Endovascular Treatment of Intracranial Aneurysms With Guglielmi Detachable Coils
Analysis of Midterm Angiographic and Clinical Outcomes

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Background and Purpose—The previous decade has witnessed increasing application of Guglielmi detachable coils (GDCs) for the treatment of intracranial aneurysms. However, the midterm angiographic and clinical outcomes are not well documented. We report here the angiographic and clinical outcomes of patients treated with GDCs over an 8-year period.

Methods—Between 1992 and 1998, 144 patients with 160 intracranial aneurysms were treated with GDCs. Clinical follow-up data were obtained from medical records, questionnaires, and telephone interviews. Angiographic studies were reviewed by 2 neuroradiologists to obtain consensus regarding the degree of aneurysm occlusion.

Results—Eighty-one patients had ruptured aneurysms; 63 had unruptured aneurysms. Technical success was achieved in 91% of patients, with complete aneurysm occlusion in 46%, neck remnants in 16%, and residual body filling in 38%. Angiographic follow-up revealed that residual body filling in some aneurysms was resolved, small neck remnants were stable, and the recanalization rate decreased with time. All 63 patients with unruptured aneurysms were discharged from hospital with independent clinical status (Glasgow Outcome Score, 1 or 2). For patients with ruptured aneurysms, discharge clinical status correlated with the Hunt & Hess clinical grade at the time of treatment. Clinical follow-up for a minimum of 2 years was available in 98.5% of patients. Ninety-four percent of patients treated for unruptured aneurysms were independent at 2 years, and 82% of Hunt & Hess grade I to II patients were independent.

Conclusions—Coil embolization is a safe and effective treatment for both ruptured and unruptured aneurysms. Increasing angiographic stability is demonstrated in treated aneurysms up to 3 years from coil embolization. Therefore, follow-up angiography until this time is advisable. (Stroke. 2002;33:210-217.)

Key Words: cerebral aneurysm ■ embolization ■ endovascular therapy ■ recanalization ■ subarachnoid hemorrhage

Since its inception in 1991, direct endovascular occlusion of intracranial aneurysms using electrolytically detachable platinum coils has gained popularity as an alternative to surgical clipping. Rapid developments in coil technology and aneurysm remodeling techniques have broadened the application of endovascular therapy to an ever-increasing range of intracranial aneurysms. To date, >80 000 patients have been treated with Guglielmi detachable coils (GDCs).

Short-term results of coil embolization of both ruptured and unruptured aneurysms have been favorable compared with traditional microsurgery. Because of its short history, long-term data on GDC treatment are not yet available, and midterm outcomes of coil embolization are not well established. By documenting the clinical and angiographic outcomes of GDC embolization over an 8-year period, this report advances the current knowledge of the durability of this treatment modality.

Subjects and Methods

Patients
From July 1992 to August 1998, 160 aneurysms (81 ruptured, 79 unruptured) in 144 patients were treated with GDCs (Target Therapeutics) at our institution. A retrospective review of the medical records, outpatient charts, and operative reports was performed.

Angiographic Analysis
The diagnostic, procedural, and follow-up angiograms were reviewed by 2 experienced neuroradiologists per reading session to obtain consensus regarding the degree of aneurysm occlusion. Aneurysm fundus and neck sizes were taken to be the maximal respective measurements. Neck size was considered narrow if <4 mm and wide if ≥4 mm. Fundus size was classified as small if ≤1 cm and large if >1 cm. Aneurysm shape was classified as simple if the aneurysm was smooth and unilocular; aneurysms that were multilocular or had irregular margins were classified as complex. Technical success was defined as the ability to superselectively catheterize and deploy ≥1 coils into the aneurysm. The degree of
aneurysm occlusion after coiling was classified into 3 categories: complete occlusion, neck remnant, and residual body filling (Figure 1).

Because the endovascular technique and angiographic end point for coiling of ruptured and unruptured aneurysms do not differ, analysis of angiographic outcome was performed on all aneurysms as a group.

This report analyzes the midterm outcomes of primary (first-stage) GDC treatment. Patients requiring subsequent procedures such as surgical clipping, coil repacking, or balloon occlusion of the parent vessel were considered to have experienced delayed treatment failure and thereafter were excluded from analysis of outcome. Limited details of those aneurysms requiring coil repacking are provided here.

Procedure-related morbidity was defined as a neurological deficit lasting >7 days that was attributable to the coil embolization procedure.

Clinical Analysis
Because clinical outcome for patients with ruptured aneurysms is expected to differ from those with unruptured aneurysms, these 2 groups were analyzed separately.

The clinical status of patients with subarachnoid hemorrhage (SAH) was assessed at the time of treatment according to the Hunt & Hess1 (H&H) scale. The Glasgow Outcome Score 2 (GOS) (Table 1) was used to grade the clinical status of patients at the time of hospital discharge and at subsequent follow-up. Clinical follow-up data were supplemented by postal questionnaires and telephone interviews to obtain a GOS.

Results
Patients
One hundred forty-four patients, 81 with ruptured and 63 with unruptured aneurysms, were treated. Table 2 summarizes our study population. Fifty-four patients (38%) were male; 90 were female (62%). Patient ages ranged from 3 to 91 years (mean, 52 years).

Of 44 patients who had multiple aneurysms, 15 had >1 aneurysm treated. Of these, 7 patients had ≥1 unruptured aneurysms treated (6 had 2 treated, 1 had 3 treated). Eight patients had 1 ruptured and 1 unruptured aneurysm treated.

Of 81 patients with ruptured aneurysms, 22 (27%) were H&H grade I, 31 (38%) were grade II, 18 (22%) were grade III, 8 (10%) were grade IV, and 2 (3%) were grade V. Of 63

TABLE 1. Glasgow Outcome Score 2

<table>
<thead>
<tr>
<th>Score</th>
<th>Definition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Good recovery</td>
<td>Independent: resumption of normal life even though there may be minor neurological or psychological deficits</td>
</tr>
<tr>
<td>2</td>
<td>Moderate disability</td>
<td>Independent: has neurological or intellectual impairment but is capable of traveling by public transportation and working in a sheltered environment</td>
</tr>
<tr>
<td>3</td>
<td>Severe disability</td>
<td>Conscious but totally dependent on others for daily support</td>
</tr>
<tr>
<td>4</td>
<td>Vegetative survival</td>
<td>Unresponsive and speechless</td>
</tr>
<tr>
<td>5</td>
<td>Dead</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 2. Study Population

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Ruptured</th>
<th>Unruptured</th>
<th>Both</th>
<th>Technical Success</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients, n</td>
<td>144</td>
<td>81</td>
<td>63</td>
<td>15</td>
<td>131</td>
</tr>
<tr>
<td>Aneurysms, n</td>
<td>160</td>
<td>79</td>
<td>. .</td>
<td>135</td>
<td></td>
</tr>
</tbody>
</table>
patients with unruptured aneurysms, 60 (95%) were asymptomatic, and 3 (5%) presented with cranial nerve dysfunction.

Aneurysm Characteristics
The anatomic location of aneurysms is shown in Figure 2. Overall, the anterior communicating artery was the most frequent location. The basilar artery apex was the most common location in the posterior circulation. Of 160 aneurysms treated, 149 were berry aneurysms; 3 were aneurysms on feeding arteries of arteriovenous malformations; and 8 were aneurysm remnants after surgical clipping. There was no statistical difference between ruptured and unruptured aneurysms in terms of their location in the anterior compared with the posterior intracranial circulation (P = 0.110, $\chi^2$ test), shape ($P = 0.114, \chi^2$ test), or fundus size ($P = 0.121, \chi^2$ test). There were significantly more narrow-necked aneurysms in the ruptured group (n = 66) than in the unruptured group (n = 38; $P = 0.0001, \chi^2$ test).

Technical Success
Technical success was achieved in 58 of 63 patients (92%) treated for unruptured aneurysms, 73 of 81 patients (90%) with ruptured aneurysms, or 135 of 160 aneurysms treated (84%). Narrow-necked aneurysms were associated with a higher rate of coil deployment than those with wide necks (96 of 104 or 92% versus 39 of 56 or 70%; $P < 0.0001, \chi^2$ test).

Technical failure occurred in 25 of 160 aneurysms (8 ruptured, 17 unruptured). Of these cases, 19 were aborted because of coil prolapse into the parent vessel, 5 because of an inability to catheterize the aneurysm, and 1 after coil fracture requiring snare retrieval.

Initial Aneurysm Occlusion
Of 135 procedures in which coils were deployed, the immediate postprocedural angiogram showed complete aneurysm occlusion in 62 cases (46%); 22 had neck remnants (16%); and 51 had residual body filling (38%). The proportion of cases in which complete aneurysm occlusion was achieved was not significantly different between the ruptured and unruptured groups (36 of 73 versus 24 of 62; $P = 0.217, \chi^2$ test).

There was a significantly higher rate of complete occlusion for aneurysms with narrow necks compared with wide necks (50 of 104 or 48% versus 12 of 56 or 27%; $P = 0.001, \chi^2$ test) and small compared with large fundi (57 of 133 or 43% versus 5 of 27 or 18.5%; $P = 0.018, \chi^2$ test).

Procedural Complications
Of 160 procedures, 33 (21%) were complicated. Intraprocedural aneurysm rupture occurred in 14 cases, thromboembolic events in 21, internal carotid artery (ICA) dissection in 1, and coil fracture requiring snare retrieval in a single case. Four cases had >1 complication.

Of 14 intraprocedural ruptures, significantly more occurred during treatment of ruptured aneurysms than unruptured aneurysms (13 of 81 or 16% versus 1 of 79 or 1.3%; $P < 0.001, \chi^2$ test). Two of these patients died; 8 were clinically independent (GOS, 1 or 2); and 4 were disabled at the time of hospital discharge.

Of 21 thromboembolic complications, 17 were evident during the procedure; 13 of these were treated with local intraarterial infusion of fibrinolytic or antiplatelet agents. Eleven patients (8.5%) sustained a neurological deficit. Of these, 10 patient (91%) were independent at hospital discharge, and 1 was disabled (GOS, 3).

All patients treated for unruptured aneurysms were independent at hospital discharge, and there were no procedure-related deaths in this group.

The overall procedure-related morbidity rate was 6.9% (11 of 160), and the procedure-related mortality rate was 1.2% (2 of 160). The procedure-related morbidity rate was 5.1% (4 of 79) in the unruptured group and 8.6% (7 of 81) in the ruptured group. The procedure-related mortality was 0% in the unruptured group and 2.5% (2 of 81) in the ruptured group.

Angiographic Outcome
Aneurysms with angiographic follow-up of ≥6 months were included in the analysis of final outcome. Aneurysms requiring further procedures (delayed treatment failures) were excluded thereafter from analysis of outcome. Of these, 4 underwent surgery, 11 had coil repacking, and 1 had permanent balloon occlusion of the parent artery. Eight aneurysms were excluded by 6 months and another 8 by 2 years. Fifteen patients had died by 6 months after their procedure; and 17 had died by 2 years. Of the remaining 112 patients, 82 had follow-up angiography for ≥6 months (73%), and 54 of 102 (53%) had follow-up for >2 years.

Body Filling
Of 51 aneurysms demonstrating body filling immediately after coil embolization, 25 were angiographically examined after 6 to 12 months. Eleven of 25 (44%) showed resolution of body filling. Similarly, 3 of 10 aneurysms (30%) with body filling at 6 to 12 months showed resolution after ≥2 years from coil embolization. Figure 3A depicts the trend for body filling to resolve with time.

Neck Remnants
Eleven of 22 aneurysms having small neck remnants immediately after coil embolization were angiographically examined after 6 to 12 months, and 12 aneurysms having small neck remnants at 6 to 12 months were imaged after 2 years.
Figure 3B depicts the outcome of these aneurysms. There was a tendency for small neck remnants to remain stable (occlusion status unchanged) with time. A corresponding reduction in the recanalization rate from 27% in the first year to 8% over the following year was evident. Similarly, resolution of remnants occurred at a higher rate in the first year than the following year (18% versus 8%).

Complete Occlusion
Thirty of 62 aneurysms initially demonstrating complete aneurysm occlusion were angiographically examined after 6 to 12 months; 7 of these (23%) showed recanalization (6 neck remnants, 1 body filling). Of 14 aneurysms showing complete occlusion at 6 to 12 months, 2 developed recanalized neck remnants after 2 years (14%).

Effect of Neck Size
Over a 2-year period after coil embolization, 102 aneurysms were analyzed to determine the effect of neck size on angiographic outcome. The effect of an aneurysm having a narrow compared with a wide neck is summarized in Table 3. Narrow-necked aneurysms demonstrated a higher rate of resolution of body filling and displayed greater angiographic stability throughout the 2-year period.

Table 3: Effect of Neck Size on Angiographic Outcome at Follow-Up Over a 2-Year Period

<table>
<thead>
<tr>
<th></th>
<th>Narrow Neck, n (%)</th>
<th>Wide Neck, n (%)</th>
</tr>
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<tbody>
<tr>
<td>Stable complete occlusion* (n=40)</td>
<td>24/31 (77)</td>
<td>2/9 (22)</td>
</tr>
<tr>
<td>Stable small neck remnant* (n=23)</td>
<td>15/16 (94)</td>
<td>5/7 (71)</td>
</tr>
<tr>
<td>Resolution of body filling† (n=39)</td>
<td>20/31 (65)</td>
<td>2/8 (25)</td>
</tr>
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</table>

n=102.
*Stable compared with previous angiography.
†Residual body filling demonstrated on angiography that resolved during the follow-up period.

Figure 4. Overall recanalization rate. Rate decreases with time from coil embolization.

**TABLE 4. Effect of Early Compared With Delayed Treatment on Angiographic Outcome at 6 to 12 Months**

<table>
<thead>
<tr>
<th></th>
<th>Early (&lt;13 d) n (%)</th>
<th>Delayed (&gt;14 d) n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stable complete occlusion* (n=16)</td>
<td>11/14 (79)</td>
<td>2/2 (100)</td>
</tr>
<tr>
<td>Stable neck remnant* (n=8)</td>
<td>4/7 (57)</td>
<td>1/1 (100)</td>
</tr>
</tbody>
</table>

n=24.
*Stable compared with baseline after coil embolization angiography.

Effect of Early Versus Delayed Treatment
Twenty-two aneurysms examined angiographically at 6 to 12 months after coil embolization were analyzed to determine the effect of the timing of treatment on angiographic outcome. Table 4 summarizes the effect of early (within 14 days) compared with delayed coil embolization from the time of SAH. A higher proportion of aneurysms treated after 14 days demonstrated angiographic stability at 6- to 12-month follow-up.

Overall Recanalization Rate
Deterioration in the degree of aneurysm occlusion occurred in 12 of 43 patients (28%) in the first year. Six of 30 completely occluded aneurysms (20%) immediately after coil embolization developed small neck remnants, and 1 (3%) developed body filling, whereas 5 of 13 (8%) with neck remnants showed an increase in remnant size.

At 1 to 2 years, 5 of 25 aneurysms (20%) showed features of recanalization. One completely occluded aneurysm developed a neck remnant; 3 neck remnants increased in size; and 1 completely occluded aneurysm developed body filling. At 2 to 3 years, 1 of 7 aneurysms (14%) demonstrated an increase in neck remnant size. A constant decline in the recanalization rate up to 3 years after GDC treatment is depicted in Figure 4.

Reembolization or Subsequent Surgical Clipping
Eleven of 135 aneurysms (8%) treated with GDC required a repeated coil embolization procedure: 9 because coil compaction and 2 because of aneurysmal growth. Six aneurysms with body filling were repacked after a mean period of 8.6 months (range, 4.3 to 16 months). One of these patients had a giant, cavernous ICA aneurysm that required subsequent permanent balloon occlusion of the ICA at 26 months as a result of further recanalization. Three neck remnants were repacked after a mean period of 7 months. Both cases demonstrating aneurysmal growth were repacked within 5...
months; 1 of these required an additional repacking procedure at 54 months.

Two patients underwent surgical clipping of their aneurysm during the original hospital admission because of GDC complications and unsatisfactory aneurysm occlusion. Another patient had aneurysmal growth detected at the 18-month follow-up angiography that necessitated surgical clipping.

**Initial Clinical Outcome**

*Patients With Unruptured Aneurysms*

All 63 patients treated for unruptured aneurysms were discharged from hospital with independent clinical status. Fifty-six were classified as GOS 1; 7 were GOS 2.

*Patients With Ruptured Aneurysms*

Of 73 patients treated for ruptured aneurysms, 14 (19%) died in hospital. Of these, 1 patient was H&H grade I on admission, 3 were grade II, 3 were grade III, 5 were grade IV, and 2 were grade V. Initial clinical outcome was correlated to the clinical grade on admission. Three of 10 H&H grade IV to V patients (30%) were independent at discharge compared with 42 of 48 who were H&H grade I to II (88%). This difference was statistically significant \(P<0.0001, \chi^2\) test).

**Final Clinical Outcome**

Only patients with clinical follow-up data for 2 years were included in this analysis. Patients undergoing a subsequent procedure on their aneurysm were thereafter excluded. Follow-up data were available for 129 of 131 patients (98.5%). Two patients (both had unruptured aneurysms) were lost to follow-up.

*Patients With Unruptured Aneurysms*

Of 58 patients who had coils deployed in 62 aneurysms, 4 were excluded from analysis (3 had repacking procedures, 1 had permanent balloon occlusion of the parent artery) by 6 months. Two patients (3.4%) were lost to follow-up. Of the remaining 52 patients, 51 (98%) were independent (GOS, 1 or 2) at 6 months, and 1 had died of an unrelated cause.

At 2 years aftercoil embolization, another 4 patients were excluded from analysis because of repacking procedures. Forty-four of the remaining 48 patients (94%) remained independent (GOS <3), and 3 more had died: 1 because of a rebleed from an incompletely coiled aneurysm and 2 from unrelated causes.

*Patients With Ruptured Aneurysms*

Of 73 patients who underwent technically successful procedures, 18 were H&H grade I, 29 were grade II, 15 were grade 3, 8 were grade IV, and 2 were grade V at the time of treatment. At 2 years after coil embolization, 7 patients (2 were grade I, 2 were grade II, 3 were grade III) were excluded from analysis (2 underwent surgical clipping and 5 had repacking procedures). Table 5 summarizes the results of the remaining patients. Midterm clinical outcome correlated strongly with the H&H clinical grade at the time of treatment.

**Delayed Rebleeding From Treated Aneurysms**

Two patients (1.5%) experienced delayed rebleeding from a coil-embolized aneurysm after a mean period of 9 months.

One patient treated for an unruptured aneurysm had residual body filling immediately after coil embolization. This patient declined angiographic follow-up and experienced a fatal rebleed at 7 months. The other patient was treated for a ruptured aneurysm. An 8-month follow-up angiogram demonstrated complete aneurysm occlusion. The aneurysm rebled at 11 months, leaving the patient severely disabled.

**Discussion**

Our institution was involved in an international multicenter trial of aneurysm coil embolization approved by the US Food and Drug Administration in July 1992. It was not until February 1995 that GDCs were approved for standard patient treatment at our institution. Consequently, there exists an interim period when GDCs were used only for patients in whom surgery had failed or was contraindicated because of inaccessibility, poor clinical status after SAH, or significant preexisting medical comorbidities. Despite this selection bias in the early years, our results compare favorably with open surgery in terms of procedure-related morbidity and mortality (Figure 5), clinical outcome,6,7 and delayed rebleeding rate.8

This report focuses on the angiographic and clinical outcomes of the primary coil embolization procedure. Patients in whom additional coil embolization or subsequent surgical clipping was performed were excluded from further analysis. Twenty-five aneurysms (16%) had required a subsequent procedure at 2 years after the original coil embolization treatment. Previous reports3,4 have documented delayed first-stage treatment failure rates of 18% to 19%. However, the midterm clinical outcomes of these patients before additional intervention did not significantly differ from the outcomes of

### Table 5. Clinical Outcome of Patients With Ruptured Aneurysms at 2 Years After Coil Embolization

<table>
<thead>
<tr>
<th>H&amp;H Grade</th>
<th>Independent</th>
<th>Disabled (GOS &gt;2)</th>
<th>Dead</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-II (n=44)</td>
<td>36 (82)</td>
<td>2 (4.5)</td>
<td>6 (13.5)</td>
</tr>
<tr>
<td>III (n=12)</td>
<td>7 (47)</td>
<td>1 (6.5)</td>
<td>4 (26.5)†</td>
</tr>
<tr>
<td>IV-V (n=10)</td>
<td>3 (30)</td>
<td>0 (0)</td>
<td>7 (70)‡</td>
</tr>
</tbody>
</table>

\*Four died in hospital of SAH sequelae; 2 died of unrelated causes.  
†Three died in hospital of SAH sequelae; 1 died of an unrelated cause.  
‡All died of SAH sequelae.

![Figure 5. Procedure-related morbidity and mortality. Comparison with other endovascular and surgical series.](http://stroke.ahajournals.org/content/214/1/214.full)
patients who underwent GDC embolization as a definitive treatment.4

Degree of Aneurysm Occlusion
It is difficult to directly compare our occlusion results with other reports because many authors3,9–11 have chosen to categorize the degree of aneurysm occlusion based on the “percentage” of aneurysm overlaid by coils. These methods are based on calculations that use 2-dimensional digital subtraction angiography images. However, aneurysms are 3-dimensional, often lobulated structures. Even with ostensible tight packing, only as little as 25% of the aneurysm volume may be filled with coils.12 Therefore, “percentage” occlusion values of up to 100% described in such studies may be misleading. Because of the small size of many aneurysms, measurement errors may also be exacerbated when used in area calculations. Therefore, we have chosen to use a 3-tier scale: complete occlusion, neck remnant, and body filling. Thus, an aneurysm with a minuscule amount of body filling visible between coil interstices would score ≈100% or nearly complete occlusion in some reports, whereas it would be placed in our worst category. Moreover, residual body filling has been reported as a predictor of long-term failure.13 This is not to say that any body filling should be regarded as an inevitable failure because our results demonstrated that almost half of these cases resolved within the first year, resulting in a number of delayed successes.

The only category lending itself to direct comparison between reports is that of complete or 100% occlusion. Our figure of 46% compares favorably with previous reports describing complete occlusion rates of 40% to 64%.3,10 Neurosurgical series describe a small residual aneurysm neck of ≤2 mm as a success in that it does not pose a risk for future SAH.14 Our results are concordant with this, showing that small neck remnants (<2 mm) tend to remain stable or improve. If this subgroup and the delayed successes from resolution of body filling are included, our overall success rate is substantially higher than the 46% of cases with immediate complete occlusion.

Technical Complications
Despite our overall complication rate of 22%, the procedure-related morbidity and mortality rates were significantly lower at 6.9% and 1.2%, respectively. Previous reports have documented complication rates ranging from 8% to 17%,3,7,11,15,16 with morbidity rates of 3% to 6.5% and mortality rates of 0% to 6.5%.3,11

We have documented all complications regardless of clinical consequence, contributing to the disparity between our complication rate versus morbidity and mortality rates compared with other reports. When appropriate, thromboembolic complications were promptly treated with locally infused fibrinolytics and/or antiplatelet agents, reducing the rate of neurological sequelae.

Most of the intraprocedural aneurysm ruptures occurred during treatment of acutely ruptured aneurysms (93%); the intraprocedural rupture rate for unruptured aneurysms was 1.3%. Mortality rates related to intraprocedural rupture have been reported at 0.5% to 45%17,18 and in our series was 14%.

This series includes our initial experience with GDCs performed by 3 operators who have evolved continuously in terms of their technical skills, strategies, and judgment. Similarly, improvements in microcatheter and coil technology have resulted in higher rates of technical success and fewer complications.

Angiographic Outcome
Very few endovascular series have angiographic follow-up periods >2 years. Moreover, the small number of patients with this length of follow-up in these reports limits their usefulness. Our series has almost double the number of patients with midterm follow-up compared with the next largest series by Kuether et al.3

Our data have permitted the depiction of trends in each occlusion category that have not previously been described. These include a tendency for minor residual body filling to improve, particularly in the first year; a tendency for small neck remnants to remain stable or improve, particularly after the first year; and a tendency for completely occluded aneurysms to recanalize at a lower rate after the first year. Further analysis revealed that narrow-necked aneurysms were associated with a higher rate of technical success, a lower recanalization rate, higher coil stability over time, and a greater tendency to show resolution of body filling.

Aneurysms treated within 14 days of SAH showed a lower rate of resolution of body filling, higher recanalization rates, and a reduced stability of small neck remnants. This may be due to the presence of acute intraneurysmal and/or perianeurysmal soft thrombus, resulting in an increased tendency for coil compaction. Additionally, resolution of SAH-induced vasospasm may lead to alteration of neck geometry and parent vessel hemodynamics predisposing to coil compaction.

The overall recanalization rate was shown to decline fairly constantly with time. There was a trend toward aneurysm stability with decreasing rates of recanalization and resolution of body filling from the time of coil embolization (Figures 3 and 4).

We are aware that some operators choose not to perform angiographic follow-up beyond 6 months if the aneurysm is completely occluded at this time. Our data suggest that this may be premature because recanalization potentially continues to occur. Although longer-term studies are required to elucidate the optimal follow-up period, our data indicate that at least 3 years is required.

Clinical Outcome
Previous authors have reported that 80% to 98.5%3,6 of patients undergoing endovascular treatment for unruptured aneurysms are independent at the time of hospital discharge. In our series, 100% returned to independent clinical status, which compares favorably with previous reports, including a surgical series,6 as shown in Figure 6.3,6,7 For ruptured aneurysms, clinical outcome correlated strongly with the H&H clinical grade at the time of treatment as previously reported.3,4,11

Most reports of clinical outcome have been based on short-term follow-up periods of <2 years.3,7,11 To the best of our knowledge, only 2 previous studies analyzing both
ruptured and unruptured aneurysms have obtained longer-term clinical follow-up data. Kuether et al\(^1\) reported on 72 patients with a minimum of 6 months of clinical follow-up (mean, 2.2 years), and Malisch et al\(^4\) reported on 88 patients with at least 2 years of follow-up (mean, 3.5 years). Our mean follow-up period was 3.8 years, for which 129 patients had such data. In our report, 92% of patients treated for unruptured aneurysms were independent after 2 years, which compares favorably to the aforementioned series (Figure 7).

**Aneurysm Recanalization**

Regardless of the immediate postprocedural result, aneurysm recanalization can occur in all occlusion categories. Our analysis has shown that recanalization of aneurysms showing complete occlusion occurs in almost a quarter of cases in the first year and in 8% the following year.

Factors affecting the occurrence and degree of aneurysm recanalization may be divided into aneurysm factors, parent vessel factors, and coil factors. Aneurysm factors may be subdivided into aneurysm morphology (overall size, neck size), aneurysm location (end artery such as basilar tip), presence of intraluminal or perilesional thrombus (especially if soft or acute thrombus is present), and aneurysm growth such as in inflammatory/mycotic aneurysms. Parent vessel factors include parent vessel size and hence blood flow and the presence or vasospasm that can distort the neck at the time of treatment. As vasospasm resolves, blood flow can increase and the neck may “open up.” Coil factors can be divided into the overall density of coil packing (which is difficult to accurately assess on 2-dimensional images), coil density at the neck and in particular the inflow zone, and the type coils used. Coil geometry (regular versus 3-dimensional), coil size (10 versus 18 series), and softness (standard versus soft versus ultra soft) may all play a role in resisting recanalization.

**Delayed Rebleeding From Treated Aneurysms**

Two patients (1.5%) experienced delayed rebleeding after coil embolization. Other authors, including a surgical series,\(^6\) have experienced rebleeding rates of 0.9% to 3.3%.\(^4,19\)

The occurrence of rebleeding only 3 months after documentation of complete aneurysm occlusion was unexpected and disappointing. We believe rapid recanalization and/or aneurysm regrowth was the likely underlying event. As previously discussed, recanalization can occur for a number of reasons even in completely occluded aneurysms. Rapid aneurysm regrowth lends consideration to an underlying mycotic/inflammatory cause. Although we still would not advocate earlier angiographic follow-up in such a case, it does highlight the need for ongoing angiographic follow-up regardless of early results.

**Conclusions**

Our results confirm that coil embolization is a safe and effective treatment for both ruptured and unruptured aneurysms. Procedure-related morbidity and mortality rates, midterm clinical outcome, and rebleeding rates compare favorably with open neurosurgery. Additional data are required to determine long-term angiographic and clinical outcomes.

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