Natural history of the neck remnant of a cerebral aneurysm treated with the Guglielmi detachable coil system

MOTOHARU HAYAKAWA, M.D., YUICHI MURAYAMA, M.D., GARY R. DUCKWILER, M.D., Y. PIERRE GOBIN, M.D., GUIDO GUGLIELMI, M.D., AND FERNANDO VINUELA, M.D.

Division of Interventional Neuroradiology, School of Medicine, University of California at Los Angeles, California

Object. The long-term durability of Guglielmi detachable coil (GDC) embolization of cerebral aneurysms is still unknown. The purpose of this study was to evaluate the anatomical evolution of neck remnants in aneurysms treated with GDCs.

Methods. Of 455 aneurysms treated with GDCs from 1990 to 1998 at the University of California at Los Angeles Medical Center, 178 aneurysms (39%) had residual necks postembolization. Long-term follow-up angiograms were obtained in 73 of these aneurysms in 71 patients. The mean duration of angiographic follow up was 17.3 months. Twenty-four of the aneurysms were small with small necks, 24 were small with wide necks, 15 were large, and 10 were giant aneurysms.

In small aneurysms with small necks, postembolization angiography revealed 12 aneurysms (50%) with progressive thrombosis, eight (33%) unchanged, and four (17%) with recanalization. In small aneurysms with wide necks, six (25%) had progressive thrombosis, eight (33%) remained unchanged, and 10 (42%) had recanalization. In large aneurysms, two (13%) were unchanged and 13 (87%) had recanalization. Of the giant aneurysms only one (10%) remained unchanged and nine (90%) had recanalization. Overall, 18 aneurysms (25%) exhibited progressive thrombosis, 19 (26%) remained unchanged, and 36 (49%) displayed recanalization on follow-up angiography. During the last 2 years of the study, the recanalization rate decreased and a higher rate of progressive thrombosis was noted in aneurysms with small necks. These positive changes are related to important new technical developments.

Conclusions. Treatment with GDCs appears to be effective and the results permanent in most small aneurysms with small necks. However, there are important technical limitations in the current GDC technology that prevent recanalization in wide-necked or large or giant aneurysms.

KEY WORDS • cerebral aneurysm • Guglielmi detachable coil • residual neck • neck remnant • natural history • embolization

The goal of treatment of a cerebral aneurysm is its complete isolation from the parent artery. Surgical clipping continues to be the gold standard for treatment of these aneurysms. The GDC procedure was first introduced by Guglielmi and colleagues15,17 in 1991 and has become a popular alternative to conventional surgery for the treatment of cerebral aneurysms. Recent technical developments in the GDC system have enabled the interventional neuroradiologist to improve anatomical and clinical outcomes.44 Endovascular treatment of cerebral aneurysms using GDCs has produced encouraging results in preventing rebleeding during the acute phase of subarachnoid hemorrhage.1,4,6,10,14,27,43

In a recent clinical study, Viñuela, et al.,43 reported that complete GDC occlusion was achieved in 70.8% of small aneurysms with small necks, 31.2% of small aneurysms with wide necks, 35% of large aneurysms, and 50% of giant aneurysms. A neck remnant was observed in 21.4% of small aneurysms with small necks, 41.6% of small aneurysms with wide necks, 57.1% of large aneurysms, and 50% of giant aneurysms.

A neck remnant is not infrequently seen after GDC embolization,20 particularly in wide-necked aneurysms.11 However, the long-term outcomes of these neck remnants, determined using angiography, have not previously been reported.

In this study, we evaluated long-term anatomical outcomes of neck remnants in aneurysms treated with GDCs at the UCLA Medical Center.

Clinical Material and Methods

Patient Population

Four hundred one patients with 455 aneurysms were treated with GDCs from 1990 to 1998 at the UCLA Medical Center. One hundred seventy-eight aneurysms (39%) in 173 patients had residual necks postembolization. It is the policy of our center to recommend postembolization
Patient Selection

The therapeutic alternatives for each patient were discussed among members of the UCLA cerebrovascular team. The indications for GDC treatment included: failed surgical exploration in 11 patients (15%); poor medical condition in 13 patients (18%); refusal to undergo surgery in 10 patients (14%); and age older than 70 years in 10 patients (14%). Thirty-seven patients (52%) were referred directly by their neurosurgeons for endovascular treatment.

Locations of Aneurysms

Forty-seven aneurysms (64%) with neck remnants were located in the anterior circulation and 26 (36%) in the posterior circulation. The most common location was the ophthalmic or paracclinoid segment of the ICA in 21 aneurysms (29%), followed by the posterior communicating artery or the anterior choroidal segment of the ICA in 13 aneurysms (18%), and the basilar artery tip in 12 aneurysms (16%) (Table 1).

Method of GDC Embolization

Details of the GDC embolization procedure have been published elsewhere.3,7,13,15,16,18,34,37–39,42,43 In this series, the same basic method was applied to endovascular embolization of intracranial aneurysms. In the last 2 years of the study, we used softer, smaller coils, which allowed denser packing of aneurysms. In selected cases of wide-necked aneurysms, we used a balloon-assisted method (nine cases) and new-generation 3D GDCs.

Angiographic Evaluation

The rate of aneurysm obliteration was evaluated using postembolization angiography in multiple projections. The anatomical results of treatment were categorized as follows: complete occlusion (no contrast filling of the dome, body, or neck of the aneurysm); neck remnant (some contrast filling of part of the neck of the aneurysm); and incomplete occlusion (some contrast filling of the dome and incomplete GDC packing).

Special attention was paid to the angiographic appearance of the neck remnant. The same angiographic view was used to compare anatomical results or follow-up angiograms obtained at different times. The angiographic images were installed into a Macintosh computer (Apple Computer Co., Cupertino, CA) by using a jet scanner (resolution 150–300 dots per in). The obliteration rate was then calculated using imaging software (Image, version 1.70; supplied by the National Institutes of Health, Bethesda, MD at the following website: www.rbs.info.nih.gov/nih-image). This program was used to figure the area (number of pixels) of the aneurysm neck remnant and the area (number of pixels) of the GDC mass, from which we then calculated the obliteration rate as follows: obliteration rate (%) = (number of pixels in the GDC mass) / (number of pixels in GDC mass + number of pixels in neck remnant) × 100. This equation was used to compare immediate postprocedural angiograms with long-term follow-up angiograms.

The anatomical findings were classified as: unchanged (increased contrast filling in the aneurysm that is < 10% or decreased contrast filling, but not complete disappearance of the aneurysm [Fig. 1]); recanalization (increased contrast filling in the aneurysm that is > 10% of the obliteration rate [Fig. 2]); and progressive thrombosis (disappeared contrast filling in the residual neck [Fig. 3]).

### TABLE 1

<table>
<thead>
<tr>
<th>Aneurysm Location</th>
<th>No. of Aneurysms (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>anterior circulation</td>
<td>47 (64)</td>
</tr>
<tr>
<td>ICA</td>
<td></td>
</tr>
<tr>
<td>ophthalmic or paracclinoid segment</td>
<td>21 (29)</td>
</tr>
<tr>
<td>PCoA or anterior choroidal segment</td>
<td>13 (18)</td>
</tr>
<tr>
<td>bifurcation</td>
<td>3 (4)</td>
</tr>
<tr>
<td>ACoA</td>
<td>6 (8)</td>
</tr>
<tr>
<td>MCA bifurcation</td>
<td>4 (5)</td>
</tr>
<tr>
<td>posterior circulation</td>
<td></td>
</tr>
<tr>
<td>BA tip</td>
<td>12 (16)</td>
</tr>
<tr>
<td>PCA</td>
<td>1 (1)</td>
</tr>
<tr>
<td>SCA</td>
<td>4 (5)</td>
</tr>
<tr>
<td>BA trunk</td>
<td>3 (4)</td>
</tr>
<tr>
<td>AICA</td>
<td>2 (3)</td>
</tr>
<tr>
<td>VA–BA junction</td>
<td>2 (3)</td>
</tr>
<tr>
<td>PICA</td>
<td>2 (3)</td>
</tr>
<tr>
<td>total</td>
<td>73 (100)</td>
</tr>
</tbody>
</table>

* ACoA = anterior communicating artery; AICA = anterior inferior cerebellar artery; BA = basilar artery; MCA = middle cerebral artery; PCA = posterior cerebral artery; PCoA = posterior communicating artery; PICA = posterior inferior cerebellar artery; SCA = superior cerebellar artery; VA = vertebral artery.

angiography for all treated patients within 6 months post-treatment.

Follow-up cerebral angiograms were obtained in 71 patients. One hundred two patients were not included in this study. Follow-up angiography in 29 patients could not be performed due to poor medical condition or death; 32 patients referred from outside hospitals did not undergo follow-up angiography or, if they did, the angiograms were nondiagnostic; 19 patients refused to undergo follow-up angiography; and one patient only underwent follow-up magnetic resonance angiography. Twenty-one patients are referred directly by their neurosurgeons for endovascular surgery in 10 patients (14%); and age older than 70 years in 10 patients (14%). Thirty-seven patients (52%) were referred directly by their neurosurgeons for endovascular treatment.

Angiographic Evaluation

The rate of aneurysm obliteration was evaluated using postembolization angiography in multiple projections. The anatomical results of treatment were categorized as follows: complete occlusion (no contrast filling of the dome, body, or neck of the aneurysm); neck remnant (some contrast filling of part of the neck of the aneurysm); and incomplete occlusion (some contrast filling of the dome still observed due to incomplete GDC packing).

Special attention was paid to the angiographic appearance of the neck remnant. The same angiographic view was used to compare anatomical results or follow-up angiograms obtained at different times. The angiographic images were installed into a Macintosh computer (Apple Computer Co., Cupertino, CA) by using a jet scanner (resolution 150–300 dots per in). The obliteration rate was then calculated using imaging software (Image, version 1.70; supplied by the National Institutes of Health, Bethesda, MD at the following website: www.rbs.info.nih.gov/nih-image). This program was used to figure the area (number of pixels) of the aneurysm neck remnant and the area (number of pixels) of the GDC mass, from which we then calculated the obliteration rate as follows: obliteration rate (%) = (number of pixels in the GDC mass) / (number of pixels in GDC mass + number of pixels in neck remnant) × 100. This equation was used to compare immediate postprocedural angiograms with long-term follow-up angiograms.

The anatomical findings were classified as: unchanged (increased contrast filling in the aneurysm that is < 10% or decreased contrast filling, but not complete disappearance of the aneurysm [Fig. 1]); recanalization (increased contrast filling in the aneurysm that is > 10% of the obliteration rate [Fig. 2]); and progressive thrombosis (disappeared contrast filling in the residual neck [Fig. 3]).
Results

Eighteen aneurysms (25%) exhibited progressive thrombosis, 19 (26%) were unchanged, and 36 (49%) displayed recanalization on postembolization angiography. In the unchanged group, additional embolization was performed in one aneurysm, surgical clipping was performed in one aneurysm, and 17 aneurysms were treated conservatively. In the recanalization group, 18 aneurysms were treated with additional embolizations, two aneurysms were treated with parent artery occlusion, five aneurysms were treated with surgical clipping, and 11 aneurysms were treated conservatively. In this study, there was one temporary ischemic procedural complication. There were no permanent procedural complications.

Small Aneurysms With Small Necks

There were 24 small aneurysms with small necks. Results of postembolization angiography demonstrated that 12 (50%) had developed progressive thrombosis, eight (33%) remained unchanged, and four (17%) had recanalization (Fig. 4). In the 10 aneurysms that were treated between 1990 and 1996, four (40%) exhibited progressive thrombosis, four (40%) remained unchanged, and two (20%) displayed recanalization. In the 14 aneurysms treated between 1997 and 1998, these numbers were eight (57%), four (29%), and only two (14%), respectively (Fig. 5 upper). Thus, in the last 2 years of the study in small aneurysms with small necks, the rate of recanalization decreased and the rate of progressive thrombosis increased. These improved anatomical results are mainly related to the use of a combination of standard and soft coils. This technical modification allows denser and tighter packing of GDCs in an aneurysm without increasing the risk of aneurysm rupture.

We also compared the degree of aneurysm obliteration measured on the immediate postembolization angiogram with long-term anatomical outcome. In the group of aneurysms exhibiting progressive thrombosis, the immediate average rate of obliteration was 89.1%. In the unchanged group, the average rate of obliteration rate was 89.6%. In the recanalization group, the rate was 85.5% (Table 2). There was no statistical correlation between the immediate obliteration rate and long-term anatomical outcome (Pearson’s correlation coefficient 0.146).

We also compared long-term anatomical outcomes of ruptured aneurysms with those of unruptured aneurysms. Of 13 ruptured aneurysms postembolization, six (46%) exhibited progressive thrombosis, five (38%) remained unchanged, and two (15%) displayed recanalization. Of 11 unruptured aneurysms postembolization, six (54%) exhibited progressive thrombosis, three (27%) remained unchanged, and two (18%) displayed recanalization. There was almost the same recanalization rate in ruptured aneurysms as there was in unruptured aneurysms.

Small Aneurysms With Wide Necks

There were 24 small aneurysms with wide necks. On
postembolization angiograms, we noted that six aneurysms (25%) had developed progressive thrombosis, eight (33%) remained unchanged, and 10 (42%) displayed recanalization (Fig. 4). Of the 12 aneurysms that were treated between 1990 and 1995, three (25%) exhibited progressive thrombosis, four (33%) remained unchanged, and five (42%) displayed recanalization. Of the 12 aneurysms that were treated between 1996 and 1998, three (25%) exhibited progressive thrombosis, four (33%) remained unchanged, and five (42%) displayed recanalization (Fig. 5 lower). No difference between the two experiences was noted. In the aneurysms with progressive thrombosis, the immediate average obliteration rate was 85.7%; in those remaining unchanged, the obliteration rate was 89.4%; and in those with recanalization, the immediate occlusion rate was 88.6% (Table 2). There was no statistical correlation between the immediate obliteration rate and long-term anatomical outcome (Pearson’s correlation coefficient -0.152).

We also compared long-term anatomical outcomes of ruptured aneurysms with those of unruptured aneurysms. Postembolization angiography revealed that, of the 12 ruptured aneurysms, one (8%) had progressive thrombosis, four (33%) remained unchanged, and seven (58%) had recanalization. Of the 12 unruptured aneurysms, five (42%) had progressive thrombosis, four (33%) remained unchanged, and three (25%) exhibited recanalization. Thus, in small aneurysms with wide necks, the recanalization rate was higher in ruptured aneurysms than in unruptured aneurysms.

**Large Aneurysms**

There were 15 large aneurysms. Results of postembolization angiography revealed that two (13%) remained unchanged and 13 (87%) had recanalization (Fig. 4). The average obliteration rate was 93% (Table 2).

**Giant Aneurysms**

There were 10 giant aneurysms. Postembolization angiograms revealed that only one (10%) remained unchanged and nine (90%) had recanalization (Fig. 4). The average obliteration rate was 87.3% (Table 2).
Location of Aneurysms

There was no correlation between the location of an aneurysm and a residual neck and its outcome.

Discussion

Long-Term Durability of Treated Aneurysms

Surgical clipping continues to be the gold standard for treatment of intracranial aneurysms. The efficacy and limitations of this therapy have been extensively discussed in the literature. The reported incidence of residual neck after surgical clipping of an aneurysm ranges between 3.8% and 18%.1,2,12,24,26 The rebleeding rate of aneurysms with residual necks has been reported to be between 3.5% and 28%,8,12 and aneurysm regrowth has been reported to occur in 3.5 to 15% of patients.9,12 A 2.7% rate of aneurysm rerupture was reported even after complete surgical clipping of the aneurysm.4 The incidence of aneurysm neck remnant after surgery is relatively rare in the anterior circulation and in small aneurysms, and higher in the posterior circulation and in large or giant aneurysms.8

On the other hand, the long-term anatomical outcome of GDC treatment is still unclear. Murayama, et al.,34 reported their experience with GDC embolization of 120 incidental cerebral aneurysms. They observed no cases of delayed aneurysm recanalization in 52 aneurysms completely occluded with GDCs. Although their study had a limited number of patients, it emphasizes the concept that an aneurysm completely embolized with GDCs can be permanently excluded from the circulation.

However, aneurysms embolized with GDCs may have...
a residual neck, especially in the wide-necked or large aneurysms. Murayama, et al., reported that approximately one third of aneurysms with a neck remnant showed further thrombosis, one third remained unchanged, and one third showed recanalization. It is still unknown whether the risks of rupture in aneurysms with neck remnants treated endovascularly or surgically are similar or different. A histopathological comparison of neck remnants in these two groups could shed some light on the probable natural histories of these treated aneurysms.

**Small Aneurysms With Small Necks**

It is well known that these aneurysms can be completely occluded with GDCs. In a series of patients with aneurysms treated at UCLA, complete occlusion of this type of aneurysm was achieved in approximately 70% of cases. In the present study, the recanalization rate of the neck remnant in small aneurysms with small necks was very low (17%). Furthermore, the recanalization rate in this type of aneurysm was significantly reduced during the last 2 years of the study (14%). The use of softer and smaller coils enabled us to achieve early control of the aneurysm inflow zone, as well as denser packing of the body of the aneurysm. Denser packing with GDCs may allow neo-intimal and neo-endothelial proliferation across the neck of the aneurysm. Although histopathological evaluation of GDC-treated aneurysm specimens in humans is limited, it is postulated that neo-endothelial proliferation may occur in small-necked aneurysms.

**Small Aneurysms With Wide Necks**

In our results, approximately 60% of these aneurysms with residual necks remained anatomically unchanged or exhibited further thrombosis and approximately 40% displayed recanalization. We performed strict short-term follow-up angiography for wide-necked aneurysms with neck remnants. Recanalization was frequently seen on the first follow-up angiogram, which was obtained 3 months after the first embolization. In contrast to small aneurysms with small necks, the recanalization rate observed during the last 3 years is the same as that from our earlier experience. There was no relationship between obliteration rate and prognosis. Recanalization tends to develop in these aneurysms if their inflow zone cannot be controlled and occluded during the first session of embolization. The recanalization occurs due to the blood-flow water-hammer effect and concomitant strong hemodynamic shear stress observed in the aneurysm inflow zone. In aneurysms with wide necks, it is technically difficult to place GDCs in the aneurysm body and dome without coil protrusion into the parent artery. Balloon-assisted technology and the use of the new generation of 3D coils has improved and, in many cases, solved this technical problem.

**Large and Giant Aneurysms**

The complete occlusion rate in large and giant aneurysms treated with GDCs has been reported to range from 25 to 50%. Molyneux, et al., and Mizoi, et al., reported histological findings in giant aneurysms incom-
The present technical problem of aneurysm recanalization in aneurysms with wide necks. The option of GDC therapy for large and giant aneurysms should be carefully considered because of the technical problem of aneurysm recanalization. Anatomical and clinical factors such as the patient’s medical condition, age, location of the aneurysm, and risk of morbidity of using a surgical procedure should be thoroughly evaluated. Further technological and biological developments need to be incorporated into the present GDC technology to improve present anatomical and clinical outcomes. This statement is particularly true in small aneurysms with wide necks, as well as large and giant aneurysms.

**References**


Manuscript received September 1, 1999. Accepted in final form June 6, 2000.
Address reprint requests to: Motoharu Hayakawa, M.D., Department of Neurosurgery, School of Medicine, Fujita Health University, 1-98 Dengakugakubo, Kutsukake, Toyoake, Aichi, 470–1192, Japan.

M. Hayakawa, et al.