Endovascular Treatment of Asymptomatic Cerebral Aneurysms: Anatomic and Technical Factors Related to Ischemic Events and Coil Stabilization

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Abstract

The present study assessed the safety and efficacy of embolization using Guglielmi detachable coils (GDCs) in 100 asymptomatic cerebral aneurysms classified as sidewall (70) or terminal (30) aneurysms according to the parent artery (68 small aneurysms with a small neck, 21 small aneurysms with a wide neck, and 11 large aneurysms). A balloon-assisted technique was used in 49 aneurysms. Immediate angiography revealed that 71 aneurysms were completely obliterated. Transient deficits occurred in 19 patients, permanent deficits in four patients, and one patient died. Most complications occurred during or immediately after treatment and resolved within a few minutes to a few weeks. None of the surviving patients manifested significant morbidity at 1-year follow up. Follow-up angiographic study was performed in 79 aneurysms. Rates of recanalization and progressive thrombosis (total occlusion of the residual aneurysm at follow up) were 11% and 38%, respectively, in sidewall aneurysms, and 26% and 0%, respectively, in terminal aneurysms. Treatment with GDCs was effective for patients with small aneurysms with small necks, the morbidity was acceptable, and progressive thrombosis occurred during the follow-up period. GDC treatment achieved unsatisfactory results in patients with small terminal aneurysms with wide necks and in large aneurysms, because the obliteration rate was low, and the recanalization and complication rates were high. Multivariate analysis showed that complete occlusion was associated with small-necked aneurysms, and ischemic events tended to occur in terminal aneurysms and in aneurysms treated by the balloon-assisted technique.

Key words: asymptomatic cerebral aneurysm, embolization, Guglielmi detachable coil

Introduction

The detection rate for unruptured aneurysms has increased due to advances in neuroradiological techniques. Controversy continues to surround the management of such incidentally detected cerebral aneurysms and the size critical for rupture. Since the overall surgical outcome for ruptured aneurysms remains unsatisfactory, preventive radical clipping and endovascular surgery are considered alternative strategies. The endovascular approach using Guglielmi detachable coils (GDCs) has improved the overall treatment of patients with incidental aneurysms.

Recanalization or progressive thrombosis may occur in the short or medium term after the endovascular treatment of ruptured aneurysms. A pathological study revealed that the walls of ruptured and unruptured aneurysms differ with respect to endothelial damage, fragility, and macrophage invasion. The anatomic relationship between the aneurysm and parent artery results in hemodynamic effects that may influence the outcome of endovascular embolization.
Materials and Methods

I. Patient population

One hundred seventy-nine patients with 192 cerebral aneurysms underwent endovascular embolization with GDCs at the National Cardiovascular Center between January 1998 and April 2001. Among these, 92 patients, 20 males and 72 females aged from 31 to 77 years (mean 58 years), were treated by endosaccular embolization with GDCs for 100 asymptomatic unruptured aneurysms. Patients scheduled for parent artery occlusion and patients with extra-dural aneurysms were excluded from this study. Follow-up angiographic studies were performed in 72 of the 92 patients up to April 2002.

Eighty-five asymptomatic unruptured aneurysms were discovered incidentally in 81 of the 92 patients during examination for an unrelated medical condition. Multiple aneurysms were found in 15 of these 81 patients: nine patients had two aneurysms, and six patients had three aneurysms. Thirteen of these aneurysms were treated by surgery before or after GDC embolization, 19 were treated by GDC embolization, and four were observed. Fifteen asymptomatic unruptured aneurysms were discovered by cerebral angiography for subarachnoid hemorrhage due to aneurysm rupture in the other 11 patients. Two patients had two aneurysms, six patients had three aneurysms, two patients had four aneurysms, and one patient had six aneurysms. All ruptured aneurysms were treated within 2 weeks by surgical clipping or GDC placement.

Clipping is the standard treatment for surgically accessible cerebral aneurysms at our institute, especially aneurysms involving the middle cerebral artery, the anterior communicating artery, and the internal carotid artery-posterior communicating artery. The treatment strategy considers the technical and anatomic factors, and the wishes of the patient for aneurysms in the internal carotid artery-paraclinoid segment, the basilar artery (BA) bifurcation, and other areas in the posterior circulation. Therefore, these 92 patients were selected for endovascular treatment because 81 patients had aneurysms which were considered to be difficult to treat surgically, four patients were elderly (>70 years), five patients refused conventional surgery, and two patients had medical conditions necessitating this approach. All patients were informed of alternative therapies and all gave written, informed consent. Clinical follow up ranged from 4 days to 38 months (mean 22 months), and angiographic follow up from 1 to 26 months (mean 8.4 months).

The location and type of the aneurysms are shown in Table 1. Eighty-nine of the 100 aneurysms were small (diameter <10 mm), 11 were large (diameter 10–25 mm); with neck diameter less than 4 mm in 70 aneurysms and exceeding 4 mm in 30 aneurysms. The method used to determine these measurements has been described elsewhere.

II. GDC embolization technique and clinical evaluation

The pre-procedure workup included computed tomography (CT) and digital subtraction angiography, three-dimensional CT angiography with and without subtraction, and magnetic resonance (MR) imaging. Starting in August 2000, we routinely used three-dimensional rotational digital angiography. Endovascular treatment was performed via the transfemoral route with local anesthesia. Systemic heparinization was used to keep the activated clotting time at 2 to 2.5 times the baseline throughout the endovascular procedure. Our center usually uses local rather than general anesthesia, in contrast to most centers, to assess the neurological status during the procedure, detect thromboembolic complications early, and minimize neurological complications. General anesthesia was used if...
warranted by the patient's clinical condition.

A microcatheter was introduced into the aneurysm sac using biplane fluoroscopy and road-mapping guidance. Balloon-assisted techniques were used in wide-necked aneurysms with a dome-to-neck ratio less than 1.5 and in large aneurysms.\textsuperscript{28} These techniques were modified in some small-necked aneurysms to fix the tip of the microcatheter to facilitate suitable placement of the GDCs.\textsuperscript{10} A non-detachable silicone balloon catheter was inflated for periods not exceeding 2–4 minutes. If we anticipated difficulties because the microcatheter could not be introduced into the aneurysm sac by conventional GDC techniques, or because the coils might protrude into the parent artery, we first introduced the balloon into the parent vessel. GDCs were introduced until tight coil packing was achieved using soft, two-diameter or three-dimensional coils (Target Therapeutics/Boston Scientific, Fremont, Calif., U.S.A.) as necessary. Systemic heparinization was not reversed, and the patient was transferred to the neurosurgical intensive care unit and received anti-thrombin agent (argatroban, Slonnon Injection; Daiichi Pharmaceutical Co., Ltd., Tokyo) for 2 days and anti-platelet agents (ticlopidine hydrochloride or aspirin) orally for 3 months.

All procedure records were reviewed to determine the number of GDCs placed, the total coil lengths, and the time required for the procedure. All complications occurring during the procedure, e.g. transient slight motor weakness and abnormal sensations due to balloon occlusion of the parent artery, were defined as procedure-related complications and recorded as transient if the deficits resolved within 1 month, or as permanent if persisting for more than 1 month. The treatment outcomes were scored according to the modified Rankin Scale.\textsuperscript{44}

All embolized aneurysms were evaluated immediately by angiography and at follow up by members of our neurosurgery department. The degree of occlusion was determined by the packing density using conventional digital subtraction angiography. Embolization was classified as complete, no filling of the aneurysm remnant and no neck remnant, or as incomplete, small neck remnant or partial occlusion.

III. Follow-up evaluation

The patients were followed up as outpatients. Follow-up angiography was usually scheduled for 6 and 12 months post-embolization if complete occlusion was achieved by the initial procedure. Patients with incomplete occlusion underwent the first follow-up evaluation at 3 months post-embolization. Follow-up results were classified as unchanged (no marked change from immediate postoperative results), progressive thrombosis (progression to complete occlusion), and recanalization (marked increase of dome filling). Patients with recanalization underwent additional embolization or clipping, or were closely monitored. The neurosurgery team made treatment decisions on a case-by-case basis. Additional follow-up angiography was performed in all patients at risk of recanalization.

IV. Statistical analysis

Multiple aneurysms were considered separately as a possible source of ischemic events. The association of clinical and anatomic factors, and procedures that did or did not involve balloon-assisted techniques with procedure-related ischemic events was analyzed. Continuous independent, dichotomous, and multiple variables included the mean aneurysm diameter, the mean neck diameter, the flow pattern (sidewall/terminal aneurysm), the use of balloon-assisted techniques, the anatomic results (complete or incomplete occlusion), and the occurrence of ischemic events. The association of these factors was tested by univariate analysis using the chi-square test, the Fischer exact test, and by multivariate analysis using logistic regression. Calculations were performed with the statistical software package Stat View (Abacus Concepts, Berkeley, Calif., U.S.A.). A p value of less than 0.05 was considered to indicate a statistically significant correlation.

Results

I. Initial anatomic and clinical findings

Ninety-four endovascular procedures were performed to treat 100 aneurysms in 92 patients; multiple aneurysms were treated in six patients as one procedure. Balloon-assisted techniques were used in 49 aneurysms. Complete occlusion was obtained in 71 of the 100 aneurysms. Symptomatic complications were encountered in 24 of the 92 patients (Table 2). Seven of 10 patients with minor complications during the procedure recovered fully within a few minutes, and the other three recovered within a few days after anticoagulation and volume expansion or thrombolytic therapy, or both. Post-treatment, 12 patients experienced thromboembolic events within a few hours after the procedure, and after 2 days in two patients. Eight of the 12 patients recovered fully, but four patients were discharged with permanent deficits. Vessel or aneurysm perforation occurred in two patients, one patient died on the day following this event, the other
## Table 2 Profile of 24 patients with complications

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yr) / Sex</th>
<th>Aneurysm location</th>
<th>Aneurysm configuration</th>
<th>Optional treatment</th>
<th>Anatomical result</th>
<th>Presenting symptom</th>
<th>Onset of symptom</th>
<th>Cause of complication</th>
<th>Treatment for complication</th>
<th>Lasting of complication</th>
<th>mRS at 1 yr follow up</th>
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<tr>
<td>1</td>
<td>63 / F</td>
<td>ICA-paraclinoid segment</td>
<td>S/S</td>
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<td>slight hemiparesis</td>
<td>intraoperation</td>
<td>emboli</td>
<td>urokinase</td>
<td>few min</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2</td>
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<td>BAT</td>
<td>complete</td>
<td>slight hemiparesis</td>
<td>intraoperation</td>
<td>emboli</td>
<td>fluid</td>
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<td>0</td>
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<tr>
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<td>seizure</td>
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<td>parent artery spasm</td>
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<td>dysesthesia</td>
<td>intraoperation</td>
<td>emboli</td>
<td>balloon inflation</td>
<td>balloon deflation</td>
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<td>fluid</td>
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<tr>
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<td>neck remnant</td>
<td>disorientation</td>
<td>intraoperation</td>
<td>emboli</td>
<td>urokinase</td>
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<td>0</td>
<td></td>
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<td>dome filling</td>
<td>visual field loss</td>
<td>1 hr after</td>
<td>emboli</td>
<td>fluid</td>
<td>1 day</td>
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<td></td>
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<td>heparin</td>
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<td>BAT</td>
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<td>BAT</td>
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<td>disorientation</td>
<td>intraoperation</td>
<td>emboli</td>
<td>fluid</td>
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<td>0</td>
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<td>BAT</td>
<td>dome filling</td>
<td>slight hemiparesis, cranial nerve III palsy</td>
<td>2 hrs after</td>
<td>emboli</td>
<td>heparin</td>
<td>3 days</td>
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<td>BAT</td>
<td>dome filling</td>
<td>cerebellar ataxia</td>
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<td>emboli</td>
<td>fluid</td>
<td>3 days</td>
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<tr>
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<td>BAT</td>
<td>neck remnant</td>
<td>cerebellar ataxia</td>
<td>1 hr after</td>
<td>emboli</td>
<td>anti-convulsant</td>
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<tr>
<td>16</td>
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<td>heparin</td>
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<td>BAT</td>
<td>neck remnant</td>
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<td>intraoperation</td>
<td>emboli</td>
<td>embolization of aneurysm</td>
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<td>fluid</td>
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<td>1 hr after</td>
<td>emboli</td>
<td>urokinase</td>
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<td>L</td>
<td>BAT</td>
<td>neck remnant</td>
<td>dementia</td>
<td>1 hr after</td>
<td>occlusion of perforating artery</td>
<td>fluid</td>
<td>permanent</td>
<td>2</td>
</tr>
<tr>
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<td>68 / F</td>
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<td>L</td>
<td>BAT</td>
<td>—</td>
<td>—</td>
<td>intraoperation</td>
<td>emboli</td>
<td>BA occlusion</td>
<td>death (next day)</td>
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Table 3  Predisposing factors for complete occlusion at initial procedure

<table>
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<th>Multivariate analysis</th>
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<tr>
<td>Flow type</td>
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<td>0.6403</td>
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<tr>
<td>Balloon-assisted technique</td>
<td>0.6624</td>
<td>0.5014</td>
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</tbody>
</table>

CI: confidence interval, OR: odds ratio.

achieved full neurological recovery. The permanent morbidity and mortality were 4.3% (4/92) and 1.1% (1/92), respectively. There was one procedure-related death, but the other 93 procedures did not result in significant morbidity (modified Rankin Scale 3–5) at 1-year follow up.

The 70 sidewall aneurysms included 54 small aneurysms with a small neck, 11 small aneurysms with a wide neck, and five large aneurysms. Of these, 44 small, small neck, eight small, wide neck, and two large aneurysms were completely occluded at the initial procedure. Balloon-assisted techniques were used in 47 of the 70 sidewall aneurysms, 31 small, small neck, eight small, wide neck, and four large aneurysms. Neurological complications related to the endovascular procedure occurred in 11 patients, and were associated with the balloon-assisted technique. The complications were permanent and consisted of visual field loss, slight hemiparesis, and cognitive impairment.

The 30 terminal aneurysms included 14 small, small neck, 10 small, wide neck, and six large aneurysms. Of these, 12 small, small neck, two small, wide neck, and three large aneurysms were completely occluded at the initial procedure. Balloon-assisted techniques were used in six of the 30 terminal aneurysms, one small, small neck, four small, wide neck, and one large aneurysms. Neurological deterioration occurred in 13 patients. One of the three patients with large terminal aneurysms suffered unexpected intraoperative vessel rupture and died the following day of brain stem and cerebellar infarction related to BA occlusion. The aneurysm was perforated in another patient, but volume expansion was performed and she recovered fully with rehabilitation, and was discharged 1 month after the procedure without neurological deficits. Both patients were treated using the balloon-assisted technique.

II. Follow-up anatomic and clinical findings

Seventy-two patients with a total of 79 aneurysms underwent follow-up angiographic studies. Of the 20 patients with no follow up, one died on the day following the procedure, 11 were awaiting follow-up angiographic study at the time of writing, seven were lost to follow up, and one refused angiographic study. The latest angiographic evaluation after the initial procedure was performed at less than 6 months (8 patients), at 6 to 12 months (54 patients), and at more than 12 months (10 patients).

Follow-up angiography showed that 62 of the 79 aneurysms appeared unchanged, and 12 manifested evidence of recanalization. Five of the 24 aneurysms that were incompletely occluded at the initial procedure progressed to complete occlusion. Four of the 12 recanalized aneurysms were treated by additional embolization and the remaining eight were closely monitored. None of the surviving patients in this series experienced hemorrhagic or embolic events during the follow-up period.

Fifty-six sidewall aneurysms were followed up by angiography, 42 small, small neck, 10 small, wide neck, and four large aneurysms. Recanalization was noted in six aneurysms, two small, small neck, two small, wide neck, and two large aneurysms. Thirteen aneurysms were incompletely occluded by the initial procedure, and five had developed progressive thrombosis by follow-up angiography, three of seven small, small neck, one of three small, wide neck, and one of three large aneurysms.

Twenty-three terminal aneurysms were followed up, nine small, small neck, nine small, wide neck, and five large aneurysms. Six aneurysms were recanalized, four small, wide neck and two large aneurysms. All nine small, small neck aneurysms were completely occluded at the initial embolization.

III. Statistical results

Univariate analysis showed that the mean aneurysm diameter (p = 0.0003) and neck diameter (p < 0.0001) were associated with complete occlusion (Table 3). The mean aneurysm diameter (p = 0.0207), the neck diameter (p < 0.0001), the flow type (p = 0.0105), the anatomic results
Table 4  Predisposing factors for complications

<table>
<thead>
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<td>Anatomic results</td>
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<td>Balloon-assisted technique</td>
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CI: confidence interval, OR: odds ratio.

Table 5  Predisposing factors for complete occlusion at follow up

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<td>Aneurysm diameter</td>
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<td>Flow type</td>
<td>0.0036</td>
<td>0.0538</td>
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</table>

CI: confidence interval, OR: odds ratio.

(p = 0.0221), and the balloon-assisted technique (p = 0.0377) were associated with complications (Table 4).

Multivariate analysis identified an association between complete occlusion and small-necked aneurysms (p = 0.0204, odds ratio [OR] 2.136, 95% confidence interval [CI] 1.124–4.058), between ischemic events and terminal aneurysm (p = 0.0124, OR 0.065, 95% CI 0.008–0.554), and between ischemic events and the balloon-assisted technique (p = 0.0156, OR 0.072, 95% CI 0.009–0.607) (Tables 3 and 4). The mean aneurysm diameter was not significant with respect to either complete occlusion (p = 0.5335, OR 1.065, 95% CI 0.873–1.300) or ischemic complications (p = 0.5224, OR 1.084, 95% CI 0.846–1.389).

In the follow up, only neck diameter (p = 0.0321) was associated with coil compaction (recanalization, progressive thrombosis, or unchanged). Complete occlusion at follow up was associated with mean aneurysm diameter (p = 0.0018), neck diameter (p < 0.0001), and flow type (p = 0.0036) using univariate analysis, but only neck diameter (p = 0.0103, OR 2.705, 95% CI 1.265–5.785) using multivariate analysis (Table 5).

IV. Additional treatment

Four of the 12 recanalized aneurysms were treated by additional embolization. Complete embolization was achieved in three, but the other remained incompletely occluded because of its wide neck. The eight other aneurysms were closely monitored without additional treatment because of high patient age, the difficulty of additional embolization, or patient refusal of further treatment. Follow-up angiography showed that 47 of 56 sidewall and 13 of 23 terminal aneurysms were completely occluded at the end of the current study period after progressive thrombosis, recanalization, and additional treatment.

Discussion

This retrospective study of 100 unruptured aneurysms examined the safety, efficacy, and limitations of GDC embolization, and identified predisposing factors for the occurrence of ischemic events using statistical methods. The study provided information on the short-term natural course of endovascularly treated unruptured aneurysms and indicates strategies to treat aneurysms that were incompletely occluded at the initial procedure.

I. Relationships of aneurysm size and location to outcome

The primary goal of endovascular therapy is to occlude the aneurysm sac and to isolate the sac from the circulation, but may not be achievable if the aneurysm neck is wide or if a major arterial branch is incorporated into the aneurysm. The diameter of the neck rather than aneurysm size appears to be the critical factor for achieving complete occlusion.6] In
wide-necked aneurysms, bridging the neck with coil mesh is difficult because of the risk of coil deposits in the parent vessel, increasing the danger of parent vessel thrombosis.\(^4,21,45\) The anatomic relationship of the aneurysm to its parent artery, and the presence and extent of wall thrombi all affect the hemodynamic characteristics and outcome of endovascular embolization.\(^4,21,45\) Considerable inflow force can alter the coil shape or displace coils, and fill the aneurysm, whereas blocking or displacing the inflow can induce thrombosis with preservation of the parent artery.\(^2,6,23,34,39\)

The present study found that among sidewall aneurysms, most small-necked internal carotid artery-paraclinoid segment aneurysms could be completely occluded with low mortality and morbidity. The balloon-assisted technique was useful in wide-necked aneurysms because the parent artery allows suitable positioning of the balloon.

Endovascular treatment of posterior circulation aneurysms is reportedly more effective than surgical clipping,\(^31,45\) and navigation of the microcatheter is facilitated by the straight course of the BA. However, there are limitations in the endovascular treatment of BA aneurysms.\(^9,14,42,49\) The occlusion rate of small aneurysms with small necks is satisfactory and the complication rate is low, but aneurysms with wide necks and large aneurysms present problems because of coil instability. The balloon-assisted technique is not so suitable for aneurysms of the BA because complete occlusion is difficult to achieve without unintentional occlusion of the parent artery. In our series, all six patients with BA bifurcation aneurysms treated with the balloon-assisted technique experienced neurological complications and there was one procedure-related death. In addition, recanalization and thromboembolism formation were common. Therefore, the advisability of treating incidental BA bifurcation aneurysms by endovascular methods, including balloon-assisted techniques, must be considered carefully.\(^1,9\)

II. Natural history of cerebral aneurysms treated with GDCs

Post-treatment progressive thrombosis, and regrowth and recanalization of neck remnants are strongly dependent on arterial inflow.\(^12,39,40\) Direct arterial inflow is reduced in aneurysms with a small neck. However, the geometric mismatch between the convex margin of the GDC surface and the neck allows continuous arterial inflow in aneurysms with a wide neck and large aneurysms that carry a high risk of parent artery compromise.\(^9,42\) This mismatch results in deformity of the coil mass and/or new shear stress on the aneurysm wall, leading to recanalization and rupture due to coil compaction and/or aneurysm regrowth.\(^22,33\)

Coil embolization may induce flow stagnation and promote thrombus formation in sidewall aneurysms.\(^11,23\) A higher rate of progressive thrombosis was reported for sidewall aneurysms with a diameter larger than that of the orifice.\(^14\) In contrast, GDCs are exposed to the “water-hammer effect” in terminal aneurysms,\(^18\) and stagnation and thrombus formation may not occur after partial embolization because the blood flow renders the environment “unstable” for thrombosis.\(^2,34\)

The immediate angiographic results in aneurysms with later recanalization and regrowth are often unsatisfactory.\(^22,24,43\) Aneurysms completely embolized with GDCs were permanently excluded from the circulation.\(^29\) However, in our series, three of 56 completely occluded aneurysms manifested recanalization. There are few histopathological studies on human GDC-treated aneurysms.\(^27,40\) In an experimental model, only 23–26% of the aneurysm sac volume was replaced by coils,\(^41\) and radiologic and histopathologic findings on obliteration were variable.\(^34,39\) Complete aneurysm occlusion with GDCs is difficult to unequivocally determine despite multiple angiographic projections and completeness of initial packing.\(^21,43\) Our follow up of aneurysms treated with GDCs is relatively short term and we are continuing our efforts to record the natural history of these aneurysms and to determine the incidence of bleeding of the remnants. Our findings will help to determine how complete the occlusion must be to prevent regrowth or bleeding.

Follow-up angiographic study of unruptured aneurysm treated by endovascular methods is standard procedure. However, iterative invasive angiography may have adverse effects, and the required duration of close surveillance remains to be determined.\(^36\) Noninvasive MR angiography is currently limited due to metallic artifacts,\(^46\) but advances in MR techniques, the study of large series, and long follow-up periods may increase the usefulness of this modality for the monitoring of such aneurysms.

III. Additional treatments

The surgical treatment of aneurysm remnants is controversial.\(^8,20\) The incidence of rebleeding from remnants was 3.7% if the sac was not obliterated in surgically treated aneurysms.\(^10\) The overall rebleeding rate in surgically treated patients was 0.14%. Whether endovascular treatment and surgical clipping produce similar results with respect to the remnants of ruptured and asymptomatic aneurysms remains to be determined. The
rebleeding rate of aneurysms filled with coils is reportedly extremely low.\textsuperscript{5} We also found that a significant number of our aneurysms remained stable or progressed to occlusion. Spontaneous obliteration occurred more frequently in small than large remnants, but small remnants can become enlarged and bleed.\textsuperscript{12} The surgical approaches to wide-necked aneurysm remnants, e.g. clipping and intra-aneurysmal endarterectomy, are difficult because of the presence of intra-aneurysmal coils, blood clots, and the danger of iatrogenic vessel occlusion,\textsuperscript{25} so the radical treatment of aneurysm remnants can be justified only if the risk is acceptably low.\textsuperscript{13} Aneurysms enlarge more rapidly in young than in older patients.\textsuperscript{20} Therefore, we usually perform additional clipping or embolization in younger patients with large residual neck or sac portions or with evidence of marked regrowth after GDC treatment.

Post-embolization thrombosis in the aneurysm remnant may lead to embolic complications.\textsuperscript{14,24} Long-term administration of prophylactic anti-platelet aggregation medication should be considered to prevent such delayed thromboembolism. Our patients were instructed to continue taking anti-platelet agents orally for 3 months after the operation, and no thromboembolic events were encountered.

IV. Limitations of this study

Statistical studies of thromboembolic events require caution because the involvement of a common mechanism is far from clear. Multivariate analysis identified a larger aneurysm diameter and protruding coil loops as risk factors for ischemic events after GDC embolization.\textsuperscript{7} The frequency of thromboembolic events was low, so aneurysm diameter and prolapsed coils affected positive ischemic events. Theoretically, protruding coils are encountered in wide-necked or large aneurysms treated without balloon-assisted techniques more than in small aneurysms. No significant association was found between adverse effects and aneurysm configuration, small aneurysms with small necks were significantly completely occluded, and there was a high incidence of recanalization of wide-necked aneurysms.\textsuperscript{36} Although these results were similar to those in our series, the use of balloon-assisted techniques and multivariate analysis were not used. The incidence of thromboembolic events did not differ if the balloon-assisted technique was compared with conventional GDC techniques.\textsuperscript{19,28} However, use of the balloon-assisted technique necessitates the sophisticated manipulation of two catheters and the increased number of guidewires and microcatheters adds complexity. The potential sites and the time for the generation of microemboli increase with increased procedural complexity.\textsuperscript{37,38}

The present study suggested that wide-necked aneurysms require the balloon-assisted technique, and sidewall aneurysms also need the balloon-assisted technique, so the predisposing risk factors might not necessarily be independent. Future prospective studies should take these problems into account, and analyze a larger number of each anatomical type of aneurysm and each modified technique of endovascular treatment.

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Commentary on this paper appears on the next page.
Commentary

The authors have carried out a comprehensive study of GDC treatment in 100 asymptomatic unruptured aneurysms, with detailed statistical analysis of factors involved in complications and completeness of treatment, along with an extensive literature review. The results are in general agreement with many other reports and do not show anything startlingly new, but it was very useful to see the statistical correlations on this large number. As one would expect, larger aneurysms, wider necks, and a need for balloon assistance were associated with a higher risk of complications and lower incidence of complete occlusion. It was interesting also to see the effect of flow type — terminal aneurysms at the carotid or basilar bifurcation were more likely to lead to complications, and more likely to recanalize after complete occlusion. Perhaps, as discussed, this latter is related to a more direct impact of blood pressure in these than in side-wall aneurysms.

These results are useful in confirming factors that lead to problems with GDC treatment. As noted, not all the patients have yet had complete follow up. I encourage the authors to continue with this work as more patients accumulate. In future studies, it may also be useful to look at the influence of the aspect ratio of each aneurysm, easy to calculate and combining as it does the size of the neck and the size of the aneurysm.

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