Progress Review

Guglielmi Detachable Coil Embolization of Posterior Circulation Aneurysms
A Systematic Review of the Literature

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Background—Early multicenter trials of Guglielmi detachable coil embolization of posterior circulation aneurysms have been followed by the publication of numerous single-center experiences.

Summary of Review—We performed a MEDLINE literature search and extracted data from single-center reports containing at least 10 posterior circulation aneurysms. Twelve reports (495 aneurysms) were specific to the posterior circulation. Eighty-two percent of aneurysms arose near the basilar apex. Eighty-one percent of patients harbored unruptured aneurysms or presented in good clinical condition. Sixty-three percent of lesions were small, and 41% exhibited a narrow neck. Coil deposition was achieved in 97.6% of cases. Procedural complication and morbidity rates were 12.5% and 5.1%, respectively. Procedural and 30-day mortality rates were 1.4% and 6.7%, respectively. Complete aneurysm occlusion was achieved in 47.6%, near-complete occlusion (90% to 99%) in 43.4%, and incomplete occlusion in 9.0% of cases. There were a total of 52 recurrences (22.2%) in a subset of 234 evaluable patients. Ninety-two percent of these aneurysms exhibited wide necks. The annual risk of subarachnoid hemorrhage after embolization was 0.8%. Eighty-five percent of patients achieved functional independence, while only 5.3% lived dependent lifestyles. The overall mortality rate was 9.8%.

Conclusions—The published literature approximates a large series of basilar apex aneurysms. Embolization is moderately effective in completely excluding an aneurysm from the posterior circulation. The incidence of recurrence in wide-neck aneurysms and incompletely coiled aneurysms is substantial. Coil embolization is effective in preventing early rebleeding. Its role in the treatment of unruptured aneurysms remains unclear. (Stroke. 2002;33:2509-2518.)

Key Words: aneurysm ■ basilar artery ■ embolization, therapeutic ■ subarachnoid hemorrhage

Early multicenter trials enrolling both ruptured and unruptured posterior circulation aneurysms have confirmed that Guglielmi detachable coil (GDC) embolization can be accomplished with low rates of periprocedural morbidity and mortality.1-3 The vast majority of aneurysms in these trials were located at the basilar apex. In midterm follow-up of patients in the Food and Drug Administration trial, conservative mortality rates were estimated at up to 23% for ruptured basilar apex aneurysms and up to 12% for the unruptured group.1 Permanent deficits due to stroke occurred in up to 5% and 9%, respectively. The delayed annual subarachnoid hemorrhage (SAH) rates were 2.9% and 5.0% for treated ruptured and unruptured aneurysms, respectively (annual rates based on the number of hemorrhages divided by the total number of patient-years of clinical follow-up; simple rates [hemorrhages/patients×100] of 3.3% for ruptured aneurysms and 4.1% for unruptured aneurysms were given in the original publication).

Several recent developments have led to improved anatomic and clinical outcomes. Microcatheter improvements have allowed for secure positioning of the catheter tip within aneurysms that were previously inaccessible. Evolving coil technology has led to the introduction of softer, more densely packable coils as well as 3-dimensional coils that allow for more complete obliteration at the initial procedure. Embolization techniques, including balloon- and stent-assisted methodology, have been developed to increase the safety of embolization of wide-necked aneurysms. The effect of the learning curve, in terms of improved judgment, skill, and patient selection, has also been well documented.4,5

In recent years, numerous reports of single-center experiences with embolization of basilar apex and other posterior circulation aneurysms have been published. A focused review of this literature is currently lacking. A synthesis of the available data is pivotal for informing both patients and their referring physicians about the most current documented risks and benefits of endovascular treatment of these challenging lesions.

We performed a systematic review of the posterior circulation endovascular literature to assess the types of lesions...
treated, the degree and durability of aneurysm occlusion, and the short-term outcome after GDC embolization. We hope that this compilation will serve as an interim benchmark for evaluating the safety and efficacy of this evolving treatment modality.

Methods

Search Strategy

We performed a MEDLINE search of the English language literature from 1990 onward using the keywords aneurysm(s), GDC, Guglielmi, coil(s), and endovascular in varying combinations with the keywords posterior, vertebral, or basilar. The bibliographies of all identified studies were searched for additional references; this method was repeated until no further studies were found.

Eligibility

Inclusion criteria required treatment of at least 10 patients with posterior circulation aneurysms with the use of GDC. The majority of lesions in any given series were required to be saccular aneurysms not associated with an arteriovenous malformation nidus; studies including a minority of fusiform, traumatic, mycotic, or dissecting aneurysms were not excluded. Studies without data on aneurysm type or in which data regarding treatment efficacy and complications could not be attributed to posterior circulation lesions were excluded. When the same patients were described in multiple publications, data were extracted from the most recent publication or the publication that provided the most complete information.

Data Extraction

A single author (A.P.L.) extracted data from eligible studies by means of a standardized data extraction spreadsheet. Data extracted included (1) study design, (2) baseline characteristics, (3) procedural characteristics, and (4) outcome. Data extractions for study design included prospective or retrospective data collection, study period, criteria for inclusion, and type of outcome measure.

Data extractions for baseline characteristics included number of patients, sex, mean age, number of ruptured and unruptured aneurysms, clinical condition before embolization, aneurysm location, aneurysm size, and aneurysm neck size. Clinical condition was categorized with the use of the Hunt and Hess grading scale. For the classification of aneurysm size, we used the categories small, large, and giant as defined in each study. For aneurysm neck size, we used the categories narrow (≤4 mm) and wide (>4 mm), as described by Fernandez Zubillaga et al.

Data extractions for procedural characteristics included number of aborted procedures, number and type of complications, morbidity and mortality, degree of aneurysm occlusion, and durability of aneurysm occlusion. Procedural complications were classified as intraoperative rupture, coil protrusion, parent vessel thrombosis, embolism, or dissection. Coil protrusion included any herniation of the coil mass into the lumen of the parent artery without regard to clinical significance. Parent vessel thrombosis included any clotting of the parent vessel irrespective of clinical deficits. Embolism included any instance of intraoperative embolization noted by the operators or any instance of MRI findings consistent with embolic infarcts in the appropriate vascular territory. Procedural morbidity included only those complications that produced transient or permanent neurological deficits or resulted in unplanned procedures (e.g., emergent thrombectomy). Nonprocedural morbidity included all other sources of morbidity occurring within 30 days of the procedure (e.g., delayed cerebral ischemia, hydrocephalus, or major medical complications). Mortality was accounted for separately. Angiographic aneurysm occlusion was evaluated on immediate postoperative studies and on follow-up angiograms obtained at least 3 months after the procedure. The degree of aneurysm occlusion was graded on a 3-tier system. Incomplete occlusion corresponds to <90% occlusion or contrast filling of the body and/or dome of the aneurysm. Near-complete occlusion represents 90% to 99% occlusion or residual contrast opacification of the neck region. Complete occlusion designated aneurysms in which no residual neck was detected. The complete category occasionally included aneurysms coiled to 99% rather than 100% occlusion. Durability of aneurysm occlusion was assessed by the same criteria on available follow-up angiograms. We also tracked the number of patients in each occlusion category while accounting for patients who were lost to follow-up. An aneurysm was designated as recurrent if any of the following criteria were satisfied: (1) downgrading of occlusion category on the follow-up study, (2) >5% decrease in aneurysm occlusion within the 90% to 99% category or >10% decrease in aneurysm occlusion within the <90% category, or (3) the author designated an aneurysm as recurrent.

Outcome data extractions included the number of patients for whom clinical follow-up was available, duration of clinical follow-up, incidence of postembolization SAH, 30-day mortality, and outcome at latest clinical follow-up. Outcome measures were dichotomized into independent (Rankin Scale 0 to 2, Glasgow Outcome Scale 1 to 2) or dependent (Rankin Scale 3 to 5, Glasgow Outcome Scale 3 to 4). Procedural mortality (within 30 days) was tracked as a subset of overall mortality.

Data Analysis

Data from all studies were equally weighted and pooled. We calculated percentages for all parameters described under Data Extraction. Annual SAH risk was calculated as the number of postembolization hemorrhages divided by the total duration of clinical follow-up for all patients in years.

Results

Study Characteristics: Overview

The early multicenter trials and all studies eligible for inclusion in the review are listed in Table 1. Eighteen studies reporting on the endovascular treatment of 1101 aneurysms in 1024 patients met the inclusion criteria. Seven hundred twenty-eight of these aneurysms were located in the posterior circulation. Twelve of 18 studies, describing 495 aneurysms in 489 patients, were exclusive to the posterior circulation. Six of these studies, describing 228 aneurysms in 226 patients, were limited to the basilar apex. The 6 remaining studies containing a sizable minority of posterior circulation aneurysms. In none of these studies were patient demographics, procedural characteristics, or outcome measures specifically attributable to posterior circulation aneurysms. As such, these 6 studies were excluded from further analysis. Thus, this review integrates the results of 12 single-center experiences in treating aneurysms exclusive to the posterior circulation with detachable platinum coils. The review is divided into those studies exclusive to the basilar apex and those including posterior circulation aneurysms at all locations (including the basilar apex).

Study Characteristics: Basilar Apex

Six studies describe the result of GDC embolization of aneurysms exclusive to the basilar apex. Five of the studies were retrospective evaluations of single-center cohorts; in 1 of these studies data were collected prospectively. Three studies contributed patients in part or in full to the multicenter trial administered by the Food and Drug Administration. Bavinzski et al initially restricted treatment to poor surgical candidates but subsequently included patients with small, narrow-neck aneurysms regardless of clinical grade. Gruber et al recommended endovascular therapy for
patients of advanced age, with neurological deficits or poor clinical grade, or with comorbid medical conditions. Klein et al.\(^{11}\) reported on a patient population that was “nonselected.” Raymond et al.\(^{12}\) did not describe their indications for GDC embolization. Tateshima et al.\(^{5}\) and McDougall et al.\(^{9}\) provided specific data regarding their indications for endovascular therapy (Table 2).

### TABLE 2. Eligible Studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Treatment Dates</th>
<th>n</th>
<th>% Posterior Circulation That Are BA</th>
<th>% SAH</th>
<th>% Grade 4/5</th>
<th>Mean Clinical Follow-Up, mo</th>
<th>% Independent</th>
<th>% Complete Occlusion</th>
<th>Post-GDC SAH</th>
<th>Reported Morbidity, %</th>
<th>Procedural Mortality, %</th>
<th>Overall Mortality, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eskridge(^{1})</td>
<td>1991–1995</td>
<td>150</td>
<td>100</td>
<td>100</td>
<td>49</td>
<td>11</td>
<td>12.0</td>
<td>78</td>
<td>N/A</td>
<td>4</td>
<td>2.7</td>
<td>18.2</td>
</tr>
<tr>
<td>Guglielmi(^{2})</td>
<td>1990–1991</td>
<td>43</td>
<td>100</td>
<td>54</td>
<td>56</td>
<td>10</td>
<td>2.0</td>
<td>83</td>
<td>40</td>
<td>1</td>
<td>4.8</td>
<td>7.0</td>
</tr>
<tr>
<td>Vinuela(^{8})</td>
<td>1990–1995</td>
<td>403</td>
<td>50</td>
<td>63</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Exclusively basilar apex: single-center cohorts

| Tateshima\(^{5}\) | 1990–1999 | 75 | 100                              | 100   | 58          | 8                           | 31.3          | 86                  | 45           | 1                     | 1.4                    | 8.4                   |
| Bavinskii\(^{10}\) | 1992–1998 | 45†| 100                              | 100   | 75          | 24                          | 27.4          | 73                  | 54           | 1                     | 4.4                    | 2.2                   |
| Gruber\(^{4}\) | 1993–1996 | 21 | 100                              | 100   | 52          | 0                           | 26.0          | 90                  | 14           | 0                     | 9.5                    | 0                     |
| Klein\(^{11}\) | 1993–1996 | 21 | 100                              | 100   | 76          | 19                          | 9.8           | 91                  | 67           | 0                     | 4.8                    | 4.8                   |
| McDougall\(^{9}\) | 1991–1995 | 33 | 100                              | 100   | 70          | 12                          | 15.0          | N/A                 | 21           | 1                     | 3.0                    | 12.1                  |
| Raymond\(^{12}\) | 1992–1995 | 31 | 100                              | 100   | 74          | 10                          | 15.5          | 87                  | 42           | 0                     | 3.2                    | 3.2                   |

Basilar apex and other posterior circulation location: single-center cohorts

| Uda\(^{14}\) | 1990–1999 | 41 | 100                              | 0      | 69          | 3                           | 21.0          | 90                  | 32           | 1                     | 2.6                    | 2.6                   |
| Steiger\(^{13}\) | 1990–1998 | 16 | 100                              | 63     | 69          | 56                          | 6.0           | 88                  | 69           | 0                     | 6.3                    | 6.3                   |
| Lempart\(^{15}\) | 1991–1998 | 112| 100                              | 49     | 100         | 29                          | 13.1          | 83                  | 54‡         | 1                     | 2.8                    | 15.0                  |
| Birchall\(^{17}\) | 1992–1998 | 35 | 100                              | 77     | 46          | 9                           | 42.7          | 86                  | 46           | 1                     | 3.4                    | 8.6                   |
| Nichols\(^{16}\) | 1992–1995 | 28 | 100                              | 68     | 100         | 12                          | 6.0           | 80                  | 61           | 0                     | 3.8                    | 15.4                  |
| Perot\(^{18}\) | 1993–1994 | 35 | 100                              | 66     | 91          | 0                           | 4.8           | 91                  | 73           | 0                     | 2.9                    | 8.8                   |

Reports with >10 posterior circulation aneurysms: single-center cohorts

| Qureshi\(^{21}\) | 1990–1999 | 150 | 31     | 74      | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) |
| Murayama\(^{23}\) | 1991–1998 | 120 | 28     | 67      | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) |
| Solander\(^{22}\) | 1990–1997 | 84  | 30     | 52      | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) |
| Kuether\(^{20}\) | 1992–1996 | 77  | 47     | 61      | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) |
| Malisch\(^{4}\) | 1990–1994 | 104 | 49     | 59      | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) |
| Casasco\(^{19}\) | 1989–1992 | 71  | 59     | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) | \(\text{N/A}\) |

\(n\) indicates number of aneurysms; BA, basilar apex; N/A, not available.

\(^{+}52\% \text{ “adverse event” rate, including a 23% cerebral embolism rate resulting in a 6.7% incidence of clinical stroke. Other patient morbidity attributable to these events is unclear in the source paper.}

\(^{†}\) on an intent-to-treat basis.

\(^{‡}\) on an intent-to-treat basis.

### Baseline Characteristics: Basilar Apex

Tables 3, 4, and 5 show the baseline characteristics of 226 patients harboring basilar apex aneurysms that were treated by GDC embolization. All studies classified small aneurysms as <10 mm, large aneurysms as 11 to 25 mm, and giant lesions as >25 mm. The majority of patients were in good clinical condition (Hunt and Hess grades 0 to 3). Although
57.5% of aneurysms were classified as small, 60% of aneurysms displayed wide necks.

### Complications: Basilar Apex

Tables 6 and 7 describe procedural complications as well as associated morbidity and mortality. GDCs were deposited in 220 of 228 aneurysms for an intent-to-treat success rate of 96.5%. All treatment failures occurred secondary to unfavorable anatomy. No complications of any type occurred in 196 patients (86.0%). Thirty-two patients experienced complications directly related to the procedure (14.0%). Coil protrusion (n = 9; 3.9%) and parent vessel thrombosis (n = 9; 3.9%) occurred with the greatest frequency. There were 7 cases of intraoperative rupture of the aneurysm. Five of these cases were asymptomatic, 2 led to poor neurological outcomes, and 2 caused the patients to expire. Fifteen patients experienced procedure-related morbidity (6.6%). Ten patients (4.4%) died within 30 days of the procedure.

Reporting of nonprocedural complications was inconsistent. Four of 6 studies noted the development of cerebral vasospasm (26 of 154 SAH patients; 16.9%). Two of 6 studies noted the development of cerebral vasospasm (26 of 154 SAH patients; 16.9%). Two patients designated grade 1 or 2.

### Degree and Durability of Occlusion: Basilar Apex

Three-tiered follow-up angiography was available for 96 of 220 treated aneurysms (43.6%). In this subgroup (Table 8), the percentage of patients with incompletely occluded aneurysms was markedly increased (12.3% versus 27.1%).

We also evaluated the relationship between neck size, angiographic occlusion, and recurrence. One hundred eighty-nine patients were identified as having undergone postprocedural angiography and having had an assessment of neck size (Table 9). One hundred thirty-eight of these patients underwent follow-up angiography. Unfortunately, we were unable to track initial neck size category in the follow-up angiograms. There were 34 recanalizations in the follow-up cohort. Thirty-two of 34 recanalized aneurysms had necks >4 mm (94.1%). By assigning the 51 patients with inadequate follow-up as narrow-neck aneurysms, we estimate a recurrence rate of 7.7% for narrow-neck lesions compared with 28.6% for wide-neck lesions. Conversely, by assigning the 51 patients with inadequate follow-up as wide-neck aneurysms, we estimate a recurrence rate of 2.6% for narrow-neck lesions compared with 52.5% for wide-neck lesions. The true recurrence rates for narrow- and wide-neck aneurysms lie between these extremes.

The relationship between initial occlusion category and durability of occlusion in all studies with adequate follow-up is shown in Table 10.

### Outcome and Postprocedural SAH: Basilar Apex

Five studies reported outcome with the use of variations of the Glasgow Outcome Scale. In sum, 3 instances of delayed SAH were reported over 5390.6 months of observation, representing a 0.7% annual risk of SAH after embolization (Table 11). Eighty-four percent of patients were independent at latest clinical follow-up, while 6.8% were dependent and 9.5% were dead. These data are further subdivided into ruptured and unruptured categories in Table 12.
to specifically exclude basilar apex aneurysms; some of the patients in this study are included in the multicenter report by Guglielmi et al.\textsuperscript{2} Indications for GDC embolization were attributed to high surgical risk, failed surgical exploration, or poor clinical grade by Birchall et al.\textsuperscript{17} Nichols et al\textsuperscript{16} and Pierot et al\textsuperscript{18} cite referral from neurosurgeons as their indication for embolization. Lempert et al\textsuperscript{15} note that “a significant proportion of patients in the early phases of the study period were referred for coil therapy either because they were poor surgical candidates or had failed open surgical clipping.” Both Uda et al\textsuperscript{14} and Steiger et al\textsuperscript{13} provide specific accounting of their indications for embolization (Table 2).

### Baseline Characteristics: Posterior Circulation

Tables 3, 4, and 5 show the baseline characteristics of 263 patients harboring 267 posterior circulation aneurysms. The majority of aneurysms were located at the basilar apex (n=135; 50.6%), followed distantly by superior cerebellar artery aneurysms (n=36; 13.5%) and midbasilar aneurysms (n=35; 13.1%). The report by Lempert et al\textsuperscript{15} includes 25 fusiform aneurysms; because of the authors’ method of data presentation, we were unable to exclude these patients from the larger data set. Pierot et al\textsuperscript{18} include 5 patients treated with mechanical detachable spirals rather than GDC.

Descriptions of aneurysm fundus and neck dimensions were variable. Pierot et al\textsuperscript{18} define small aneurysms as <15 mm; Birchall et al\textsuperscript{17} define small aneurysms as <12 mm; Nichols et al\textsuperscript{16} and Uda et al\textsuperscript{14} define small aneurysms as <10 mm; Lempert et al\textsuperscript{15} and Steiger et al\textsuperscript{13} report the range of saccular aneurysm sizes in figures and tables, respectively, allowing us to categorize aneurysms <10 mm as small. All 6 studies describe aneurysms >25 mm as giant. All studies assessed neck size with the exceptions of Pierot et al\textsuperscript{18} and Steiger et al\textsuperscript{13} Nichols et al\textsuperscript{16} defined wide as >4 mm or a sack-to-neck ratio <3:1. Birchall et al\textsuperscript{17} categorized 11 aneurysm necks as wide without defining the term. Lempert et al\textsuperscript{15} graphically depicted neck size for 78 aneurysms, allowing us to categorize necks >4 mm as wide. Uda et al\textsuperscript{14} used the criteria of Fernandez Zubillaga et al.\textsuperscript{7}

### Complications: Posterior Circulation

Tables 6 and 7 describe procedural complications as well as associated morbidity and mortality. GDCs were deposited in 263 of 267 aneurysms for an intent-to-treat success rate of 98.5%. Three treatment failures occurred secondary to unfavorable anatomy preventing safe coil deposition.\textsuperscript{15} One treatment failure was secondary to intraoperative rupture of the aneurysm, resulting in brain circulatory arrest and death.\textsuperscript{18} In 5 other cases in which intraoperative rupture occurred, coil deposition was completed. Four of these patients returned to baseline neurological condition,\textsuperscript{15,17,18} and 1 died.\textsuperscript{14} No complications of any type occurred in 237 embolization attempts (88.8%). Thirty patients experienced complications directly related to the procedure (11.2%). Parent vessel thrombosis occurred with the greatest frequency (n=18; 6.7%). Only 12 patients experienced procedure-related morbidity (4.5%). Twenty-three patients (8.6%) died within 30 days of the procedure.

Reporting of nonprocedural complications was limited. Three of 6 studies reported single cases of fatal cerebral vasospasm.\textsuperscript{15,16,18} Lempert et al\textsuperscript{15} reported that the presence of vasospasm was inversely correlated with clinical outcome, but the authors failed to report the incidence of vasospasm by grade or for the entire cohort. Two studies\textsuperscript{15,18} reported 7 patients who suffered medical complications resulting in morbidity (myocardial infarction and aspiration pneumonia; pulmonary embolism [n=2]; pancreatitis, candidal sinusitis, and severe fungemia; gastrointestinal bleeding [n=3]). No study described the incidence of hydrocephalus.

### Degree and Durability of Occlusion: Posterior Circulation

Postprocedural angiograms graded on a 3-tier scale were available for 236 patients. Follow-up angiography for >3 months was available for 112 of these patients (Table 8). All of the patients from Lempert et al\textsuperscript{15} were excluded from this analysis because of inadequate data presentation. In this limited subgroup, the percentage of patients with incom-

### TABLE 5. Aneurysm Location: Posterior Circulation and Entire Cohort

<table>
<thead>
<tr>
<th>Aneurysm Location</th>
<th>Posterior circulation</th>
<th>Basilar Apex</th>
<th>SCA</th>
<th>PICA</th>
<th>Midbasilar</th>
<th>VB Junction</th>
<th>Vertebral</th>
<th>PCA</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>267</td>
<td>135 (50.6%)</td>
<td>36</td>
<td>17</td>
<td>35</td>
<td>19</td>
<td>14</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>495</td>
<td>363</td>
<td>17</td>
<td>35</td>
<td>19</td>
<td>14</td>
<td>9</td>
<td>2</td>
</tr>
</tbody>
</table>

SCA indicates superior cerebellar artery; PICA, posterior inferior cerebellar artery; VB, vertebrobasilar; and PCA, posterior cerebral artery.

### TABLE 6. Procedural Complications

<table>
<thead>
<tr>
<th>Intent to Treat</th>
<th>Total Procedural Complications</th>
<th>Intraoperative Rupture</th>
<th>Coil Dissection</th>
<th>Parent Vessel Thrombosis</th>
<th>Embolism</th>
<th>Dissection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basilar apex</td>
<td>228</td>
<td>220 (96.5%)</td>
<td>7 (3.1%)</td>
<td>9 (3.9%)</td>
<td>4 (1.8%)</td>
<td>3 (1.3%)</td>
</tr>
<tr>
<td>Posterior</td>
<td>267</td>
<td>263 (98.5%)</td>
<td>6 (2.3%)</td>
<td>18 (6.7%)</td>
<td>1 (0.4%)</td>
<td>0 (0.0%)</td>
</tr>
<tr>
<td>Total</td>
<td>495</td>
<td>483 (97.6%)</td>
<td>13 (2.6%)</td>
<td>27 (5.5%)</td>
<td>5 (1.0%)</td>
<td>3 (0.6%)</td>
</tr>
</tbody>
</table>
completely occluded aneurysms was markedly increased compared with postprocedural studies (6.0% versus 16.1%).

We also evaluated the relationship between neck size, angiographic occlusion, and recurrence using the previously defined criteria. Ninety-six patients were identified as having undergone follow-up angiography and having had an assessment of initial neck size.\textsuperscript{15,16} There were 18 recanalizations in this cohort. Sixteen of 18 recanalized aneurysms had necks >4 mm (88.9%).

### Outcome and Postprocedural SAH: Posterior Circulation

All studies reported outcome using variations of the Glasgow Outcome Scale\textsuperscript{24} or the Rankin Scale of disability.\textsuperscript{25} Two hundred thirty-nine subjects (90.9% of treated patients) had a total of 4018.8 months of clinical follow-up beyond hospital discharge (mean, 16.8 months). Three instances of delayed SAH were reported in this subgroup, representing a 0.9% annual risk of SAH after embolization (Table 11). Eighty-six percent of patients were independent at latest clinical follow-up, while 4.2% were dependent, and 10.0% were dead. These percent of patients were independent at latest clinical follow-up.

#### TABLE 7. Morbidity and Mortality

<table>
<thead>
<tr>
<th>Intent to Treat</th>
<th>Procedural Morbidity</th>
<th>Procedural Mortality</th>
<th>30-Day Mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basilar apex</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>228</td>
<td>15 (6.6%)</td>
<td>3 (1.3%)</td>
<td>10 (4.4%)</td>
</tr>
<tr>
<td>Posterior circulation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>267</td>
<td>12 (4.5%)</td>
<td>4 (1.5%)</td>
<td>23 (8.6%)</td>
</tr>
<tr>
<td>Total</td>
<td>495</td>
<td>25 (5.1%)</td>
<td>7 (1.4%)</td>
</tr>
</tbody>
</table>

#### TABLE 8. Angiographic Occlusion Rates for Treated Aneurysms

<table>
<thead>
<tr>
<th>n</th>
<th>100%</th>
<th>90–99%</th>
<th>&lt;90%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basilar apex</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-GDC\textsuperscript{6,10–12}</td>
<td>220</td>
<td>43.2%</td>
<td>44.6%</td>
</tr>
<tr>
<td>6-mo follow-up\textsuperscript{6,10–12}</td>
<td>96</td>
<td>36.5%</td>
<td>36.5%</td>
</tr>
<tr>
<td>Posterior circulation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-GDC\textsuperscript{6,10–12}</td>
<td>236</td>
<td>51.7%</td>
<td>42.4%</td>
</tr>
<tr>
<td>3-mo follow-up\textsuperscript{6,10–12}</td>
<td>112</td>
<td>51.8%</td>
<td>32.1%</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-GDC</td>
<td>456</td>
<td>47.6%</td>
<td>43.4%</td>
</tr>
<tr>
<td>Follow-up</td>
<td>208</td>
<td>44.7%</td>
<td>34.1%</td>
</tr>
</tbody>
</table>

### Data Accessibility and Data Quality

Our literature search identified 18 studies describing the attempted GDC embolization of 728 posterior circulation aneurysms. Unfortunately, we were unable to include 233 (32.0%) of these aneurysms in this review because of insufficient data presentation in the source papers. Of the remaining 495 aneurysms, 363 (73.3%) were located at the basilar apex. If one defines the basilar apex more broadly to include aneurysms arising from the basilar artery between the origins of the superior cerebellar artery and the P1 segment or along the P1 segment, then 408 (82.4%) of the reported aneurysms in this review arise near the basilar apex. The literature contains only 1 series of posterior circulation aneurysms exclusive of the basilar apex,\textsuperscript{14} although several case reports describing the challenges provided by specific sites in the posterior circulation are available.\textsuperscript{26–28} In summary, the published literature describing GDC embolization in the posterior circulation closely approximates a large series of basilar apex aneurysms.

Data presentation was not uniform among the source papers and posed challenges for data compilation. The most accessible data arose from articles that presented tables listing the baseline characteristics, initial and follow-up angiographic occlusion percentages, complications, and clinical

#### TABLE 9. Relationship Between Neck Size, Angiographic Occlusion, and Recurrence in Treated Aneurysms

<table>
<thead>
<tr>
<th>Basilar Apex\textsuperscript{6,10–12}</th>
<th>Total</th>
<th>Narrow Neck</th>
<th>Wide Neck</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% occluded</td>
<td>88</td>
<td>62</td>
<td>26</td>
</tr>
<tr>
<td>90–99% occluded</td>
<td>81</td>
<td>15</td>
<td>66</td>
</tr>
<tr>
<td>&lt;90% occluded</td>
<td>20</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>Total</td>
<td>189</td>
<td>77</td>
<td>112</td>
</tr>
<tr>
<td>Inadequate follow-up</td>
<td>51</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Adequate follow-up</td>
<td>138</td>
<td>26–77</td>
<td>61–112</td>
</tr>
<tr>
<td>Recurrence</td>
<td>34</td>
<td>2</td>
<td>32</td>
</tr>
<tr>
<td>% Recurrence</td>
<td>24.6</td>
<td>2.6–7.7</td>
<td>28.6–52.5</td>
</tr>
</tbody>
</table>

#### TABLE 10. Relationship Between Initial Occlusion Category and Durability of Occlusion in All Studies With Adequate Follow-Up

<table>
<thead>
<tr>
<th>n\textsuperscript{10–14,16,18}</th>
<th>Total</th>
<th>100%</th>
<th>90–99%</th>
<th>&lt;90%</th>
</tr>
</thead>
<tbody>
<tr>
<td>No follow-up</td>
<td>50</td>
<td>36</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>Follow-up</td>
<td>166</td>
<td>78</td>
<td>78</td>
<td>10</td>
</tr>
<tr>
<td>% Recurrence</td>
<td>76.9</td>
<td>68.4</td>
<td>89.7</td>
<td>66.7</td>
</tr>
<tr>
<td>Recanalized</td>
<td>43</td>
<td>8</td>
<td>29</td>
<td>6</td>
</tr>
<tr>
<td>% Recanalized</td>
<td>25.9</td>
<td>10.3</td>
<td>37.2</td>
<td>60.0</td>
</tr>
<tr>
<td>Stable</td>
<td>113</td>
<td>70</td>
<td>40</td>
<td>3</td>
</tr>
<tr>
<td>% Stable</td>
<td>68.1</td>
<td>89.7</td>
<td>51.3</td>
<td>30.0</td>
</tr>
<tr>
<td>Progressive thrombosis</td>
<td>10</td>
<td>. . .</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>% Progressive thrombosis</td>
<td>6.0</td>
<td>. . .</td>
<td>11.5</td>
<td>10.0</td>
</tr>
</tbody>
</table>
outcome measures for individual patients. Other studies provided tables, charts, or text descriptions of subsets of the cohort from which data were extracted with varying degrees of difficulty. Data regarding aneurysm occlusion on initial and postoperative angiograms were often presented in such a way that it was difficult or impossible to track the fate of an individual aneurysm. Overlap in authors’ definitions of small and large aneurysms in the 10- to 15-mm range also confounded any analysis of aneurysm size that might have been considered. In cases in which we could not characterize a given parameter with a high degree of certainty, we chose to exclude the data from that source.

**Baseline Characteristics**

The majority of patients (81.2%) included in this review harbored an unruptured aneurysm or presented in good clinical condition (Hunt and Hess grade 1 to 3) after SAH. Sixty-three percent of lesions were classified as small. Unruptured aneurysms were treated at greater than twice the frequency in the exclusively basilar apex series compared with the posterior circulation series. Sixty percent of aneurysms in the basilar apex series exhibited wide necks compared with only 24.5% in the posterior circulation series. Although the number of aneurysms treated concurrently by open surgery was not available, these data suggest that endovascular therapy in the posterior circulation was not being reserved for patients in poor clinical condition. “Unfavorable surgical anatomy” was frequently cited as an indication for GDC embolization. However, the high frequency of small aneurysms, which when located at the basilar apex are often favorable for clipping in expert hands, suggests that referral patterns or physician preference may have played a more prominent role in recommending endovascular therapy over surgical clipping.

**Procedural Complications**

Procedural complications were noted in 62 of 495 cases (12.5%) on an intent-to-treat basis. We encountered substantial heterogeneity in the reporting of procedural complications. The most consistently reported complication was intraoperative rupture. Descriptions of thrombotic complications were ambiguous in several reports. Only 25 (40.3%) of these complications were reported to contribute to patient morbidity. We were unable to calculate 30-day morbidity rates because of erratic reporting of medical and nonprocedural neurological complications (e.g., delayed cerebral ischemia with persistent deficit).

### Table 11. Post-GDC SAH

<table>
<thead>
<tr>
<th>Risk Group</th>
<th>Patients With Clinical Follow-Up</th>
<th>Post-GDC SAH</th>
<th>Duration of Clinical Follow-Up, mo</th>
<th>Mean Clinical Follow-Up, mo</th>
<th>Annual SAH Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basilar apex6,8–12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>221*</td>
<td>3†</td>
<td>5390.6</td>
<td>24.4</td>
<td>0.7%</td>
</tr>
<tr>
<td>Posterior circulation13–18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>239‡</td>
<td>3§</td>
<td>4018.8</td>
<td>16.8</td>
<td>0.9%</td>
</tr>
<tr>
<td>Total</td>
<td>460</td>
<td>6</td>
<td>9409.4</td>
<td>20.5</td>
<td>0.8%</td>
</tr>
</tbody>
</table>

*Four treatment failures and 1 patient lost to follow-up not included.
†Two ruptured and 1 unruptured aneurysms.
‡Four treatment failures and 20 patients lost to follow-up not included.
§One ruptured and 2 unruptured aneurysms.

### Table 12. Clinical Outcome

<table>
<thead>
<tr>
<th>Risk Group</th>
<th>Patients With Clinical Follow-Up, mo</th>
<th>Duration of Clinical Follow-Up, mo</th>
<th>Mean Clinical Follow-Up, mo</th>
<th>Independent</th>
<th>Dependent</th>
<th>Dead</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basilar apex6,8,10–12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ruptured</td>
<td>126</td>
<td>N/A</td>
<td>N/A</td>
<td>101 (80.2%)</td>
<td>11 (8.7%)</td>
<td>14 (11.1%)</td>
</tr>
<tr>
<td>Unruptured</td>
<td>64</td>
<td>N/A</td>
<td>N/A</td>
<td>58 (90.6%)</td>
<td>2 (3.1%)</td>
<td>4 (6.3%)</td>
</tr>
<tr>
<td>Total</td>
<td>190</td>
<td>4955.6</td>
<td>26.1</td>
<td>159 (83.7%)</td>
<td>13 (6.8%)</td>
<td>18 (9.5%)</td>
</tr>
<tr>
<td>Posterior circulation13–18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ruptured</td>
<td>221</td>
<td>N/A</td>
<td>N/A</td>
<td>186 (84.1%)</td>
<td>11 (5.0%)</td>
<td>24 (10.9%)</td>
</tr>
<tr>
<td>Unruptured</td>
<td>39</td>
<td>N/A</td>
<td>N/A</td>
<td>37 (94.9%)</td>
<td>0</td>
<td>2 (5.1%)</td>
</tr>
<tr>
<td>Total</td>
<td>260</td>
<td>4018.8</td>
<td>15.5</td>
<td>223 (85.8%)</td>
<td>11 (4.2%)</td>
<td>26 (10.0%)</td>
</tr>
<tr>
<td>Total</td>
<td>450</td>
<td>8974.4</td>
<td>19.9</td>
<td>382 (84.9%)</td>
<td>24 (5.3%)</td>
<td>44 (9.8%)</td>
</tr>
</tbody>
</table>

N/A indicates not available. The number of patients with clinical follow-up differs between Tables 11 and 12 because clinical outcome for patients lost to follow-up was determined at discharge (0 months of clinical follow-up). Clinical outcome could not be extracted from McDougall et al.9
Technical Success and Durability of Occlusion

Ninety-one percent of all aneurysms not treated with parent artery occlusion were >90% occluded on postprocedural angiograms. Evaluating the durability of occlusion was plagued by difficulty in following the fate of an individual treated lesion. Likewise, there may be an underlying selection bias favoring follow-up angiography for lesions in which recurrence is anticipated. Nevertheless, we were able to identify 166 treated aneurysms that had both postprocedural and >3-month follow-up studies that were graded on a 3-tiered scale. This subgroup was derived from 7 studies treating 216 aneurysms with 50 lesions (23.1%) lost to follow-up (Table 10). Initial occlusion was a strong predictor of degree of occlusion at follow-up. The recanalization rates were 10%, 37%, and 60% for treatments that were graded complete, near complete, and incomplete on postprocedural studies, respectively. For treatments that were near complete or incomplete on postprocedural studies, some degree of progressive thrombosis was observed in 11.5% and 10% of follow-up studies, respectively. We were not able to account for the effect of neck size in this subgroup analysis.

In the basilar aneurysm series, aneurysm neck size was a major factor related to initial technical success. According to the data from Table 9, 70% of aneurysms in which 100% occlusion was achieved displayed narrow necks. Conversely, in lesions in which ≤99% occlusion was achieved, 85% exhibited wide necks. When all narrow-neck aneurysms are considered, 81% were 100% occluded and none were ≤90% occluded. In contradistinction, only 23% of wide-neck aneurysms were initially 100% occluded, while 18% were ≤90% occluded. There were 34 documented recurrences in 138 follow-up studies, with 51 of 189 patients lost to follow-up. All but 2 of these recurrences occurred in patients harboring wide-neck aneurysms. We were unable to determine the percentages of narrow- and wide-neck aneurysms that were lost to follow-up; if one assumes an equal distribution, the estimated recurrence rates are 4% (range, 2.6% to 7.7%) for narrow-neck lesions and 37% (range, 28.6% to 52.5%) for wide-neck lesions.

The best available data on the natural history of neck remnants in a cerebral aneurysm treated by GDC embolization comes from the extensive experience at the University of California at Los Angeles (UCLA). In 77 patients with 79 incidental aneurysms treated with GDCs, 52 were completely occluded, 22 demonstrated small neck remnants, and 5 were incompletely treated. No recanalization was observed in the 52 completely occluded lesions at a mean follow-up of 16.3 months. In the 22 aneurysms with small neck remnants, 8 (36%) showed further aneurysm thrombosis, 7 (32%) remained anatomically unchanged, and 7 (32%) showed recanalization. In another study of 455 patients, 178 aneurysms (39%) had residual necks after embolization. Seventy-one patients harboring 73 aneurysms with residual necks underwent long-term angiographic follow-up (mean, 17.3 months). In small aneurysms with narrow necks (n=24), 50% progressed to thrombosis, 33% remained unchanged, and 17% recanalized. In small aneurysms with wide necks (n=24), 25% exhibited progressive thrombosis, 33% remained unchanged, and 42% recanalized. In large aneurysms (n=15), 13% of neck remnants were stable, and 87% of lesions recanalized. In giant lesions (n=10), only 10% of neck remnants were stable, while 90% of aneurysms recanalized. On the basis of these findings, the UCLA group notes, “Although GDC treatment appears to be effective and durable in aneurysms with small necks, its long-term durability is more limited in aneurysms with wide necks.”

Postembolization SAH

Delayed SAH occurred in 6 patients after 460 embolizations with a total of 9409.4 months of clinical follow-up. These incidents yielded an annual SAH risk rate of 0.8%. Delayed SAH risks of 0.6% to 2% per year after coil embolization of both ruptured and unruptured aneurysms are consistent with reports that are not limited to the posterior circulation. Kuether et al reported the results of treating 77 aneurysms with GDCs over a 4.5-year period. There were 2 cases of delayed SAH after incomplete and near-complete embolizations of previously unruptured lesions. There were no repeated hemorrhages after treatment of 41 ruptured aneurysms that had at least 6 months of follow-up. Byrne et al treated 317 patients with aneurysmal SAH by coil embolization and followed the cohort for a median of 22.3 months. Aneurysm recurrence was documented in 38 (14.7%) of 259 aneurysms that underwent follow-up angiography. Rebleeding was caused by aneurysm recurrence in 4 patients. The annual rebleeding rates were 0.8% in the first year, 0.6% in the second year, and 2.4% in the third year after embolization. Malisch et al reported the “midterm” clinical results of the first 100 consecutive GDC-treated patients at UCLA. They found postembolization hemorrhage rates of 0% for small aneurysms, 4% for large aneurysms, and 33% for giant lesions.

The postembolization hemorrhage risk for GDC-treated ruptured and unruptured lesions must be compared not only with surgical series (where it is approximately 0.2% annually) but with the natural history of untreated lesions. Sixty percent of patients with ruptured aneurysms that are treated conservatively die within 6 months of the initial hemorrhage; 25% to 40% of survivors experience significant morbidity by 6 months. Nishioka et al reported a cumulative 37% risk of rebleeding at 4 weeks. The estimated overall mortality rate from second hemorrhages in conservatively managed patients ranges from 34% to 42%,. It is well documented that GDC embolization of ruptured aneurysms provides significant protection against early rebleeding and allows for the initiation of aggressive hemodynamic therapy. However, rather than essentially eliminating the risk of recurrent SAH, GDC embolization of ruptured aneurysms appears to reduce the risk of SAH to a rate approximating that found in unruptured cohorts.

The overall risk of rupture of an incidental aneurysm has been demonstrated in several observational studies to lie between 1% and 3% annually, although 1 recent study reports a substantially lower estimate. The risk of rupture is correlated with dome size. Aneurysms at midline locations, particularly at the basilar apex, also carry an increased relative risk of rupture. The finding that postembolization hemorrhage rates approach 1% per year for both ruptured and
unruptured aneurysms raises the question of whether embolization confers any protection against SAH in incidental lesions. The majority of aneurysms in this review were located at the basilar apex; likewise, a substantial percentage (33.5%) was classified as large or giant. Given these baseline characteristics, we suspect that lesions in this study carry a risk of rupture that exceeds the average risk of 1% to 3% reported in the literature. Thus, embolization of unruptured posterior circulation aneurysms may provide some reduction in the relative risk of rupture compared with no treatment. Nevertheless, the cumulative data from 1990 to the present suggest that the risk of postembolization SAH remains tangible.

**Outcome**

Clinical follow-up for >3 months was available for 90.9% of the entire cohort; 84.9% of these patients achieved functional independence (Glasgow Outcome Scale 1 or 2), while only 5.3% lived dependent lifestyles. The overall mortality at follow-up was 9.8% (61% of which was attributable to periprocedural death). For patients presenting with SAH, Hunt and Hess grade at presentation was a strong predictor of clinical outcome. Direct comparisons between surgical and endovascular series are hampered by differences in clinical condition at presentation, referral practices, and anatomic considerations. Nevertheless, the aforementioned results are comparable to those obtained in the most accomplished surgical series. As with most surgical series, adjudication of patient outcome was rare. Only Lempert et al identified the study outcome assessors, which consisted of a combination of university hospital neurologist, referring neurologists or neurosurgeons, and clinical nurse specialist.

**Conclusions**

Although the published endovascular experience with poste-
rior circulation aneurysms is hampered by limited, inconsis-
tent, and at times incomplete data presentation, our review and synthesis of the literature draw several conclusions. First, the published literature describing GDC embolization in the posterior circulation closely approximates a large series of basilar apex aneurysms. Second, procedural morbidity and mortality are decreased in recent reports compared with those seen in the Food and Drug Administration multicenter trial; furthermore, these rates are comparable to those found in the best surgical data. Third, embolization is moderately effective in completely excluding (but very effective at partially excluding) an aneurysm from the posterior circulation after the initial procedure. Fourth, the incidence of early recanalization is substantial in wide-neck and incompletely coiled aneurysms but not altogether insignificant in small-neck and completely coiled aneurysms. Last, coil embolization is without question effective in preventing early rebleeding from ruptured posterior circulation aneurysms. Its role in the treatment of unruptured aneurysms remains unclear, as em-
bolization appears to offer only a marginal risk reduction against SAH compared with the natural history of an unrup-
tured aneurysm. To confirm these conclusions, future studies will need to adopt standardized methods of data presentation and outcome assessment.

**Acknowledgment**

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