=5). Two patients failed endovascular treatment, even when a balloon-assisted technique was used because they had wide-neck aneurysms with small sacs. These 22 patients were referred to surgery and not included in the study population.

We did not use stents in the patients with acutely ruptured intracranial berry aneurysms. In three patients, there were unruptured cervical ICA aneurysms in addition to intracranial ruptured aneurysms. These aneurysms were treated with bare and/or covered stents. The cervical ICA aneurysm was treated with a stent-assisted coiling technique in the first patient, with bare and covered stents in the second patient, and with bare stents without coiling in the third patient.

Immediate postembolization results

A total of 481 successfully coiled aneurysms were documented. With increasing experience, we came to use coil embolization with a balloon-assisted technique in 245 aneurysms (51%). The overall immediate postembolization angiographic results were as follows: 305 (63.4%) were completely occluded, 148 (30.8%) had neck remnants, and 28 (5.8%) were incompletely occluded. The detailed postembolization results are summarized by aneurysm size in Table 3.

Complications

Complications during the coiling procedure occurred in 75 cases (15.6%). Ten of these patients died from various causes, including aneurysm perforation, ischemic complications, and retroperitoneal hemorrhage. The complications encountered during the endovascular treatment are presented in Table 4.

Rupture during coil embolization

Rupture occurred during coil embolization in 12 (2.5%) of the cases. Of these cases, two (16.7%) were MCA aneurysms, seven (58.3%) were AcomA aneurysms, and three (25%) were PcomA aneurysms. The causes of the aneurysm ruptures were microcatheter perforation in three patients, coil perforation in six patients, and microgu-

Table 2. The location of the cerebral aneurysms

Aneurysm localizations	Number of aneurysms (%)
Anterior circulation	433 (90.0)
ACA	
AcomA	221 (45.9)
ACA A1 segment	10 (2.1)
ACA pericallosal segment	26 (5.4)
Total	257 (53.4)
ICA	
Proximal ICA, paraophthalmic, cavernous	22 (4.6)
PcomA	85 (17.7)
ICA bifurcation	19 (4.0)
Total	126 (26.2)
MCA	
Proximal to bifurcation (M1)	4 (0.8)
Bifurcation	43 (8.9)
Distal of MCA	3 (0.6)
Total	50 (10.4)
Posterior circulation	48 (10.0)
Basilar tip	22 (4.6)
Basilar trunk	1 (0.2)
Superior cerebellar artery	7 (1.5)
PICA	11 (2.3)
Posterior cerebral artery	4 (0.8)
Vertebral artery	3 (0.6)
Total	481 (100.0)

ACA, anterior cerebral artery; AcomA, anterior communicating artery; ICA, internal carotid artery; MCA, middle cerebral artery; PcomA, posterior communicating artery; PICA, posterior inferior cerebellar artery.

Table 3. The initial postembolization occlusion grade of the aneurysms, by aneurysm size

Occlusion grades	Aneurysm size		
	Small (<10 mm)	Large (11–24 mm)	Giant (>25 mm)
Class I	256 (71.5)	44 (43.1)	5 (23.8)
Class II	92 (25.7)	45 (44.1)	11 (52.4)
Class III	10 (2.8)	13 (12.7)	5 (23.8)

Data are given as number of aneurysms (%).

idewire perforation in three patients. Among the ruptured aneurysms, all but one were small (<10 mm), six were 3 mm, four were between 4 and 8 mm, one was 10 mm, and one was 12 mm in size. Five patients (41.7%) with intraoperative perforations died, three patients (25%) recovered without any clinical sequelae, and four patients (33.3%) suffered neurological deterioration.

We treated the ruptured aneurysms by immediately reversing the heparin (1 mL of protamine sulfate was used to reverse 1000 units of heparin) and continuing with the coiling without withdrawing the microcatheter. If we were using a microballoon across the neck of the aneurysm, we temporarily inflated the balloon while reversing the heparin and coiling the aneurysm. Immediately after the embolization, we checked the extent of the hemorrhage with serial CT scans and measured the cerebrospinal fluid pressure. If necessary, ventricular and/or cerebrospinal fluid drainage was performed to reduce intracranial pressure.

Coil protrusion and migration

Coil protrusion into the parent artery occurred in seven patients (1.5%), and complete coil migration to distal vascular arteries occurred in two patients (0.4%). One of the patients with coil migration had azygos anterior cerebral artery and anterior cerebral artery aneurysms at the bifurcation of the azygos artery. The second patient had a 3-mm left ICA bifurcation aneurysm with a wide neck. In these two patients, the coils migrated into a pericallosal branch of the left anterior cerebral artery after detachment. We retrieved the migrated coils with a 2-mm microsnares (Microvena Corp., White Bear Lake, Minnesota, USA).

Thromboembolic complications

Thromboembolic complications were encountered during coil embolization in 33 patients (6.9%). Eleven of these patients were clinically asymptomatic. Ten of the patients recovered with mild neurological deficits. Four patients died from ischemic complications of the coiling. Seven of the patients recovered with permanent and severe neurologic deficits, and two of these patients remained completely dependent on caregivers. The overall

permanent morbidity and mortality rates were 3.5% and 0.8% in thromboembolic patients, respectively.

The rate of thromboembolic complications and intraoperative rupture were not significantly different in the conventional coil embolization and balloon remodeling groups. Although the mortality rate of intraoperative rupture in the remodeling group (0.8%) was lower compared with the conventional coiling group (1.3%), the difference was not statistically significant (Table 5).

After 2003, we routinely used intra-arterial tirofiban (glycoprotein IIb/IIIa inhibitor) for thromboembolic events if the aneurysm sac was completely occluded. We used selective intra-arterial or intravenous tirofiban in 17 of the patients with thromboembolic complications. In nine (53%) of these 17 patients, the thrombus resolved completely. In six patients, the thrombus resolved partially, and in

two patients, the thrombus remained unchanged. One of these patients died. Initially, we used 0.5 mg of tirofiban and waited for 10 min. After a control DSA, we repeated this tirofiban dose if necessary. The maximum dose used for thromboembolic events was 2 mg. None of the patients died from tirofiban complications. In two patients, we used intra-arterial recombinant tissue plasminogen activators (r-tPA) after administering tirofiban. One of these patients completely recovered. The other patient recovered with permanent neurological deficits.

Retroperitoneal hemorrhage

Retroperitoneal hemorrhage due to hemostasis problems of the femoral artery puncture site was observed in five patients (1%). One of these patients died as a result of hemorrhagic shock. Four were encountered before using the vascular closure device, while one

Table 4. Complications encountered during endovascular treatment of ruptured aneurysms

Complications	Number of procedures (%)	Morbidity (n [%])	Mortality (n [%])
Aneurysm perforation	12 (2.5)	4 (0.8)	5 (1)
Thromboembolism	33 (6.9)	17 (3.5)	4 (0.8)
Coil protrusion	7 (1.5)	0	0
Coil stretching	8 (1.7)	0	0
Coil migration	2 (0.4)	0	0
Parent artery occlusion	1 (0.2)	0	0
Third nerve paralysis	3 (0.6)	3 (0.6)	0
Retroperitoneal hemorrhage	5 (1)	3 (0.6)	1 (0.2)
Dissection	4 (0.8)	0	0
Total	75 (15.6)	27 (5.6)	10 (2)

Table 5. Complications of aneurysms perforation and thromboembolism according to balloon remodeling and standard coiling

	n (%)	Morbidity (n [%])	Mortality (n [%])
Balloon remodeling (n=245)			
Aneurysm perforation	5 (2)	2 (0.8)	2 (0.8)
Thromboembolism	17 (7)	8 (3.2)	2 (0.8)
Standard coiling (n=236)			
Aneurysm perforation	7 (3)	2 (0.8)	3 (1.3)
Thromboembolism	16 (6.7)	9 (3.8)	2 (0.8)

The morbidity and mortality rates for balloon remodeling and standard coiling groups were not significantly different ($P > 0.5$).

occurred after sealing the femoral puncture.

Follow-up results

The following patients were excluded from the follow-up study: patients who were lost to follow-up (35 patients), patients who refused any follow-up imaging (17 patients) and patients who died due to the severity of the SAH (79 patients). Nineteen patients died from conditions unrelated to their SAH, such as cancer, cardiovascular disease, and other systemic diseases. The follow-up included 331 patients (68.8%).

The overall angiographic results showed stable occlusion in 234 aneurysms (70.7%) and recurrence in 97 aneurysms (29.3%). Forty-five (46.3%) of the recurrent aneurysms had been treated by standard coil embolization, while 52 (53.6%) had been treated using the balloon remodeling technique. The recurrence rates were not significantly different between the two techniques. During the follow-up period, 42 recurrences underwent retreatment. Thirty-eight recurrences had a second embolization, and four of the recurrences had a third embolization because of a second recurrence. Our retreatment rate was 12.6%. The follow-up results are summarized in Table 6 and Fig.

Rebleeding

In our series, two patients (0.4%) experienced rebleeding during the follow-up period. The first patient had an AcomA aneurysm, even though total coil embolization had been performed. The bleeding occurred three days after the embolization. The second patient had an MCA aneurysm that was treated with incomplete coil embolization. Rebleeding occurred 24 hours after the coil embolization. None of the patients were admitted to the hospital with late rebleeding.

Discussion

We primarily treat ruptured aneurysms; therefore, our coiling experience is mainly based on this patient population. Both endovascular treatment and microsurgical aneurysm clipping are performed at our hospital. Initially, the decision to use endovascular treatment was based largely on medical comorbidities, and the procedure was primarily used for patients

who were unsuitable for neurosurgical clipping. More recently, endovascular treatment has become the first-line treatment for all ruptured aneurysms. Although clipping is used to treat most MCA aneurysms at our hospital, a total of 50 MCA aneurysms (10.4% of all aneurysms) have been treated with coiling.

In the present study, 63.4% of the aneurysms initially showed complete occlusion, 30.8% showed a neck remnant, and 5.8% showed aneurysmal

filling on angiograms that were performed immediately after the embolization. The complete occlusion rates during follow-up were 75%, 61%, and 38.5% for small, large, and giant aneurysms, respectively. The recanalization rate during the follow-up period was 29.3%, and 70.7% of the aneurysms were stable. As the aneurysm size increases, the rate of complete sac occlusion decreases. In the present study, there was a slight difference (7.3%) in favor of standard coiling, but the re-

Table 6. Stability and recurrence of the embolized aneurysms during the follow-up period, by aneurysm size

Aneurysm size	Stable aneurysmal occlusion (n [%])	Recurrence (n [%])
Small (<10 mm)	186 (75)	62 (25)
Large (11–24 mm)	43 (61)	27 (39)
Giant (>25 mm)	5 (38.5)	8 (61.5)

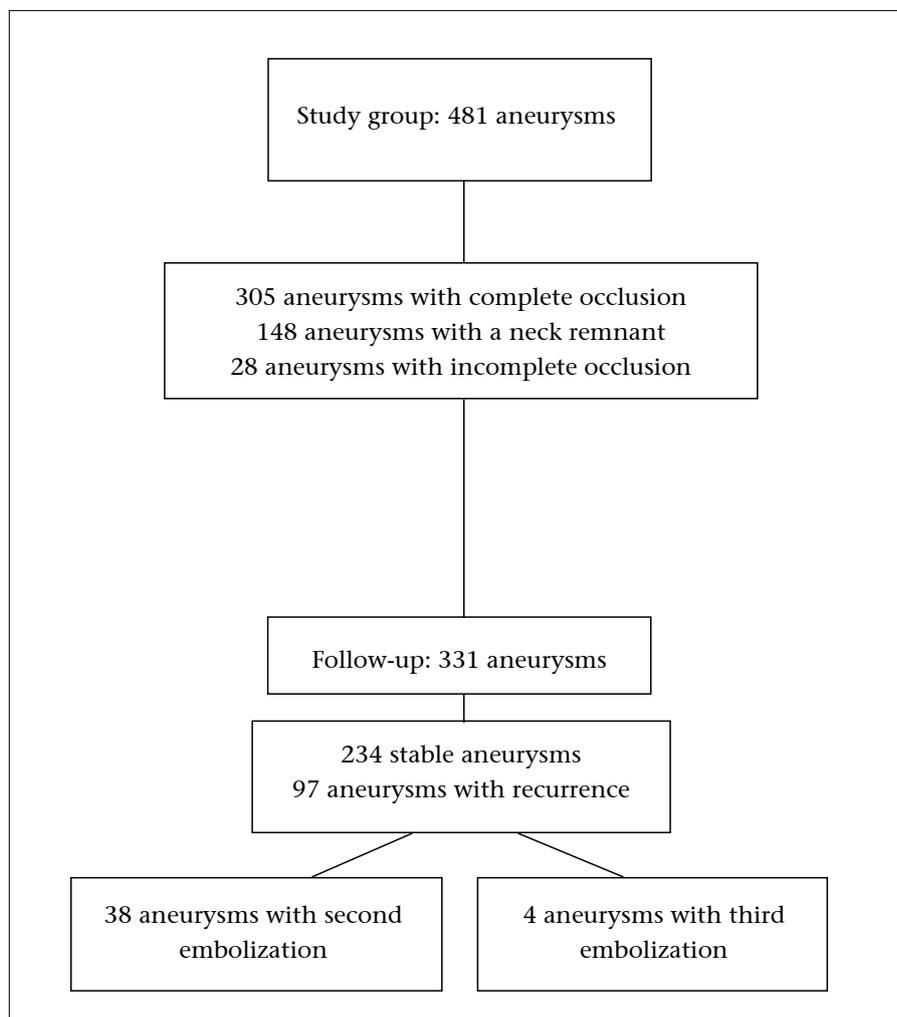


Figure. A flow-chart summarizing the treatment and follow-up findings of the aneurysms.

currence rates between the standard coiling and balloon remodeling techniques were not significantly different. The balloon remodeling technique is primarily used in the treatment of aneurysms that are not suitable for standard coiling, such as wide-neck or anatomically unfavorable aneurysms, and we found that it was as safe as conventional coil embolization. In their series of 780 aneurysms, Renowden et al. (8) reported complete occlusion (Class I) rates of 67%, 35%, and 11% for small, large, and giant aneurysms, respectively. Murayama et al. (12) reported complete occlusion rates of 72.9%, 40.8%, 41.4%, and 37.5% in small aneurysms with small necks, small aneurysms with wide necks, large aneurysms, and giant aneurysms, respectively. According to the published series in the literature, the rate of recanalization after endovascular treatment of cerebral aneurysms ranges from 14% to 34% (13–15). Several clinical, technical, and anatomical factors are implicated in the recanalization rate observed after cerebral aneurysm coiling (16, 17). The aneurysm diameter (>10 mm) and neck width (>4 mm) are the main factors determining the final degree of occlusion achieved (18). In addition to these factors, incomplete coiling or underpacking during the initial aneurysm treatment increases the rate of recanalization during the follow-up period. Using three-dimensional coils, soft coils, complex coils, bioactive coils, and the balloon-assisted technique to treat large and wide-necked aneurysms has improved the coil packing and aneurysm occlusion volume (19, 20). New coil technologies and adjuvant devices, such as intracranial stents, have reduced the recanalization rate in treated aneurysms. Geyik et al. (20) used bioactive Cerecyte coils in 84 intracranial aneurysms. In the immediate postprocedural angiograms, they found complete aneurysm occlusion in 69% of the cases, neck remnants in 29.8% and incomplete occlusion in 1.2%. In the same study, the overall recanalization rate was 11.2%, and the retreatment rate was 6.3%. In the subgroup analysis, the recanalization rates were 4.5% for small aneurysms with a small neck, 9.8% for small aneurysms with a wide neck, and 33.3% for large aneurysms. In a recent meta-analysis, the recurrence rate after embolization occurred in 20.8% of cases, and retreat-

ment was performed in 10.3%–11% (21). In the present study, the retreatment rate was 12.6% during the follow-up. Few data are available on the long-term angiographic follow-up of neurosurgically treated patients for whom postoperative angiography showed complete occlusion of the aneurysm. The main reason for this is that postoperative angiography is not obtained in all cases in many neurosurgical centers, and it is not obtained at all in others. One study showed an incidence of approximately 0.5% per year, and another showed a 0.26% retreatment rate for clipping (22, 23). In the CARAT investigators study, the annual rate of retreatment was 13.3% for coiling and 2.6% for clipping in the first year (24).

In the present study, the overall aneurysm complication rate was 15.6%, and the overall procedural morbidity and mortality rates were 5.6% and 2%, respectively. The main cause of morbidity and mortality was thromboembolism. Thromboembolic complications were observed in 33 (6.9%) of the patients in our study. Thromboembolic complications accounted for 44% of all complications. Most of the thromboembolic complications (66.7%) were transient or mild. The overall permanent morbidity and mortality rates from thromboembolic events were 3.5% and 0.8%, respectively. The rate of thromboembolic complications and the morbidity and mortality rates were not significantly different in the conventional coil embolization and balloon remodeling groups. In previously reported series, the thromboembolic complication rate has ranged from 2.5% to 28% (18, 25). In a large series consisting of 717 patients, Renowden et al. (8) reported a thromboembolic complication rate of 4.4%. The overall permanent morbidity and mortality rate is 1.4%, with 1.0% of patients becoming completely dependent on caregivers or dying. Our complication rates were slightly higher than these results. Park et al. (25) reported an 11% thromboembolic event rate, with an overall thromboembolic mortality rate of 3.4% and a morbidity of 5.9%.

Intraprocedural and immediate post-embolization thromboembolism can be treated with the selective intra-arterial administration of thrombolytic agents, including r-tPA, urokinase and glycoprotein IIb/IIIa inhibitors, such

as tirofiban and abciximab (26–28). In 53% of our patients, intravenous or intra-arterial tirofiban management successfully treated the thrombi resulting from the endovascular aneurysm treatment. Park et al. (25) reported 22 thromboembolic complications, of which eight were treated with superselective intra-arterial or intravenous abciximab, and one was treated with local tPA. They observed complete recanalization in six of the eight patients who were treated with abciximab, and partial recanalization was observed in two patients (25). Cronqvist et al. (28) reported the results of using superselective intra-arterial fibrinolytic therapy with urokinase to treat thromboembolic complications during endovascular aneurysm treatment in 19 patients. In nine cases, the intra-arterial fibrinolytic therapy was combined with mechanical clot fragmentation. Complete recanalization was achieved in 10 (52.5%) of the 19 patients, and partial recanalization was achieved in the remaining nine. These results are similar to our data.

Aneurysmal perforation during endovascular treatment is a serious complication that leads to devastating morbidity and mortality (8, 18, 29). In our series, aneurysmal rupture occurred in 12 patients during coiling (2.5%), and five (41.7%) of the ruptured patients died. The mortality from procedural rupture was 1%, and the morbidity was 0.8%. The rate of intraoperative rupture was not significantly different in the conventional coil embolization and balloon remodeling groups. Although the mortality rate was lower in the remodeling group, it was not statistically significant because the overall numbers were too few for a meaningful statistical analysis. Intraprocedural aneurysm rupture occurred more often (58.3%) in AcomA aneurysms. Aneurysm perforation occurred more commonly (83.3%) in small (<10 mm) aneurysms. The reported rates in the literature range from 1.4% to 16% (8, 17, 29, 30). Renowden et al. (8) reported a 4.7% rupture rate in 784 procedures. In their series, MCA bifurcation aneurysms were the most common (24%) during coiling. Park et al. (25) reported a 4.2% intraprocedural rupture rate. In their series, AcomA aneurysms were the most commonly (44%) ruptured. The main predictors of intraoperative ruptures were the

size of the aneurysm (<5 mm), timing of the coiling and endovascular experience (25). Ricolfi et al. (31) observed four procedure-related perforations in aneurysms that were 4 mm or smaller. Vinuela et al. (32) reported that nine of 11 perforated aneurysms (81.8% of all the ruptured aneurysms) measured 4–10 mm in diameter.

One of the feared complications during coiling procedures is coil herniation into a parent artery or coil migration to distal vascular structures. Although coil herniation of one or two loops into the parent artery may not cause adverse events, we believe that if the loop is free and showing blood flow pulsation, the entire coil mass should be retrieved to prevent its migration. If possible, a microballoon should be inflated across the neck of the aneurysm during herniated loop retrieval to prevent further coil herniation from the aneurysm sac. In our series, coil loops herniated into the parent artery in seven patients, and the first coils completely migrated into the distal vascular arteries in two patients. The most important limitation of using microsnares is the difficulty navigating them into distal cerebral arteries because the microcatheter for microsnares cannot be navigated distally to the migrated coil. In our patients, we used a Rapid Transit microcatheter for microsnares navigation, but alternative techniques exist for managing protruding coils (33). Sugiu et al. (34) described the rescue balloon technique for treating migrating or unraveling coils. In this technique, the herniated coil strands or the coil mass can be replaced in the aneurysm sac by inflating the microballoon across the aneurysm neck. Putting a stent across the aneurysm neck is another option for eliminating herniated coils from the lumen of the parent artery (33). We did not use stents for treating coil loops that herniated into the parent artery.

The main aim of endovascularly treating cerebral aneurysms is to prevent rebleeding of the aneurysm. In the present study, the overall incidence of rebleeding during the follow-up period was 0.4% (two patients). Rebleeding occurred within the first week of embolization. Renowden et al. (8) reported a rebleeding rate of 2.3% during the follow-up period. In other series, the reported incidence of rebleeding

after coiling ranges from 0% to 4.9% (15, 24, 25, 35). There are several reasons for rebleeding. First, the degree of aneurysm occlusion after initial embolization is a strong predictor of subsequent rupture. Second, the rate of complications and rebleeding diminishes significantly with operator experience (34). In a study of 431 patients, Sluzewski et al. (36) found that the independent risk factors for early rebleeding were an aneurysm size of less than 6 mm and an adjacent hematoma on the admission CT scan. In their study, the incidence of early rebleeding after coiling ruptured aneurysms was 1.4% (six patients), and the mortality rate was 100%. In the present study, two patients had early rebleeding following coil embolization. None of the patients had late rebleeding during the follow-up period. Although the first patient had complete coil embolization, the aneurysm bled again on the third day after embolization. We routinely use a heparin infusion for three days after embolization; therefore, we propose that the heparin infusion may have been the primary cause of rebleeding in the first patient and incomplete coil packaging may have been the cause in the second patient.

Many reports have compared endovascular coiling with surgical clipping in patients with ruptured intracranial aneurysms (5, 6). The ISAT is a comprehensive randomized trial comparing the effectiveness of surgical clipping (n=1070) with endovascular coil embolization (n=1073). At one year, the relative and absolute risk reductions in dependency or death after allocation to a coiling and neurosurgical clipping procedure were 22.6% and 6.9%, respectively. Forty-five patients had rebleeding from target aneurysms in the endovascular group, and 39 patients had rebleeding in the neurosurgical group during the first year of follow-up. In the same study, the rebleeding rates during the long-term follow-up period (a minimum of six years and a maximum of 14 years, with a mean follow-up of 8447 person-years in the endovascular group and 8177 person-years in the coiling group) were 0.1% (10 cases) in the coiling group and 0.03% (three cases) in the clipping group (6). At five years, 11% of the patients in the coiling group and 14% of the patients in the neurosurgical group had died. The risk of death was

significantly lower in the coiling group compared to the clipping group, but the survival rate at five years was not different between the two groups (6).

In conclusion, we report a 95.6% success rate for the endovascular treatment of ruptured intracranial aneurysms in our series. The postembolization results showed obliteration of the aneurysm sac with or without a residual neck in 94.2% of the aneurysms. Incomplete aneurysm occlusion was observed in 5.8% of the aneurysms. Complications during the coiling procedure occurred in 75 patients (15.6%). The morbidity, mortality, and recurrence rates did not differ between the standard coiling and balloon remodeling techniques. The overall procedure-related mortality (2%), rebleeding (0.4%), recanalization (29.3%), and retreatment (12.6%) rates were comparable to those reported in the literature. Endovascular treatment should be offered as a viable therapeutic option for all ruptured intracranial aneurysms.

Conflict of interest disclosure

The authors declared no conflicts of interest.

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