Surgical Treatment of Large or Giant Fusiform Middle Cerebral Artery Aneurysms: A Case Series

Feng Xu¹, Bin Xu¹, Lei Huang², Ji Xiong³, Yuxiang Gu¹, Michael T. Lawton⁴

BACKGROUND: Management of large or giant fusiform middle cerebral artery (MCA) aneurysms represents a significant challenge.

OBJECTIVE: To describe the authors’ experience in the treatment of large or giant fusiform MCA aneurysm by using various surgical techniques.

METHODS: We retrospectively reviewed a database of aneurysms treated at our division between 2015 and 2017.

RESULTS: Overall, 20 patients (11 males, 9 females) were identified, with a mean age of 40.7 years (range, 13–65 years; median, 43 years). Six patients (30%) had ruptured aneurysms and 14 (70%) had unruptured aneurysms. The mean aneurysm size was 19 mm (range, 10–35 mm). The aneurysms involved the prebifurcation in 5 cases, bifurcation in 4 cases, and postbifurcation in 11 cases. The aneurysms were treated by clip reconstruction (n=5), clip wrapping (n=1), proximal occlusion or trapping (n=4), and bypass revascularization (n=10). Bypasses included 7 low-flow superficial temporal artery—MCA bypasses, 2 high-flow extracranial-intracranial bypasses, and 1 intracranial-intracranial bypass (reanastomosis). Bypass patency was 90%. Nineteen aneurysms (95%) were completely obliterated, and no rehemorrhage occurred during follow-up. There was no procedural-related mortality. Clinical outcomes were good (modified Rankin Scale score ≤2) in 18 of 20 patients (90%) at the last follow-up.

CONCLUSIONS: Surgical treatment strategy for large or giant fusiform MCA aneurysms should be determined on an individual basis, based on aneurysm morphology, location, size, and clinical status. Favorable outcomes can be achieved by various surgical techniques, including clip reconstruction, wrap clipping, aneurysm trapping, aneurysm excision followed by reanastomosis, and partial trapping with bypass revascularization.

INTRODUCTION

Fusiform intracranial aneurysms are relatively uncommon, accounting for approximately 3%–13% of all intracranial aneurysms.¹ The vertebrobasilar system is the commonly affected location, followed by the middle cerebral artery (MCA).² As previously shown, fusiform aneurysms might have a wide spectrum of vascular abnormalities that range from small fusiform aneurysmal dilations to giant dolichoectatic aneurysms.³⁻⁵ Large or giant fusiform MCA aneurysms are technically difficult to treat because of their complex morphology,

Key words
- Fusiform aneurysm
- Giant aneurysm
- Middle cerebral artery
- Surgical treatment

Abbreviations and Acronyms
CT: Computed tomography
DSA: Digital subtraction angiography
EC: Extracranial
IC: Intracranial
MCA: Middle cerebral artery
MEP: Motor evoked potentials
mRS: Modified Rankin Scale
RA: Radial artery
RAG: Radial artery graft

SAH: Subarachnoid hemorrhage
STA: Superficial temporal artery

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Citation: World Neurosurg. (2018) 115:e252-e262.
https://doi.org/10.1016/j.wneu.2018.04.031

Journal homepage: www.WORLDNEUROSURGERY.org
Available online: www.sciencedirect.com

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which makes direct clipping impossible. Moreover, fusiform MCA aneurysms at the proximal (M1) segment are related at their origin to perforating lenticulostriate arteries, posing a different challenge to the microneurosurgeon. Few studies focusing on surgical treatment of fusiform MCA aneurysms have been reported. In the present study, we describe various surgical techniques used to treat large or giant fusiform MCA aneurysms during a 3-year period.

METHODS

Study Design
This retrospective study was approved by our institutional review board and all patients signed general informed consent forms. We searched a database of all aneurysms treated in the Division of Cerebrovascular Surgery in our institution between 2015 and 2017 to identify large or giant fusiform MCA aneurysms. We reviewed patient age, symptoms at presentation, aneurysm size and location, treatment modalities, postoperative images, complications, clinical outcomes, and follow-up. Clinical outcomes were measured using the modified Rankin Scale (mRS) score. Preoperative outcome and clinical follow-up were assessed by the same practitioner (F.X.). Angiographic follow-up was performed by using computed tomography (CT) angiography or digital subtraction angiography (DSA).

Definitions and Inclusion Criteria
Intracranial aneurysms are often classified according to their shape into saccular and fusiform types. Fusiform aneurysms were defined as aneurysmal dilation of >50% of the vessel wall circumference. Fusiform aneurysms can range from small fusiform aneurysmal dilations to giant dolichoectatic aneurysms filled largely with thrombus. Our inclusion criteria were patients with large (10–24 mm) or giant (≥25 mm) fusiform MCA aneurysms. All nonsaccular fusiform MCA aneurysms associated with trauma, mycosis or infection, and inflammation were excluded from our study.

Surgical Strategy
The surgical treatment strategy is complex and depends on multiple factors, including aneurysm morphology, location, size, and rupture status (Figure 1). Preoperative high-resolution magnetic resonance imaging helps us to distinguish nondissecting fusiform aneurysms from fusiform dissecting aneurysms. According to the classification proposed by Mizutani et al., specific morphologic features in our study included fusiform segmental ectasia without thrombus formation (type 2 aneurysm) and tortuous fusiform appearance with multiple dissection (type 3 aneurysm). For nondissecting fusiform aneurysms, clip reconstruction of the parent vessel lumen or clip wrapping are preferred. If the lenticulostriate artery is involved, these lesions can be treated by partial trapping and high-flow extracranial (EC)-to-intracranial (IC) bypass. For fusiform or dolichoectatic dissecting aneurysms, partial trapping and vascular bypass are recommended. The decision regarding bypass type was based on the location of the aneurysm, the caliber of the superficial temporal artery (STA) and collaterals on preoperative angiography. Electrophysiologic monitoring included motor evoked potentials (MEP) and somatosensory evoked potentials recorded intraoperatively. For ruptured fusiform aneurysms originating from the M3 or distal segments, if intraoperative somatosensory evoked potentials and MEP during the 20-minute parent artery occlusion remains unchanged, aneurysm trapping or proximal occlusion is preferred.

Assessment of Bypass Patency and Aneurysm Occlusion
The patency of bypass was assessed intraoperatively using the Doppler ultrasonic probe, indocyanine green video angiography,
or DSA. Aneurysm occlusion was regarded as complete if there was no residual contrast filling of the aneurysm dome.

**RESULTS**

**Patient Characteristics**

Between January 2015 and December 2017, 20 patients with large or giant fusiform MCA aneurysm were treated surgically (Table 1). There were 11 men and 9 women with a mean age of 40.7 years (range, 13–65 years; median, 43 years). Six patients presented initially with subarachnoid hemorrhage (SAH) or intracerebral hemorrhage. Six patients had headache, 3 had dizziness, and 5 aneurysms were incidental findings (Table 2).

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (Years), Sex</th>
<th>Presentation</th>
<th>Aneurysm Location/Size (mm)</th>
<th>Aneurysm Treatment</th>
<th>Preoperative mRS Score</th>
<th>Follow-Up mRS Score</th>
<th>Aneurysm Occlusion</th>
<th>Bypass Patency</th>
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<tr>
<td>1</td>
<td>13, M</td>
<td>Headache</td>
<td>Lt M1, 22</td>
<td>Clip reconstruction</td>
<td>1</td>
<td>0</td>
<td>Complete</td>
<td>—</td>
</tr>
<tr>
<td>2</td>
<td>65, F</td>
<td>Headache</td>
<td>Lt M1, 17</td>
<td>Clip reconstruction</td>
<td>1</td>
<td>0</td>
<td>Complete</td>
<td>—</td>
</tr>
<tr>
<td>3</td>
<td>25, F</td>
<td>Incidentally discovered</td>
<td>Rt M1, 21</td>
<td>Trapping and excision</td>
<td>0</td>
<td>1</td>
<td>Complete</td>
<td>—</td>
</tr>
<tr>
<td>4</td>
<td>46, F</td>
<td>Headache</td>
<td>Lt M1, 35</td>
<td>Proximal occlusion, ECA-RAG-M2</td>
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<td>3</td>
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<td>Patent</td>
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<tr>
<td>5</td>
<td>51, M</td>
<td>SAH</td>
<td>Lt M1, 32</td>
<td>Trapping and excision, STA-RAG-M2</td>
<td>1</td>
<td>2</td>
<td>Complete</td>
<td>Patent</td>
</tr>
<tr>
<td>6</td>
<td>43, M</td>
<td>Incidentally discovered</td>
<td>Lt M1-M2, 11</td>
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<td>0</td>
<td>Complete</td>
<td>—</td>
</tr>
<tr>
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<td>Headache</td>
<td>Rt M1-M2, 20</td>
<td>Clip reconstruction</td>
<td>1</td>
<td>1</td>
<td>Nearly complete</td>
<td>—</td>
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<td>Dizziness</td>
<td>Lt M1-M2, 11</td>
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<td>0</td>
<td>Complete</td>
<td>—</td>
</tr>
<tr>
<td>9</td>
<td>43, F</td>
<td>Dizziness</td>
<td>Rt M1-M2, 22</td>
<td>Distal occlusion, double STA-M4</td>
<td>1</td>
<td>1</td>
<td>Complete</td>
<td>Patent</td>
</tr>
<tr>
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<td>40, F</td>
<td>Dizziness</td>
<td>Rt M2, 13</td>
<td>Clip reconstruction</td>
<td>1</td>
<td>1</td>
<td>Complete</td>
<td>—</td>
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<td>11</td>
<td>17, M</td>
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<td>0</td>
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<td>33, M</td>
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<td>Lt M2, 11</td>
<td>Proximal occlusion, double STA-M4</td>
<td>0</td>
<td>0</td>
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<td>Rt M2, 10</td>
<td>Trapping, STA-M4</td>
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<td>0</td>
<td>Complete</td>
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<td>Lt M2, 14</td>
<td>Trapping, STA-M4</td>
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<td>0</td>
<td>Complete</td>
<td>Patent</td>
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<td>16</td>
<td>31, M</td>
<td>SAH</td>
<td>Lt M2, 27</td>
<td>Proximal occlusion, STA-M4</td>
<td>1</td>
<td>0</td>
<td>Complete</td>
<td>Patent</td>
</tr>
<tr>
<td>17</td>
<td>40, M</td>
<td>SAH, ICH</td>
<td>Lt M3, 12</td>
<td>Proximal occlusion</td>
<td>5</td>
<td>3</td>
<td>Complete</td>
<td>—</td>
</tr>
<tr>
<td>18</td>
<td>49, M</td>
<td>SAH, ICH</td>
<td>Rt M3, 11</td>
<td>Trapping</td>
<td>2</td>
<td>1</td>
<td>Complete</td>
<td>—</td>
</tr>
<tr>
<td>19</td>
<td>46, M</td>
<td>SAH</td>
<td>Lt M3, 22</td>
<td>Trapping and excision</td>
<td>1</td>
<td>1</td>
<td>Complete</td>
<td>—</td>
</tr>
<tr>
<td>20</td>
<td>40, M</td>
<td>SAH, ICH</td>
<td>Lt M3, 28</td>
<td>Proximal occlusion, STA-M4</td>
<td>5</td>
<td>2</td>
<td>Complete</td>
<td>Occluded</td>
</tr>
</tbody>
</table>

mRS, modified Rankin Scale; M, male; Lt, left; F, female; Rt, right; ECA, external cerebral artery; RAG, radial artery graft; SAH, subarachnoid hemorrhage; STA, superficial temporal artery; ICH, intracerebral hemorrhage.

The size of the 20 aneurysms ranged from 10 to 35 mm (mean, 19 mm; median, 18.5 mm). Five patients had a giant aneurysm. Six aneurysms were on the right side and 14 on the left. These aneurysms were classified as prebifurcation in 5 patients (25%), bifurcation in 4 (20%), and postbifurcation in 11 (55%) (Table 2).

**Treatment Modalities**

All aneurysms were exposed through pterional craniotomy and a transsylvian approach. Of all 20 aneurysms treated, 5 (25%) were managed with clip reconstruction (Figures 2 and 3), 1 (5%) by clip wrapping, 4 (20%) by proximal occlusion or trapping, and 10 (50%) by vascular bypass (Figures 4–7).

Bypasses performed in treatment of 10 aneurysms included 9 EC-IC bypasses and 1 IC-IC bypass. The EC-IC bypasses included 7 STA-MCA bypasses (Figures 5 and 7), 1 external cerebral artery–radial artery (RA) graft (RAG)-M2 bypass (Figure 4), and 1 STA-RAG-M2 bypass. The IC-IC bypass was performed in 1 patient (case 11), who was treated by aneurysm excision and M2-M2 reanastomosis (Figure 6).
Table 2. Baseline Characteristics in 20 Patients

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex, n (%)</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>11 (55)</td>
</tr>
<tr>
<td>Female</td>
<td>9 (45)</td>
</tr>
<tr>
<td>Age (years)</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>40.7</td>
</tr>
<tr>
<td>Range</td>
<td>13–65</td>
</tr>
<tr>
<td>Presentation, n (%)</td>
<td></td>
</tr>
<tr>
<td>Subarachnoid hemorrhage</td>
<td>6 (30)</td>
</tr>
<tr>
<td>Headache</td>
<td>6 (30)</td>
</tr>
<tr>
<td>Dizziness</td>
<td>3 (15)</td>
</tr>
<tr>
<td>Incidental</td>
<td>5 (25)</td>
</tr>
<tr>
<td>Aneurysm location, n (%)</td>
<td></td>
</tr>
<tr>
<td>Left side</td>
<td>14 (70)</td>
</tr>
<tr>
<td>Right side</td>
<td>6 (30)</td>
</tr>
<tr>
<td>Prebifurcation</td>
<td>5 (25)</td>
</tr>
<tr>
<td>Bifurcation</td>
<td>4 (20)</td>
</tr>
<tr>
<td>Postbifurcation</td>
<td>11 (55)</td>
</tr>
<tr>
<td>Aneurysm size, n (%)</td>
<td></td>
</tr>
<tr>
<td>Large (10–24 mm)</td>
<td>15 (75)</td>
</tr>
<tr>
<td>Giant (&gt;25 mm)</td>
<td>5 (25)</td>
</tr>
</tbody>
</table>

The bypass procedure was followed by parent artery occlusion in 9 patients: proximal occlusion in 5 patients, distal occlusion in 1 patient (Figure 5), trapping in 2 patients, and trapping with aneurysm excision in 1 patient.

Surgical Outcomes

At the end of surgery, the bypass was patent in all patients. In 1 patient with a ruptured distal aneurysm who presented with intracerebral hemorrhage and SAH (case 20), emergency hematoma evacuation and decompressive craniotomy were performed. The aneurysm was treated by proximal occlusion and STA-MCA bypass. Angiography at 3 weeks after operation showed a bypass occlusion. Overall, the bypass was patent in 9 of the 10 cases (90%) on follow-up angiography.

Postoperatively, 19 of 20 aneurysms (95%) were completely occluded. In 1 case (case 7), the aneurysm circumferentially involved segments of the parent artery with atherosclerosis. The aneurysm was nearly completely obliterated using clip reconstruction of the vessel lumen. Although postoperative CT angiography at 3 months showed no regrowth, long-term angiographic follow-up is awaited. No rebleeding occurred in any cases during the follow-up period.

Clinical Outcomes

There was no perioperative mortality. Postoperatively, 3 patients (15%, 3/20) experienced new neurologic deficits. The first patient (case 3) had an unruptured fusiform M1 aneurysm. Although lenticulostriate artery was not involved, the aneurysm had an atherosclerotic and calcified neck, which made clip reconstruction difficult. The aneurysm was excised, and a bypass was attempted. However, consecutive MEP monitoring showed no change after trapping. Moreover, intraoperative angiography showed distal MCA flow through abundant collateral circulation. Therefore, the aneurysm was treated by only trapping and excision. Although the patient had weakness of the left arm on D2 after surgery, she recovered well without neurologic deficits (mRS score, 1). In the second patient (case 4), angiography showed complete occlusion of the M1 aneurysm and a patent bypass. However, postoperative CT scan showed an ischemic lesion on left basal ganglion due to perforating artery thrombosis. She was discharged with severe disability (mRS score 4). The third patient (case 5) with a ruptured fusiform M1 aneurysm was treated by trapping/excision and STARRG-M2 bypass. Postoperatively, the patient had neurologic worsening as a result of vasospasm and edema. The patient was discharged with moderate disability (mRS score 3).

Follow-up was available for 20 patients. The mean follow-up period was 18 months (range, 1–36 months; median, 16.5 months). Overall, good outcomes (mRS score ≤2) was observed in 90% (n = 18) of patients at the last follow-up. One patient was disabled at discharge (mRS score 4) but had improved ability at follow-up (mRS score 3). Another patient recovered functionally and was able to live independently despite having mild disability (mRS score 2). At last follow-up, the mean mRS score was 0.8 (range, 0–3).

DISCUSSION

Clinical Features

Fusiform IC aneurysms are relatively uncommon compared with saccular aneurysms. In the anterior circulation, they usually occur in the MCA. Fusiform aneurysms are rare in adults, whereas they are more likely to affect children. It has been reported that fusiform aneurysms occur in younger patients with certain systemic connective tissue disorders. Besides collagen disease, other possible causes of fusiform aneurysms include atherosclerosis, dissection, or unknown factors. Day et al. reported the most comprehensive study of fusiform MCA aneurysms in both children and adults. After excluding 5 patients with atherosclerotic lesions, the average age of the remaining 94 patients with dissecting-type fusiform aneurysms was 36 years. The average patient age of 40–7 years in our series was older than the average age in the literature. The discrepancy might have several causes. Our study mainly focused on large or giant fusiform MCA aneurysms, and thus, small aneurysms were not included. In addition, pediatric patients were limited in our hospital. The male predominance observed in our study is consistent with previous findings.

The most frequent location for fusiform MCA aneurysms reported by Day et al. is the proximal segment, including...
prebifurcation and bifurcation. Of our 20 aneurysms, 9 (45%) had aneurysms at these locations and 11 (55%) were located at postbifurcation. These findings coincide with the results of Tayebi et al.\textsuperscript{16} These investigators found that the postbifurcation segment was the most common location for fusiform MCA aneurysms.

Previous studies have shown that fusiform MCA aneurysms are uncommonly associated with SAH.\textsuperscript{5} In our series, 70% of the 20 aneurysms were unruptured. Ischemic symptom and mass effect are often related to large or giant fusiform MCA aneurysms. Day et al.\textsuperscript{5} suggested that intramural hemorrhage was often observed between the elastic and media in MCA dissection, which resulted in luminal stenosis or occlusion. In contrast, vertebral artery dissection was frequently associated with SAH as a result of intramural hemorrhage between the media and adventitia.

**Surgical Treatment**

Surgical treatment of fusiform MCA aneurysms includes clip reconstruction, clip wrapping, excision (end-to-end anastomosis or placement of an interposed graft), trapping only, and trapping with bypass. Because of lack of a definable neck, direct neck clipping is impossible for fusiform MCA aneurysms. Clip reconstruction of the parent artery is feasible in nondissecting fusiform aneurysms such as fusiform segmental ectasis, especially in cases of eccentric fusiform aneurysms.\textsuperscript{6} Application of fenestrated clips is an option that effectively reconstructs the parent artery. Straight or right-angled fenestrated clips were used in most patients (Figures 2 and 4). A Yasargil T-bar may sometimes be used to reconstruct a long segment of the aneurysm.\textsuperscript{6} However, in cases with atherosclerosis, calcification, or incorporation of perforators, complete clip reconstruction is not feasible.\textsuperscript{6} After

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**Figure 2.** Case 1. Anteroposterior view (A) and three-dimensional reconstruction (B) of preoperative angiograms showing a large fusiform aneurysm in the M1 segment of the left middle cerebral artery. C. The aneurysm was exposed via the pterional transsylvian approach. D. Tandem clipping using 1 straight fenestrated clip and 2 straight clips was applied to reconstruct the parent artery and preserve the perforating vessels. Indocyanine green angiography (PComA, posterior communicating artery; AChoA, anterior choroidal artery) E and postoperative computed tomography angiography image F showing complete obliteration of the aneurysm and reconstruction of the parent artery.
clip reconstruction, the remnant or involved segment was wrapped with Gore-tex (Gore Medical, W.L. Gore & Associates, Inc., Flagstaff, Arizona, USA) to buttress the reconstructed vessel circumferentially.\textsuperscript{6,8} A wrap-clipping technique has been shown to be feasible and effective for these unclippable fusiform aneurysms. The wrapped aneurysm mostly disappeared or remained stationary, but this modality is challenging in fusiform dissecting aneurysms. In addition, this modality cannot definitely occlude the aneurysm and thus cannot completely prevent rebleeding.

To completely exclude the aneurysm from the arterial circulation, excision of the aneurysm and end-to-end anastomosis or placement of an interposed graft with RA or saphenous vein is another possible treatment.\textsuperscript{16} As previously shown,\textsuperscript{16} technical considerations for the successful primary reanastomosis included redundancy of parent arteries, extensive mobilization of the transected ends, completed excision of pathologic arterial wall, and tension-free reanastomosis. Therefore, this technique is mostly reserved for distally located aneurysms. In prebifurcation aneurysms with lenticulostriate arteries arising from the aneurysm segment, excision and reanastomosis might be not impracticable. Moreover, they have a limited role in the treatment of dolichoectatic dissecting aneurysms or giant serpentine aneurysms.

Trapping and bypass revascularization is a well-established strategy in the surgical treatment of fusiform and dolichoectatic aneurysms. Trapping strategies include complete and partial trapping.\textsuperscript{17} Complete trapping consists of exclusion of the aneurysm as well as the total arterial territory. However, complete trapping may result in ischemic complications when perforating vessels such as the lenticulostriate arteries arise from the aneurysm dome. Thus, complete trapping is not suitable for lesions at prebifurcation or bifurcation involving the perforators. In these cases, partial trapping may be an alternative. Two types of partial trapping strategies are described: proximal and distal occlusion of the parent artery. The rationale of proximal vessel occlusion with bypass is as follows: reducing flow through the aneurysm to promote its thrombosis while the bypass revascularizes the distal arterial territory and providing retrograde blood flow for the perforators. When occlusion of the M1 segment is performed, we often prefer a high-flow bypass. However, retrograde flow from the bypass into the aneurysm segment might sometimes not be enough to keep these perforators open. Distal outflow occlusion ensures antegrade perfusion of the perforators and also reduces flow to produce aneurysm thrombosis.\textsuperscript{17-20} Moreover, in rare cases, proximal inflow occlusion may be difficult or challenging because of anatomic considerations. Distal outflow occlusion is a reasonable option for such cases. The major concern of this modality is that it may be associated with aneurysm rupture as a result of an increase of intra-aneurysmal pressure. Some investigators insist that the
rupture risk must be less than the risk of a serious stroke resulting from proximal vessel sacrifice. A mathematical model showed that after distal outflow occlusion, the intra-aneurysmal pressure increased momentarily and diminished rapidly thereafter. The pressure changes in the aneurysm are less than those induced by physiologic variations during daily activities. These changes should pose no significant increases risk of aneurysm rupture. Aneurysm wall thickness might also play an important role. Therefore, we use distal occlusion and bypass for an unruptured bifurcation lesion (case 9) with stagnation of intra-aneurysmal flow. We considered that this modality was not suitable for ruptured aneurysms, because rupture after bypass and distal occlusion of giant anterior circulation aneurysms has been reported.

The choice of the type of revascularization depends on the caliber and the location of the occluded artery. The caliber of the STA and collateral circulation were also studied on the preoperative DSA. Seo et al. recommended the STA–saphenous vein graft–MCA followed trapping in fusiform M1 aneurysms, and a low-flow STA-MCA bypass or in situ bypass followed excision in distal MCA aneurysms. Kalani et al. preferred a high-flow EC-IC bypass (RA or saphenous vein graft) when occluding the M1 segment, and a low-flow STA-MCA bypass when occluding the MCA distal to M1. Tayebi et al. suggested that the bypass strategy used for complex MCA aneurysm depends on the aneurysm location, lenticulostriate anatomy, and rupture status. These investigators recommended high-flow bypasses for occluded proximal arteries with large diameters and low-flow bypassed for distal arteries with small diameters. Our bypass strategies were consistent with theirs. For lesions at prebifurcation or bifurcation, a single high-flow bypass can be selected to revascularize multiple branches. A robust STA may have a high flow-carry capacity of up to 100 mL/minute, and the RA ranges from 40 to 70 mL/minute. Thus, we used an STA-RA-MCA instead of a conventional high-flow EC-IC bypass to treat a prebifurcation lesion (case 5).
Endovascular Treatment

Previous studies have shown that giant fusiform MCA aneurysms can be effectively treated by a team approach, using complete coil occlusion of these aneurysms after protective surgical bypass.23 The combination approach offers a treatment option for giant serpentine and dolichoectatic aneurysms, especially when surgical trapping is difficult because of anatomic or functional limitations. In earlier years, Gobin et al.24 performed complete occlusion of the aneurysm and the parent artery to treat a large fusiform MCA aneurysm. The tolerance to parent artery occlusion was assessed by amytal testing or balloon test occlusion. Considering of many false-negative results, the balloon temporary occlusion test is rarely used in our series and does not affect our strategies. Parent artery occlusion with endovascular coils alone should be a treatment of last resort.

Recently, endovascular reconstruction of fusiform MCA aneurysms has been reported. Pumar et al.25 first reported a case of a fusiform aneurysm of the M1 segment in which sole stenting was performed. Follow-up angiography at 12 months showed complete thrombosis of the fusiform dissecting aneurysm. Jeong et al.26 used stent-assisted coiling to treat a proximal MCA fusiform aneurysm. Three-month follow-up angiography confirmed complete obliteration of the fusiform aneurysm with preservation of the parent artery. However, the durability and efficacy of this reconstruction technique cannot be ascertained. Recanalization is a major issue and long-term follow-up is needed to assess its role in the management of fusiform MCA aneurysms.

Flow diverters have emerged as an alternative endovascular treatment for fusiform MCA aneurysms.14,27-29 Zanaty et al.27

Figure 5. Case 9. Oblique view (A) and three-dimensional reconstruction (B) of a right internal carotid artery angiogram showing a large fusiform of the right middle cerebral artery (MCA) at the bifurcation. (C) Sagittal high-resolution magnetic resonance imaging showing intra-aneurysmal turbulent flow. The aneurysm was treated by distal occlusion and double superficial temporal artery–MCA bypass. (D) Postoperative computed tomography angiography showing aneurysm exclusion and patency of the superficial temporal artery–MCA bypass.
reported a series of 10 cases with complex MCA aneurysms treated by flow diversion. Of the 7 patients with fusiform MCA aneurysms, 2 experienced thromboembolic complications, and only 3 achieved complete obliteration of the aneurysm. Topcuoglu et al.\textsuperscript{28} reported a high occlusion rate of 75\% in a series of 13 patients with fusiform MCA aneurysms treated by flow diversion. However, the overall procedure-related mortality and morbidity were not low. In our opinion, flow diversion is not suitable for dolichoectatic dissecting aneurysms and giant serpentine aneurysms. It may be feasible in selected fusiform MCA aneurysms of the proximal segment. A major problem is the potential for perforator stroke during aneurysm thrombosis.

**Limitations**

There are some limitations that may affect our conclusions. First, our study is limited by its retrospective design. Surgical strategies were based on relatively few patients. Management of large or giant fusiform MCA aneurysms should be determined on an individual basis. Second, fewer pediatric patients were enrolled in our study. Third, our follow-up period was relatively short. Long-term angiographic follow-up is necessary to assess the durability of clip reconstruction or wrap clipping of fusiform aneurysms.

**CONCLUSIONS**

The treatment of large or giant fusiform MCA aneurysms remains challenging. Treatment strategies should be tailored on a case-by-case basis, depending on aneurysm morphology, location, size, and clinical status. Nondissecting fusiform aneurysm may be amenable to clip reconstruction and wrap clipping. Giant fusiform dissecting aneurysms cannot usually be clipped and require alternative treatment modalities, including aneurysm trapping, aneurysm excision followed by reanastomosis, and proximal or distal occlusion with bypass revascularization. These techniques can be performed with low morbidity and mortality.
Figure 7. Case 13. Anteroposterior view (A), oblique view (B), and three-dimensional reconstruction (C) of preoperative angiograms showing a large fusiform aneurysm of the left M2 segment. The aneurysm was treated by double superficial temporal artery–middle cerebral artery bypass (D, E), followed by proximal occlusion (F). (G) Postoperative angiogram, anteroposterior view, showing obliteration of the aneurysm. Anteroposterior view (H) and lateral view (I) of left external cerebral artery angiograms showing patent bypasses.
REFERENCES


