

**ORIGINAL
RESEARCH**

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Treatment of Cerebral Aneurysms with Hydrogel-Coated Platinum Coils (HydroCoil): Early Single-Center Experience

PURPOSE: The authors report their experience using HydroCoils in the treatment of cerebral aneurysms.

METHODS: We performed a retrospective review of the first 100 nonrandomized patients (104 coiled saccular cerebral aneurysms) treated with HydroCoils during a 27-month period.

RESULTS: The average percentage of HydroCoil by length detached in treated aneurysms was 45.5% (range, 9.9–100%). Immediate postprocedure angiography demonstrated complete aneurysm occlusion in 34%, neck remnant in 35%, and incomplete occlusion in 32%. Immediate procedure-related morbidity and mortality rates were 5.8% and 0%, respectively. Angiographic follow-up was obtained in 51% (51/100 patients; 53/104 aneurysms; average, 10.3 months; range, 0–31 months). In these 53 angiographically followed aneurysms, the overall recanalization rate was 21%: no recanalization occurred in 23 aneurysms with small size (<10 mm)/small neck (<4 mm) (S/S); 4 recanalizations occurred in 7 aneurysms with small size/wide neck (>4 mm) (S/W); 6 recanalizations (27%) occurred in 22 large (L) aneurysms (>10–25 mm, 70% angiographic follow-up); and 1 giant (G) (>25 mm) aneurysm recanalized. A large proportion of aneurysms that were not initially completely occluded were completely occluded on follow-up (15/43 [35%]). Clinical follow-up was obtained in 73 patients (73%; average, 5.3 months; range, 0–24 months): 93% of these patients were neurologically improved or unchanged. Three patients rehemorrhaged and 3 patients with unruptured aneurysms developed delayed hydrocephalus.

CONCLUSIONS: The overall safety profile of HydroCoils appears acceptable. Preliminary midterm observations suggest less coil compaction/aneurysm recanalization in large aneurysms. However, HydroCoil-related delayed hydrocephalus is a concern.

From its clinical introduction in 1991 in nonsurgical patients with ruptured cerebral aneurysms, the Guglielmi detachable coil (GDC; Boston Scientific Neurovascular, Natick, Mass) and other bare platinum coils have been increasingly used in patients worldwide to occlude ruptured and unruptured cerebral aneurysms.^{1–8} The short-term clinical results of endovascular treatment of cerebral aneurysms with platinum coils continue to improve and are comparable to those of microsurgical clipping.^{1,6,8–10} In particular, aneurysm occlusion with detachable inert bare platinum coils has been shown to decrease the risk of rebleeding during the acute phase and at 1-year follow-up with acceptable procedural risk.^{1,4–6,8,10} However, the long-term permanence of coil occlusion and relative effectiveness of aneurysm coiling in preventing delayed rehemorrhage are still in question.^{8,11}

Despite advances in platinum coil technology^{11,12} and in coiling techniques,¹³ important limitations of coiling with bare platinum coils persist.¹¹ In cerebral aneurysms that are wide-necked or >10 mm, complete aneurysm occlusion with bare platinum coils is achieved in <50% of patients.^{1,8,11} When aneurysms are not completely occluded, the risk of coil compaction and aneu-

rysm recanalization is significant, estimated at 5%, 20%, 35%, and 60% overall for small (<10 mm) narrow-necked (<4 mm) (S/S), small wide-necked (>4 mm) (S/W), large (>10–25 mm) (L), and giant (>25 mm) (G) aneurysms, respectively.¹¹ Given this persistent shortcoming of bare platinum coils, we believe that a new coil that resists coil compaction and decreases the risk of aneurysm recanalization would be a major advance in the treatment of cerebral aneurysms.

The HydroCoil (Microvention, Aliso Viejo, Calif) is a hybrid hydrogel polymer/platinum coil that has the property of volumetric swelling with time (maximal volume achieved in approximately 20 minutes) (Fig 1). The rationale for its use and development is that increased volumetric filling with hydrogel leads to more densely packed aneurysms and results in less coil compaction and aneurysm recanalization. In a recent study of HydroCoils in a canine bifurcation large aneurysm model, HydroCoils compacted less than bare platinum coils.¹⁴

This study describes the early anatomic and clinical outcomes of the first 100 patients with intracranial saccular aneurysms treated with HydroCoils at our institution. We investigated the safety profile of HydroCoils and whether it was associated with less coil compaction/aneurysm recanalization.

Patients and Techniques

Patient Selection

Between November 2002 and February 2005, 277 patients with cerebral aneurysms were treated with endovascular coil embolization at the Beth Israel Hyman-Newman Institute for Neurology and Neurosurgery in New York. During this period, the first consecutive 100 patients in whom HydroCoils were detached in 104 intradural saccular cerebral aneurysms were identified. Patients with HydroCoil and

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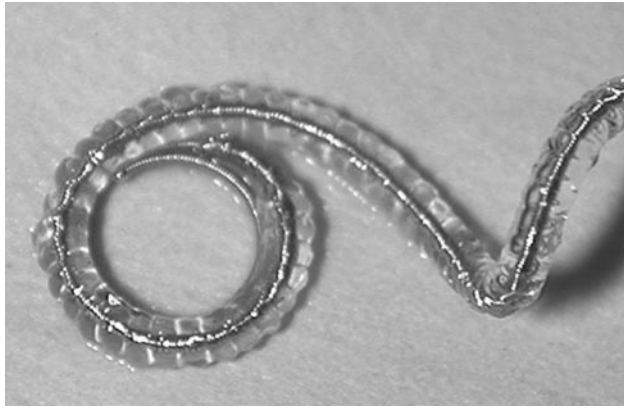


Fig 1. HydroCoil after hydrogel (translucent) coating has fully expanded around a platinum core.

treated extradural cavernous aneurysms, fusiform aneurysms, and distal aneurysms treated primarily with parent artery sacrifice were excluded. Most patients were referred from neurologic and neurosurgical centers for aneurysms or were believed to have a higher risk for surgical treatment, after failed surgical attempt, after prior evaluation by both endovascular surgery and vascular microsurgery teams recommended coiling, or because of patient refusal of surgery.

There were no strict inclusion criteria. On the basis of operator preference, the coiling procedure was augmented with HydroCoil filling coils in selected cases. In general, the tendency of the operators was to treat larger aneurysms with HydroCoils, with the rationale of decreasing the total number of coils used. Review of records could not accurately nor reliably identify patients in whom HydroCoil placement was attempted but not deployed; therefore, the exact number of patients with failed HydroCoil deployments was not recorded. The anatomic and clinical outcomes of this cohort of 100 patients with 104 HydroCoil-treated cerebral saccular aneurysms were retrospectively studied. The patient clinical and aneurysm data are summarized in Table 1. Aneurysms were divided into 4 categories¹¹: S/S, S/W, L, and G aneurysms.

Endovascular Treatment

The technique for endovascular coil treatment has been previously described.^{11,15} Eighty-seven patients were treated on a biplane angiographic system (Siemens, Erlangen, Germany) with 3D-rotational digital subtraction angiography; 13 patients were treated on a single-plane angiographic system without 3D-rotational angiography (Philips Medical Systems, Best, the Netherlands). In general, intravenous heparin infusion was continued for 24–48 hours after the procedure, with maintenance pulse transit time goal of 50 seconds. HydroCoil size and length selection were based on operator preference, and preparation was performed as specified by the manufacturer. HydroCoils were used primarily as filling coils in this series. GDC bare platinum coils were used almost exclusively initially to frame the aneurysm. Balloon-remodeling technique was used in 21 (20%) procedures.¹³ Stent-assisted coiling was performed in 8 (8%) procedures.^{16,17}

Complications

Procedure-related morbidity was recorded as a permanent new neurologic deficit after embolization. Procedure-related death was recorded as death directly related to procedure (eg, intraoperative rupture or procedure-related morbidity leading to death). Delayed rehemorrhage of treated aneurysm was recorded. Clinical follow-up data were collected by review of hospital charts, evaluation

Table 1: Patient and aneurysm characteristics

No. of patients	100
Sex	
Female	66
Male	34
Age	
Mean	53.6 y
Minimum	11 d
Maximum	86 y
No. of treated aneurysms	104
Unruptured aneurysms (%)	56 (54)
Incidental	41 (39)
Mass effect	6 (6)
Previous SAH	8 (8)
Seizure	1 (1)
Ruptured aneurysms (%)	48 (46)
Hunt and Hess grade (%)	
I	16 (15)
II	5 (5)
III	12 (12)
IV	14 (13)
V	1 (1)
Aneurysm location (%)	
Anterior	78 (75)
Cavernous	0 (0)
Ophthalmic	9 (9)
Paraophthalmic	11 (11)
PcomA	28 (27)
AchoA	1 (1)
ICA bifurcation	5 (5)
ACA	1 (1)
AcomA	14 (13)
MCA	9 (9)
Posterior	26 (25)
VB junction	1 (1)
PICA	0 (0)
Basilar trunk	3 (3)
SCA	2 (2)
Basilar tip	16 (15)
PCA	4 (4)
Aneurysm size (%)	
S/S	42 (40)
S/W	27 (26)
Large	32 (32)
Giant	3 (3)
HydroCoil length	
Range	9.9%–100%
Average	45.5%

Note:—SAH indicates subarachnoid hemorrhage; PcomA, posterior communicating artery; AchoA, anterior choroidal artery; ICA, internal carotid artery; ACA, anterior cerebral artery; AcomA, anterior communicating artery; MCA, middle cerebral artery; VB, vertebrobasilar; PICA, posterior inferior cerebral artery; SCA, superior cerebral artery; PCA, posterior cerebral artery; S/S, small size (<10 mm)/narrow-necked (<4 mm); S/W, small size/wide-necked (>4 mm); Large, >10–25 mm; Giant, >25 mm.

at last clinic visitation or follow-up angiography, or by telephone interview. Patients' neurologic outcome at last evaluation was recorded as unchanged, improved, or worse, compared with pre-treatment status.¹¹

Angiographic Evaluation

Angiographic results were recorded immediately and on last follow-up. Multiple projections with selective contrast injections were reviewed for angiographic complete occlusion, defined as no contrast

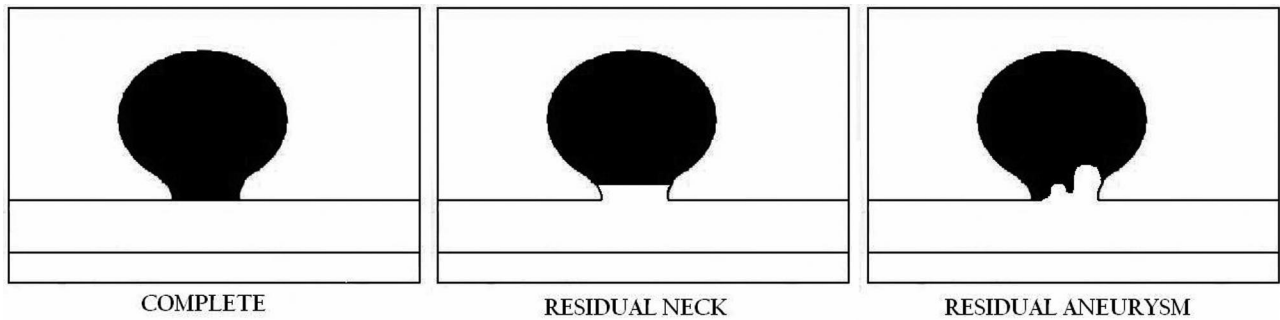


Fig 2. Diagrams of angiographic occlusion classes, adapted from Roy et al⁷: class 1, complete; class 2, residual neck; and class 3, aneurysm filling.

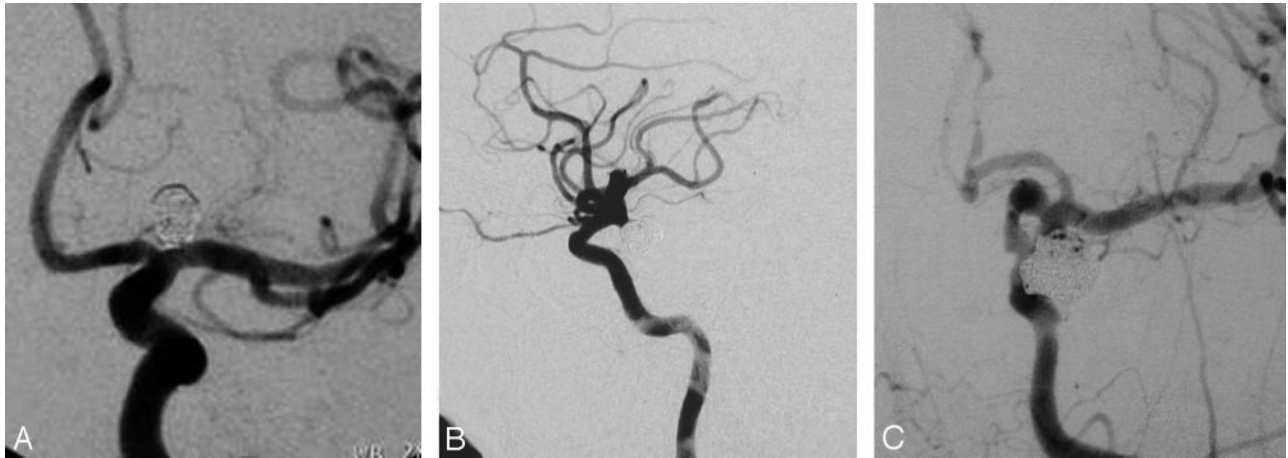


Fig 3. Example of angiographic occlusion classes 1, 2, and 3: class 1, complete occlusion; class 2, persistence of any portion of the original defect of the arterial wall as seen on any single projection but without opacification of the aneurysm sac; and class 3, aneurysm sac opacification.

within the aneurysm dome, body, and neck. We used the classification of angiographic results as defined by Roy et al⁷: class 1, complete occlusion; class 2, persistence of any portion of the original defect of the arterial wall as seen on any single projection but without opacification of the aneurysm sac; class 3, aneurysm sac opacification (Figs 2 and 3). For each patient, the pre- and postembolization and follow-up (if available) angiograms were independently reviewed by 2 attending interventionalists for initial and follow-up aneurysm occlusion grades. The interventionalists were blinded as to the type and percentage length of the HydroCoil used for each patient. Written reports were not reviewed for aneurysm occlusion grade determination. For discordant grades, the worse of the 2 occlusion grades was recorded.

Angiographic Follow-Up Strategy and Evaluation

For patients with all treated aneurysms, follow-up skull x-rays were requested at 3 months. If skull x-rays showed evidence of coil compaction, angiography was recommended immediately. Compared with the postembolization unsubtracted coil mass, visual recognition of a change in coil mass configuration on skull x-rays, either flattening, rotation, loosening, reorientation, and so forth, indicated coil compaction.¹⁸ Otherwise, for patients with ruptured aneurysms, a 6-month follow-up angiogram was recommended. For patients with unruptured aneurysms, a 1-year follow-up angiogram was recommended. Angiograms were also recommended at 3-year and at 5-year follow-up.

To better compare recanalization results with GDC bare platinum coils, we used the same definition of recanalization as that used in the 11-year UCLA experience¹¹: Recanalization was defined as more than 10% increase in contrast filling of the aneurysm; less than 10% in-

creased filling was defined as unchanged. Also for this follow-up group, class (1, 2, or 3) angiographic results were compared immediately after embolization and at last follow-up.

Results

Patient Population

Table 1 summarizes patient and aneurysm characteristics. Sixty percent of patients were women. The mean age was 54 years. Fifty-four percent of the treated aneurysms were unruptured. Three fourths of the treated aneurysms were located in the anterior circulation. S/S aneurysms composed 40%; S/W, 26%; L, 32%; and G, 3%.

Clinical Outcome

Table 2 summarizes procedural complications. Procedure-related morbidity was 5.8% and procedure-related death was 0%. One aneurysm perforation (<1%) occurred (first bare platinum coil framing coil; HydroCoil used to seal re-ruptured site) and led to permanent neurologic deficit in a surviving patient.

Thromboembolism occurred in 9 procedures, leading to 3 permanent neurologic deficits. In a 65-year-old man, a ruptured anterior communicating artery aneurysm was coiled with 20% HydroCoil by length; after the coiling procedure, thromboembolism of the left frontal and parietal cortical branches occurred and was treated with intra-arterial thrombolysis, with improved perfusion to the parietal middle cerebral artery (MCA) branches but not in the left prefrontal MCA territory, leading to a permanent

Table 2: Procedural complications

Procedures	No.	Morbidity	Mortality
Aneurysm perforation	1	1	0
Thromboembolism	9	3	0
Parent artery occlusion	1	0	0
Third nerve palsy	1	1	0
Retroperitoneal hematoma	1	1	0
Coil protrusion	1	0	0
Total	14	6 (5.8%)	0 (0%)

Note:—Results include patients with more than one complication.

language deficit. In a 22-year-old woman with a ruptured basilar trunk aneurysm, intraoperative aneurysm rupture occurred during placement of the first bare platinum coil. Heparin was reversed. A single HydroCoil was used to seal the aneurysm rupture site, but 1 of the coil loops protruded into the parent vessel. An emergent ventriculostomy catheter was then placed in the angiography suite. After ventriculostomy placement, a control angiogram showed thrombus about the coil loop, which was treated with 2 mg of intra-arterial abciximab (ReoPro). Follow-up MR imaging with diffusion imaging showed no infarct; however, the patient did not recover from the rehemorrhage and was eventually discharged to a skilled nursing facility, not cognitively able to participate in her care.

In the third patient, a 67-year-old woman with a ruptured large right posterior communicating artery aneurysm, 22% HydroCoil by length was used; the last coil, a bare platinum coil, stretched and was eventually removed without movement of the coil mass. On the postembolization control angiogram, a distal right inferior parietal branch occlusion was present. The patient was treated with intravenous heparin for 48 hours but had a mild sensory deficit. Parent artery occlusion occurred in 1 procedure, but this did not lead to a new neurologic deficit. Follow-up angiography performed 3 days later showed complete recanalization of the occluded artery.

Clinical follow-up was obtained in 73 patients from <1 month to 24 months; average, 5.3 months. Of these 73 patients, 68 (93%) had improved or unchanged neurologic status at last follow-up. Thirty-two patients had improved neurologic status, 36 patients had unchanged neurologic status, and 5 patients had worse neurologic status. Three patients experienced rehemor-

rhage after coiling (Table 3). Of the patients who rebled, 2 died. Three patients who did not have aneurysm rupture developed symptomatic hydrocephalus requiring ventriculoperitoneal shunt surgery, with recovery in all 3 (Table 4).

Immediate Angiographic Outcome

Immediate postprocedure angiography demonstrated overall class 1 complete aneurysm occlusion in 35 (34%), class 2 neck remnant in 36 (35%), and class 3 incomplete occlusion in 33 (32%). Table 5 summarizes class 1, 2, and 3 angiographic results for S/S, S/W, L, and G aneurysms. In general, more complete closure was seen in S/S aneurysms. On average, HydroCoils composed 45.5% by total length of detached coils within treated aneurysms.

Follow-Up Angiographic Outcome

Follow-up angiography was performed in 51 patients with 53 HydroCoil-treated aneurysms. Table 6 lists the clinical and aneurysm characteristics of this group of patients. Angiographic follow-up was obtained from 0 to 31 months; average, 10.3 months. Forty-two of the 51 patients (82%) had >6 month follow-up. In this angiographically followed group, 1 aneurysm was G; 22 (46%) were L; 7 were (13%) S/W; and 23 were (43%) S/S. On the basis of the initial size distribution of treated aneurysms, angiographic follow-up was obtained in 55% (23/42) of S/S aneurysms, 26% (7/27) of S/W aneurysms, 69% (22/32) of L aneurysms, and 33% (1/3) of G aneurysms. In this angiographically followed group, compared with all patients, the percentage by length of HydroCoils was similar, 51% versus 46%.

Comparison of occlusion class immediately after treatment and at last follow-up showed that 87% of the 53 aneurysms had stable or improved class and 13% had worse class (Table 7). Of the 43 class 2 and class 3 aneurysms, on follow-up, 15 (35%) aneurysms were class 1, completely occluded (Fig 4). Of note, 12/20 (60%) class 3 aneurysms converted to class 1 on last follow-up.

Aneurysm Recanalization

In these 53 angiographically followed aneurysms, overall recanalization rate was 21% (Table 8). No recanalization occurred in 23 S/S aneurysms. Four recanalizations occurred in 7

Table 3: Characteristics of 3 ruptured aneurysm patients who rehemorrhaged

Patient No./ Age/Sex	Hunt and Hess Grade	Aneurysm Location	Aneurysm Size	Immediate Occlusion Grade	% HydroCoil by Length
1/11 d/F	III	AcomA	Large	3	33
2/24 y/F	IV	Basilar apex/P1 PCA	Large	3	43
3/64 y/M	IV	AcomA	Large	2	64

Note:—AcomA indicates anterior communicating artery; PCA, posterior cerebral artery.

Table 4: Characteristics of 3 unruptured aneurysm patients who developed delayed hydrocephalus with symptoms of confusion and gait disturbance

Patient No./ Age(y)/Sex	Aneurysm Location	Aneurysm Type	Immediate Occlusion Grade	% HydroCoil	Time from Procedure (wk)	Symptoms Resolved after Shunting
1/75/F	Paraophthalmic	Large	3	62	9	Yes
2/46/M	ICA bifurcation	S/W	3	40	6	Yes
3/79/M	PcomA	Large	2	82	1	Yes

Note:—ICA indicates internal carotid artery; PcomA, posterior communicating artery.

Table 5: Immediate angiographic occlusion classification

		Class 1 (n = 35; 34%)	Class 2 (n = 36; 35%)	Class 3 (n = 33; 32%)
Overall	n			
S/S	42	22	11	9
S/W	27	9	11	7
Large	32	4	12	16
Giant	3	0	2	1

Note:—Classification is based on Roy et al.⁷. S/S indicates small size (<10 mm)/narrow-necked (<4 mm); S/W, small size/wide-necked (>4 mm); Large, >10–25 mm; Giant, >25 mm.

S/W aneurysms. Recanalization occurred in 6/22 (27%) L aneurysms. One G aneurysm recanalized.

Discussion

The overall safety profile of HydroCoils appears acceptable. In our series, the incidence of thromboembolic complication was slightly higher than our experience with bare platinum coils, and most occurred earlier in our experience. This finding may be due to the larger expanded size of HydroCoils rather than any intrinsic thrombogenic propensity of the coil material. The incidence of thromboembolic complication is probably less if the finishing coils are bare platinum coils; use of these coils was our tendency later in our experience. However, using soft platinum finishing coils may increase the risk of coil compaction. Clot at the coil–parent artery interface can usually be successively treated with intra-arterial and/or intravenous platelet glycoprotein IIb/IIIa receptor inhibitors such as Reo-Pro,¹⁹ even in acute subarachnoid hemorrhage but after the aneurysm has been secured. In patients with unruptured aneurysms, antiplatelet agents may be considered to decrease the risk of thromboembolism.

Three patients rehemorrhaged. In 1 patient, a large basilar apex/P1 posterior cerebral artery aneurysm with pseudoaneurysm was incompletely treated (class 3), and this aneurysm rebled within 24 hours of treatment. In 1 patient, a large anterior communicating aneurysm was treated (class 2), despite gram-negative ventriculitis and brain abscess; this patient rebled 4 months after treatment. In the third patient, a neonate, only 1 HydroCoil could be placed among other platinum coils into a large dysplastic aneurysm, which was not completely occluded (class 3); this aneurysm rebled 2 months later.²⁰

The development of hydrocephalus in 3 patients with unruptured aneurysms is concerning and warrants investigation. CSF analysis in 2 patients was consistent with an aseptic non-specific inflammatory process. All 3 patients had large aneurysms in which a high percentage of HydroCoils was used. Early in our experience, we steamed HydroCoils to induce memory and a tighter coiling profile before advancement into the microcatheter. The contributory role of this practice is unknown. All 3 patients returned to their neurologic baseline after shunt surgery. Steroids administered in the peri- and postprocedure period may decrease this inflammatory risk.²¹

Given the limitations of our study including selection bias and its nonrandomized and uncontrolled retrospective nature, when we compared results to different studies, the significance of any differences is unknown. With that caveat, observationally in our study, in L and S/S aneurysms, HydroCoils seemed to lead to less coil compaction and aneurysm recanalization than that reported for bare platinum coils.^{8,11,22} With almost 70% angiographic follow-up for HydroCoil-treated L

Table 6: Clinical and aneurysm characteristics of 51 patients with 53 aneurysms with angiographic follow-up

No. of patients	51
Sex	
Female	34
Male	17
Age (y)	
Mean	52.1
Minimum	11
Maximum	77
No. of treated aneurysms	53
Unruptured aneurysms (%)	31 (58)
Incidental	22 (42)
Mass effect	4 (8)
Previous SAH	4 (8)
Seizure	1 (2)
Ruptured aneurysms (%)	22 (42)
Hunt and Hess grade (%)	
I	6 (11)
II	5 (9)
III	7 (13)
IV	4 (8)
V	0 (0)
Aneurysm location (%)	
Anterior	43 (81)
Cavernous	0 (0)
Ophthalmic	6 (11)
Paraophthalmic	5 (9)
PcomA	17 (32)
AchoA	0 (0)
ICA bifurcation	2 (4)
ACA	1 (2)
AcomA	5 (9)
MCA	7 (13)
Posterior	10 (19)
VB junction	0 (0)
PICA	0 (0)
Basilar trunk	1 (2)
SCA	0 (0)
Basilar tip	8 (15)
PCA	1 (2)
Aneurysm size	
S/S	23
S/W	7
Large	22
Giant	1
HydroCoil % length	
Range	16.7%–100%
Average	51.0%

Note:—SAH indicates subarachnoid hemorrhage; PcomA, posterior communicating artery; AchoA, anterior choroidal artery; ICA, internal carotid artery; ACA, anterior cerebral artery; AcomA, anterior communicating artery; MCA, middle cerebral artery; VB, vertebrobasilar; PICA, posterior inferior cerebral artery; SCA, superior cerebral artery; PCA, posterior cerebral artery; SIS, small size (<10 mm)/narrow-necked (<4 mm); S/W, small size/wide-necked (>4 mm); Large, >10–25 mm; Giant, >25 mm.

aneurysms, the recanalization rate of 27% (6/22) appears to be an improvement over that reported for GDC-treated L aneurysms.¹¹ For S/S aneurysms, 0% (0/23) recanalization was found with 55% follow-up. In contrast, for S/W aneurysms, HydroCoils did not appear to reduce recanalization, but only 26% (7/27) follow-up was obtained in this group. Of the recanalized aneurysms, 3 were partially thrombosed at the time of treatment; 1 aneurysm was treated in a patient with gram-negative ventriculitis; and in 1 large aneurysm, only 1 HydroCoil was used. The average percentage length of HydroCoil in the recanalized cases was 42%.

Table 7: Angiographic occlusion classification: aneurysm comparison between immediate and last angiographic follow-up

Aneurysm Size		Class (%)		
		Improved	Unchanged	Worse
Overall	53	15 (28)	31 (58)	7 (13)
S/S	23	8	15	0
S/W	7	0	4	3
Large	22	7	12	3
Giant	1	0	0	1

Immediate aneurysm result		Unchanged	Improved	Worse
Class 1	10	9 (90)		1 (10)
Class 2	23	14 (61)	3 (13)	6 (26)
Class 3	20	8 (40)	12 (60)	0 (0)
Overall	53	31 (58)	15 (28)	7 (13)

Note:—Classification is based on Roy et al⁷. S/S indicates small size (<10 mm)/narrow-necked (<4 mm); S/W, small size/wide-necked (>4 mm); Large, >10–25 mm; Giant, >25 mm.
* For all classes included, the last follow-up averaged 10.3 mo.

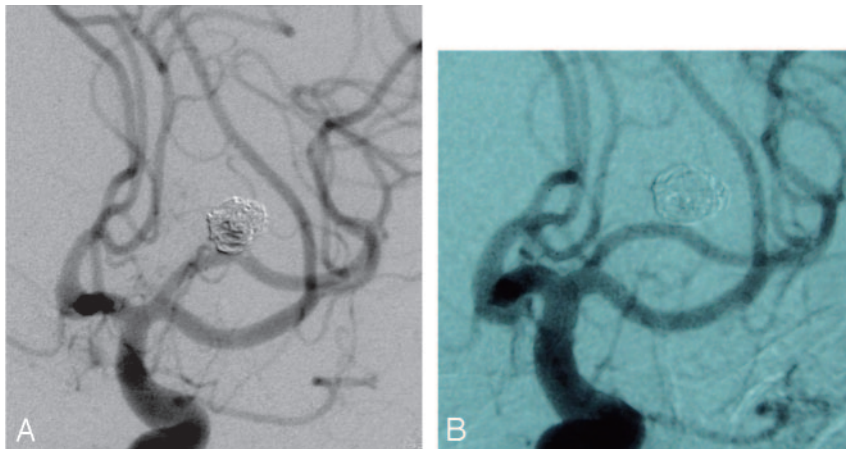


Fig 4. Example of class 3 conversion to class 1. Left accessory MCA aneurysm shows aneurysm filling (class 3) in immediate postembolization angiogram. Ten-month follow-up angiogram shows class 1 complete occlusion.

which coil compaction was seen at 2 weeks and progressed at 3 months.¹⁴ However, in a longer-term retrospective analysis of angiographic recurrences in aneurysms treated with bare platinum coils, Raymond et al²³ found that a significant percentage of aneurysms recanalized beyond 6 months. They reported that only 47% of all recurrences had been detected by 6 months, but by 36 months, 97% of all

recurrences were detected.²³ Their recurrences were associated with treatment after aneurysm rupture; large size, >10 mm; and class 3, incomplete occlusions.²³ This discrepancy may be secondary to some extent to measurement bias, with differences in timing, technique, and compliance of follow-up protocol.

Of particular interest is the natural history of a neck remnant in the UCLA GDC experience.²² In 73 coiled aneurysms with neck remnants that had angiographic follow-up (mean, 17.3 months), recanalization rates were remarkably high: 17%, 42%, 87%, and 90% for S/S, S/W, L, and G aneurysms, respectively.²² This is contrasted to our 10 large aneurysms with residual neck (class 2), of which only 30% recanalized. Of note, 2 of these recanalized aneurysms were partially thrombosed at the time of treatment, and 1 was treated in the setting of gram-negative ventriculitis.

Thirty-five percent (15/43) of aneurysms that were not completely occluded (classes 2 and 3) were found to be completely occluded (converted to class 1) on angiographic follow-up (Fig 4). Conversion from class 3 to class 1 is not typical for GDC coiled aneurysms.^{7,11} Twelve of 20 (60%) of class 3 aneurysms converted to class 1 aneurysms, even in large aneurysms. This change supports the concept that volume-packing plays an important role in recanalization. Despite attenuated packing with the GDC system, the total percentage of volume that GDC or similar bare platinum coils occupy in a treated aneurysm is usually <30%.²⁴ Tamatani et al²⁴ reported that the mean embolized coil volume of angiographically stable aneurysms was 30.8 ± 10.2% and that of recanalized aneu-

Table 8: Recanalization rates

Aneurysm Size	Recanalized (%)*
S/S 23	0 (0)
S/W 7	4 (8)
Large 22	6 (11)
Giant 1	1 (2)
Overall 53	11 (21)

Note:—S/S indicates small size (<10 mm)/narrow-necked (<4 mm); S/W, small size/wide-necked (>4 mm); Large, >10–25 mm; Giant, >25 mm.
* For all classes included, the last follow-up averaged 10.3 mo.

Although the significance of any similarities or differences is not known between the 2 retrospective studies, in our series based on 51% angiographic follow-up, the overall midterm recanalization rate was 21%, which is similar to that reported for GDC.¹¹ Vinuela et al¹ recently reported recanalization rates (similarly defined) of their 11-year pioneering experience with GDC therapy for cerebral aneurysms.¹¹ In this series, 53.4% of GDC-treated aneurysms had angiographic follow-up (average 11 months), which revealed an overall recanalization rate of 21%, with 5.1% for S/S, 20% for S/W, 35.3% for L, and 59.1% for G aneurysms, respectively. With similar percentages of angiographically followed aneurysms (51% versus 54%) and similar follow-up periods (10.3 versus 11 months), as in our experience, Vinuela et al also reported that in their experience, most aneurysm recanalizations occurred within 3 months.^{1,11}

This concept of early coil compaction is supported by our canine high-flow bifurcation wide-neck aneurysm model, in

rysms was $19.9 \pm 10.6\%$ ($P = .03$). With HydroCoils, volume-attenuation packing can reach $>70\%$.¹⁴

In our series, the immediate postembolization complete occlusion rate (class 1) was 35%; residual neck (class 2), 35%; and aneurysm filling (class 3), 30%. Our complete occlusion rate was less than previously reported (average, 54%).^{1,7,8} This discrepancy, in part, can be explained by the subjective nature of reporting results. Unfortunately, no standardization has been widely adopted. In our analysis, we have adhered to strict criteria for complete occlusion. The relatively high rate of aneurysm filling immediately after embolization can also be explained in part by operator preference. With bare platinum coils, attenuated packing is the goal. However, in our opinion, the last coil to achieve attenuated packing is often the most complication-prone.

One subjective advantage of HydroCoils is that the last coil decision becomes less of an issue. Because of the property of HydroCoils of delayed and increasing volumetric expansion, to achieve a comparable degree of coil packing, one needs relatively fewer and shorter lengths of HydroCoils. Therefore, relative underpacking with HydroCoil can ultimately lead to the same or greater volumetric packing than what is expected with GDC bare platinum coils, but this may not be seen on immediate postembolization angiography. For HydroCoil, 30-minute delayed postembolization angiography would be more accurate in assessing immediate angiographic occlusion. A 30-minute delayed angiogram was not obtained routinely in our series.

One of the limitations of HydroCoil is its relatively decreased effectiveness in partially thrombosed aneurysms. The effectiveness of bare platinum coils is also poor in these aneurysms, particularly in G aneurysms.¹¹ In partially thrombosed aneurysms, if coil compaction/migration and aneurysm recanalization occur despite the use of HydroCoils, additional considerations such as stents,^{16,17} liquid embolic agent,²⁵ microsurgical clipping, and if G, parent artery sacrifice with or without bypass should be considered.

In addition to the nonrandom uncontrolled retrospective method of the study, further limitations of our study include the small number of patients and treated aneurysms and the relatively low percentage and short duration of angiographic and, to a less degree, clinical follow-up. As a tertiary center and with a larger number of referrals from local, national, and international sources, return visits for clinical and angiographic follow-up could not be uniformly achieved despite requests. We continue to collect angiographic and clinic follow-up data for this cohort of patients. The first framing coils provide mechanical support to allow denser packing and provide a barrier to prevent hydrogel expansion into the parent vessel lumen. The contribution of bare platinum framing and finishing coils is uncertain.

Conclusions

The overall safety profile of HydroCoils appears acceptable. HydroCoil may be a higher risk/higher reward coil. Preliminary midterm observations suggest less coil compaction/aneurysm recanalization in L aneurysms treated with HydroCoil than that reported for bare platinum coils. However, longer and more complete follow-up is necessary for validation. HydroCoil-related delayed hydrocephalus is a concern. The long-term efficacy of HydroCoils is unknown.

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References

1. 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;86:475–82
2. Guglielmi G, Vinuela F, Dion J, et al. Electrothrombosis of saccular aneurysms via endovascular approach. Part 2. Preliminary clinical experience. *J Neurosurg* 1991;75:8–14
3. Guglielmi G, Vinuela F, Sepetka I, et al. Electrothrombosis of saccular aneurysms via endovascular approach. Part 1. Electrochemical basis, technique, and experimental results. *J Neurosurg* 1991;75:1–7
4. 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
5. Byrne JV, Sohn MJ, Molyneux AJ, et al. Five-year experience in using coil embolization for ruptured intracranial aneurysms: outcomes and incidence of late rebleeding. *J Neurosurg* 1999;90:656–63
6. Molyneux A, Kerr R, Stratton I, et al. Subarachnoid Aneurysm Trial (ISAT) of neurosurgical clipping versus endovascular coiling in 2143 patients with ruptured intracranial aneurysms: a randomised trial. *Lancet* 2002;360:1267–74
7. Roy D, Milot G, Raymond J. Endovascular treatment of unruptured aneurysms. *Stroke* 2001;32:1998–2004
8. Brilstra EH, Rinkel GJ, van der Graaf Y, et al. Treatment of intracranial aneurysms by embolization with coils: a systematic review. *Stroke* 1999;30:470–76
9. Brilstra EH, Rinkel GJ, van der Graaf Y, et al. Quality of life after treatment of unruptured intracranial aneurysms by neurosurgical clipping or by embolization with coils: a prospective, observational study. *Cerebrovasc Dis* 2004;17:44–52
10. Raymond J, Roy D. Safety and efficacy of endovascular treatment of acutely ruptured aneurysms. *Neurosurgery* 1997;41:1235–46
11. Murayama Y, Nien YL, Duckwiler G, et al. Guglielmi detachable coil embolization of cerebral aneurysms: 11 years' experience. *J Neurosurg* 2003;98:959–66
12. Murayama Y, Vinuela F, Tateshima S, et al. Bioabsorbable polymeric material coils for embolization of intracranial aneurysms: a preliminary experimental study. *J Neurosurg* 2001;94:454–63
13. Moret J, Cognard C, Weill A, et al. Reconstruction technic in the treatment of wide-neck intracranial aneurysms: long-term angiographic and clinical results—apropos of 56 cases [in French]. *J Neuroradiol* 1997;24:30–44
14. Yoshino Y, Niimi Y, Song YK, et al. Endovascular treatment of intracranial aneurysm: comparative evaluation in a terminal bifurcation aneurysm model in dogs. *J Neurosurg* 2004;101:996–1003
15. Guglielmi G, Vinuela F, Duckwiler G, et al. Endovascular treatment of posterior circulation aneurysms by electrothrombosis using electrically detachable coils. *J Neurosurg* 1992;77:515–24
16. Lylyk P, Ferrario A, Pasbon B, et al. Buenos Aires experience with the Neuroform self-expanding stent for the treatment of intracranial aneurysms. *J Neurosurg* 2005;102:235–41
17. Benitez RP, Silva MT, Klem J. Endovascular occlusion of wide-necked aneurysms with a new intracranial microstent (Neuroform) and detachable coils. *Neurosurgery* 2004;54:1359–67
18. Connor SE, Wes RJ, Yates DA. The ability of plain radiography to predict intracranial aneurysm occlusion instability during follow-up of endosaccular treatment with Guglielmi detachable coils. *Neuroradiology* 2001;43:680–86
19. Song JK, Niimi Y, Fernandez PM, et al. Thrombus formation during intracranial aneurysm coil placement: treatment with intra-arterial abciximab. *AJNR Am J Neuroradiol* 2004;25:1147–53
20. Song JK, Niimi Y, Brisman JL, et al. Multiple cerebral aneurysms in a neonate: occlusion and rupture. *J Neurosurg* 2005;102(suppl 1):81–85
21. Meyers P, Lavine SD, Fitzsimmons BF, et al. Chemical meningitis after cerebral aneurysm treatment using two second-generation aneurysm coils: report of two cases. *Neurosurgery* 2004;55:222–27
22. Hayakawa M, Murayama Y, Duckwiler G, et al. Natural history of the neck remnant of a cerebral aneurysm treated with the Guglielmi detachable coil system. *J Neurosurg* 2000;93:561–68
23. Raymond J, Guilbert F, Weill A, et al. Long-term angiographic recurrences after selective endovascular treatment of aneurysms with detachable coils. *Stroke* 2003;34:1398–403
24. Tamatani S, Ito Y, Abe H, et al. Evaluation of the stability of aneurysms after embolization using detachable coils: correlation between stability of aneurysms and embolized volume of aneurysms. *AJNR Am J Neuroradiol* 2002;23:762–67
25. Lubicz B, Piotin M, Mounayer C, et al. Selective endovascular treatment of intracranial aneurysms with a liquid embolic: a single-center experience in 39 patients with 41 aneurysms. *AJNR Am J Neuroradiol* 2005;26:885–93