Techniques and outcomes of microsurgical management of ruptured and unruptured fusiform cerebral aneurysms

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OBJECTIVE Fusiform cerebral aneurysms represent a small portion of intracranial aneurysms; differ in natural history, anatomy, and pathology; and can be difficult to treat compared with saccular aneurysms. The purpose of this study was to examine the techniques of treatment of ruptured and unruptured fusiform intracranial aneurysms and patient outcomes.

METHODS In 45 patients with fusiform aneurysms, the authors retrospectively reviewed the presentation, location, and shape of the aneurysm; the microsurgical technique; the outcome at discharge and last follow-up; and the change in the aneurysm at last angiographic follow-up.

RESULTS Overall, 48 fusiform aneurysms were treated in 45 patients (18 male, 27 female) with a mean age of 49 years (median 51 years; range 6 months–76 years). Twelve patients (27%) had ruptured aneurysms and 33 (73%) had unruptured aneurysms. The mean aneurysm size was 8.9 mm (range 6–28 mm). The aneurysms were treated by clip reconstruction (n = 22 [46%]), clip-wrapping (n = 18 [38%]), and vascular bypass (n = 8 [17%]). The mean (SD) hospital stay was 19.0 ± 7.4 days for the 12 patients with subarachnoid hemorrhage and 7.0 ± 5.6 days for the 33 patients with unruptured aneurysms. The mean follow-up was 38.7 ± 29.5 months (median 36 months; range 6–96 months). The mean Glasgow Outcome Scale score for the 12 patients with subarachnoid hemorrhage was 3.9; for the 33 patients with unruptured aneurysms, it was 4.8. No rehemorrhages occurred during follow-up. The overall annual risk of recurrence was 2% and that of rehemorrhage was 0%.

CONCLUSIONS Fusiform and dolichoectatic aneurysms involving the entire vessel wall must be investigated individually. Although some of these aneurysms may be amenable to primary clipping and clip reconstruction, these complex lesions often require alternative microsurgical and endovascular treatment. These techniques can be performed with acceptable morbidity and mortality rates and with low rates of early rebleeding and recurrence.

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KEY WORDS cerebral aneurysm; Gore-Tex clipping technique; microsurgery; microsurgical clipping; ruptured aneurysm; subarachnoid hemorrhage; unruptured aneurysm; vascular disorders

Fusiform cerebral aneurysms represent a small portion of intracranial aneurysms and differ from saccular aneurysms in natural history, anatomy, pathology, and treatment.1,3,8,17 The spectrum of fusiform aneurysms ranges from small fusiform aneurysmal dilations to giant dolichoectatic aneurysms.1,3 On the basis of their clinical presentation and course, fusiform lesions can be divided into 2 subcategories: acute and chronic.17 Patients with the acute dissecting type often present with emergent subarachnoid hemorrhage.8,20 Those with the chronic type have a slow course with continual growth, eventually leading to rupture and hemorrhage.17 Fusiform aneurysms are difficult to treat, because they lack a definable neck and involve the parent vessel, which is often circumferentially affected. Their management often requires unusual and technically difficult procedures. This report describes a contemporary series of ruptured and unruptured fusiform aneurysms.
Methods

We searched a database of all aneurysms treated at our institution between 2004 and 2014 to identify cerebral fusiform aneurysms of any arterial distribution. This retrospective review was approved by the institutional review board of St. Joseph’s Hospital and Medical Center, Phoenix, Arizona. Because of the retrospective nature of the review, the study was deemed exempt from informed consent requirements.

We reviewed patient age, aneurysm size and location, surgical approach and intervention, permanent shunt placement, rebleeding or recurrence, hospital stay, and clinical follow-up. For patients admitted with aneurysmal subarachnoid hemorrhage, we also reviewed presenting symptoms, Fisher grade, and presence of vasospasm and neurological decline. We divided surgical interventions into 3 main categories: clip reconstruction, clip-wrapping, and vascular bypass. The patients’ clinical examinations and imaging studies, operative and angiographic reports, and inpatient/outpatient charts were reviewed. Clinical outcome was determined by latest chart review, clinical follow-up, or telephone interview. For radiographic review, the study was deemed exempt from informed consent requirements.

We retrospectively reviewed 45 patients (18 male [40%]; 27 female [60%]), with a mean age of 49 years (median 51 years, range 6 months to 76 years). Table 1 summarizes the characteristics of the patients and aneurysms. Twelve patients (27%) had ruptured fusiform aneurysms and 33 patients (73%) had unruptured fusiform aneurysms. The mean aneurysm size was 8.9 mm (range 6–28 mm). Arterial distributions were as follows: 23 (48%) middle cerebral artery (MCA), 10 (21%) anterior cerebral artery (ACA), 8 (17%) posterior inferior cerebellar artery (PICA), 4 (8%) internal carotid artery, and 1 (2%) each in the basilar artery, posterior cerebral artery, and superior cerebellar artery. The mean (SD) hospital stay for patients with subarachnoid hemorrhage was 19.0 ± 7.4 days (median 19 days); for those with unruptured aneurysms, it was 7.0 ± 5.6 days (median 5 days).

Results

Patient Characteristics

Overall, 48 fusiform aneurysms were treated in 45 patients. Twelve patients (27%) had ruptured fusiform aneurysms and 33 patients (73%) had unruptured fusiform aneurysms. The mean aneurysm size was 8.9 mm (range 6–28 mm). Arterial distributions were as follows: 23 (48%) middle cerebral artery (MCA), 10 (21%) anterior cerebral artery (ACA), 8 (17%) posterior inferior cerebellar artery (PICA), 4 (8%) internal carotid artery, and 1 (2%) each in the basilar artery, posterior cerebral artery, and superior cerebellar artery. The mean (SD) hospital stay for patients with subarachnoid hemorrhage was 19.0 ± 7.4 days (median 19 days); for those with unruptured aneurysms, it was 7.0 ± 5.6 days (median 5 days).

Procedures

The most common surgical approaches for aneurysm treatment were pterional (16/48 [33%]) and orbitozygomatic (11/48 [23%]). Other approaches included interhemispheric (n = 5) and far-lateral, frontotemporal, suboccipital, and retrosigmoid (3 each); 4 aneurysms were treated by other approaches.

Of all 48 aneurysms treated, 22 (46%) were managed with clip reconstruction of the vessel lumen (Figs. 1 and 2 and Videos 1 and 2).

VIDEO 1. Clip reconstruction of fusiform aneurysmal dilation of an M1 aneurysm (same case as in Fig. 1). The video demonstrates dissection of the M1, M2, and M3 segments of the MCA and careful circumferential dissection of the aneurysm. After all involved vessels are recognized and dissected free from the dome of the aneurysm, the atherosclerotic calcified portion of the aneurysm is occluded with a straight 6-mm aneurysm clip. The residual aneurysm involving M1 and M3 branches is reconstructed with a curved clip. Clip application must be performed carefully, weighing aneurysm obliteration with creation of a vascular channel of sufficient size to preserve distal blood flow. Copyright Barrow Neurological Institute. Published with permission. Click here to view.

VIDEO 2. Clip reconstruction and creation of a vascular conduit (same case as in Fig. 2). The video demonstrates subarachnoid dissection in a patient with subarachnoid hemorrhage and a fusiform MCA aneurysm involving M1 branches. After the aneurysm neck is clipped, a vascular conduit is created with the aneurysm clip to ensure patency and sufficient flow from M1 into distal territories. It is beneficial to create the conduit generously (i.e., with some aneurysm residue that can be augmented with cotton) to establish adequate blood flow. Copyright Barrow Neurological Institute. Published with permission. Click here to view.

When distal branches were engulfed within the aneurysm (Fig. 1 and Video 1) or extended from the aneurysm dome, the vascular anatomy was restructured while a vascular channel was maintained. The fusiform aneurysmal dilation often had to be clip-reconstructed while creating a conduit (Fig. 2 and Video 2) to maintain adequate distal blood flow.

Of the 48 aneurysms, 18 (38%) had circumferentially involved segments of the parent vessel that required use of the clip-wrapping technique (Fig. 3 and Video 3).

VIDEO 3. Clip reconstruction and Gore-Tex wrapping of a fusiform MCA aneurysm. Copyright Barrow Neurological Institute. Published with permission. Click here to view.

Typically, in these cases a thin sheet of Gore-Tex (expand-
ed polytetrafluoroethylene, Gore Medical, W. L. Gore & Associates, Inc.) was cut in a tapered fashion. The proximal aspect of the sheet was cut in longitudinal strips to accommodate branch vessels and perforators. Microforceps were used to wrap the aneurysmal segment. The cut portion of the sheet was manipulated to enlarge the amount of wrapped arterial segment. An aneurysm clip was then applied to the Gore-Tex, and the wrap was fit snugly around the artery. Care was taken to avoid injury to perforating and branch vessels emanating from this arterial segment. This technique was used primarily for anterior circulation aneurysms.

Eight aneurysms (17%) in 8 patients were managed with trapping and bypass procedures. Of these 8 patients, 4 underwent superficial temporal artery–to-MCA bypass and aneurysm trapping. Two other patients, who had fusiform distal A2-segment aneurysms, had the distal A3 segments of the ACA anastomosed in a side-to-side fashion to provide bilateral distal flow after trapping of a more proximal aneurysm (Fig. 4). A similar approach was used for the seventh patient, who had a fusiform PICA aneurysm; in this patient, the tonsillar loops of the PICA were anastomosed to provide bilateral flow after occlusion of 1 proximal vessel. This consideration is important in PICA aneurysms proximal to the choroidal point, in which ligation would interrupt flow to important brainstem and cerebellar branch vessels. The eighth patient, who had a fusiform right PICA aneurysm, underwent aneurysm excision and end-to-end anastomosis of the proximal and distal PICA stumps (Fig. 5).

Outcomes

The mean duration of follow-up was 38.7 ± 29.5 months (median 36 months; range 6–96 months). The mean Glasgow Outcome Scale score at discharge was 3.9 for the 12 patients with ruptured aneurysms and 4.8 for the 33 patients with unruptured aneurysms. Vasospasm was observed in 5 of the 12 patients with ruptured aneurysms, with development of lacunar strokes in 3 patients who were asymptomatic. Two of the 12 patients with ruptured aneurysms required shunt placement. Operative morbidity included 3 patients who had permanent cranial nerve deficits postoperatively. One death, as outlined below, occurred in a patient with a giant recurrent dissecting MCA aneurysm. No strokes or parent vessel stenoses occurred in the 22 patients who underwent clip reconstruction or in the 18 patients who underwent clip-wrapping, but 1 patient who underwent vascular anastomosis suffered a postoperative stroke. There were a total of 151 patient follow-up years. No rehemorrhages occurred during the follow-up period, but 3 patients had aneurysm regrowth detected angiographically on follow-up. All recurrent aneurysms were unruptured upon presentation. Thus, for all aneurysms in this case series, we found an overall risk of recurrence of 2% annually and an overall risk of rehemorrhage of 0% annually. In the following section, we further detail these recurrences.

Recurrences and Complications

Three patients had recurrent aneurysms. The first patient, a 41-year-old woman, presented with an unruptured complex left fusiform MCA aneurysm that was found during a work-up for headaches. The patient was treated with clip reconstruction and Gore-Tex wrapping without complication. On clinical and angiographic follow-up over the next 4 years, the patient remained without symptoms or recurrence. However, she then experienced a single episode of sudden severe headache that prompted further imaging investigation. The patient was found to have an aneurysm recurrence medial to the original clip site. Five years after her initial surgery, the aneurysm was reexplored and managed successfully with primary clipping and cotton reinforcement. She has remained without neurological deficits for 7 years after the initial presentation and for 2 years after the recurrence.

The second patient was a 48-year-old morbidly obese man who initially presented with an unruptured complex

FIG. 1. A and B: Preoperative 3D reconstruction of MR angiography (MRA) image in the anteroposterior view (A) and axial MRA image (B) showing a fusiform aneurysm of the left M2 superior division. C and D: Postoperative anteroposterior (C) and lateral (D) catheter angiography images showing complete obliteration of the aneurysm and reconstruction of flow within the M1 and distal branches (see also Video 1). E: Illustration showing clip reconstruction of the vessel lumen and creation of a channel between the proximal and distal territories. Panel E is used with permission from Barrow Neurological Institute, Phoenix, Arizona.
fusiform right MCA aneurysm, which was treated with primary clipping. Seven years after the initial clipping, the patient had sudden onset of headaches and blurry vision. On angiographic evaluation, a recurrent giant dissecting MCA aneurysm was found posterior to the previously clipped segment. The patient underwent internal maxillary artery–to-MCA bypass with a radial artery bypass graft and aneurysm trapping. Postoperatively, the patient developed left-sided hemiparesis and was found on MRI to have a right temporal lobe infarction. On the 5th postoperative day, the patient died of respiratory failure and cardiopulmonary arrest.

The third patient, a 57-year-old woman, underwent a left pterional craniotomy for an unruptured M3 aneurysm. Clip reconstruction of the aneurysm was performed, and the involved segment was wrapped with Gore-Tex. Postoperative angiography showed complete aneurysm obliteration. At 7-year follow-up, the patient was asymptomatic but was found to have angiographic aneurysm regrowth posterior to the initial clip site. This was managed with clip reconstruction and cotton reinforcement, with the diseased segment once again wrapped with Gore-Tex. Two years after her second surgery and 9 years after her initial surgery, she was without neurological symptoms and had no rebleeding or aneurysm recurrence.

Discussion
Microsurgical Management of Fusiform Aneurysms

Universal histological features found in fusiform aneurysms include fragmentation of the internal elastic lamina and intimal hyperplasia. These initial pathological changes affecting the parent vessel wall may lead to rapid aneurysmal growth and subsequent hemorrhage. These aneurysms are particularly difficult to manage because they lack a definable neck that can be clipped or hold

FIG. 2. A–C: Axial (A), coronal (B), and sagittal (C) CTA images obtained in a patient with a ruptured fusiform MCA aneurysm. The patient presented with altered mental status, and CTA revealed a subarachnoid hemorrhage with a temporal hematoma. The patient underwent clip reconstruction. D and E: Postoperative axial (D) and sagittal (E) CTA images showing complete obliteration of the aneurysm (see also Video 2). F: Illustration showing clip reconstruction and cotton augmentation of a complex fusiform aneurysm involving several proximal and distal branches. Partial clipping of the aneurysm and creation of a vascular conduit are shown. The walls of the aneurysm (i.e., vascular conduit) are reinforced with cotton. Panel F is used with permission from Barrow Neurological Institute, Phoenix, Arizona.
Fusiform basilar and vertebrobasilar artery aneurysms represent a particular treatment challenge; and an extensive discussion of treatment timing and paradigms have been provided elsewhere. Our series contained a single patient with a fusiform basilar artery aneurysm. Our treatment paradigm for fusiform vertebrobasilar artery aneurysms has evolved, and our current treatment includes basilar artery occlusion with revascularization of the basilar apex. The grave natural history of these challenging lesions, for which there are few treatment options, has resulted in the use of less than ideal techniques for their treatment.

**Endovascular and Multidisciplinary Management**

A multidisciplinary approach with combined microsurgical and endovascular techniques may be necessary for some of these complex aneurysms, specifically with giant aneurysms and long-segment dolichoectatic involvement of the parent vessel. In some giant thrombosed aneurysms, the base of the aneurysm and pertinent parent vessel and perforator anatomy cannot be visualized appropriately microsurgically because of mass effect and surgical angle. In such cases, endovascular coil embolization and aneurysm trapping or parent vessel occlusion can be performed prior to craniotomy and aneurysmorrhaphy for decompression of the brain or visual system. An aneurysmorrhaphy can be performed with ultrasonic aspiration after the aneurysm base has been endovascularly secured and the flow dynamics have been assessed angiographically. In instances where aneurysm trapping may compromise the origin of perforators, proximal or distal coil embolization or clipping and sacrifice of the parent vessel may be used to create flow reversal in the aneurysm by retrograde flow from the bypass anastomosis or existing collaterals. Such flow reversal, combined with coiled embolization of the parent artery proximally, often results in aneurysm thrombosis. Parent vessel occlusion can be completed after evaluating the tolerance to occlusion using endovascular-approach preembolization testing by an amobarbital test or balloon test occlusion in an awake patient. One concern after endovascular parent artery occlusion is retrograde thrombosis propagation from the aneurysm to proximal territories and perforators, which may...
result in occlusion of small perforating vessels or even a larger branch vessel.\textsuperscript{2,5,8} In the future, hemodynamic studies and computer flow simulations might help to accurately predict the evolution of aneurysm thrombosis.

The endovascular treatment of fusiform aneurysms with coil embolization can be challenging, entailing a risk of coil compaction and aneurysm recanalization, secondary coil displacement, or delayed uncontrolled progression of the thrombosis.\textsuperscript{8} However, it has been reported that endovascular coil bracing may be useful as temporary wall reinforcement during symptomatic vasospasm while awaiting surgery.\textsuperscript{8}

Recently, the Pipeline Embolization Device (PED) has also been used as an alternative endovascular remodeling strategy for complex, fusiform, and dissecting aneurysms.\textsuperscript{6,14,16,18} The treatment of fusiform aneurysms at our institution is almost exclusively the domain of microsurgery. We remain conservative with the use of flow diverters for fusiform aneurysms and consider microsurgical treatment as a primary option. The PED may be used in Figure 4.

**FIG. 4.** A and B: Preoperative lateral digital subtraction angiography (A) and 3D rotational angiography lateral projection (B) images showing a dissecting left A\textsubscript{2} aneurysm. C and D: Preoperative coronal (C) and sagittal (D) CTA images showing diffuse calcification (arrows). The patient underwent proximal occlusion of the A\textsubscript{3} segment and aneurysm trapping and A\textsubscript{3}, A\textsubscript{3} bypass. E–H: Postoperative angiographic images showing the patent bypass (E and F) and complete aneurysm obliteration (G and H). Partial opacification of a portion of the anterior aspect of the left callosomarginal artery is seen on both the anteroposterior right (E) and left (F) internal carotid artery injections through the patent A\textsubscript{3}, A\textsubscript{3} anastomosis. There is termination of the contrast column, approximately along the midportion of the callosomarginal artery, and nonopacification of the A\textsubscript{2} segment of the left ACA and junction of the A\textsubscript{3} and left callosomarginal artery as depicted on the lateral projection angiograms (G and H). I: Illustration showing the technique of distal in situ bypass and proximal trapping of the aneurysm and parent vessel. Panel I is used with permission from Barrow Neurological Institute, Phoenix, Arizona.
the small subset of cases that are not amenable to microsurgical treatment. Perforator occlusion and infarcts due to neointimal overgrowth and progressive narrowing of the perforator’s orifice that induces insufficient perfusion is a concern with use of the PED for fusiform aneurysms.\textsuperscript{14,18} In a series by Siddiqui et al.,\textsuperscript{18} 7 patients underwent flow diversion for large vertebrobasilar fusiform aneurysms; 4 patients died, and the other 3 had severe disability. Furthermore, use of the PED in patients with ruptured fusiform aneurysms and subarachnoid hemorrhage may also be complicated, given that these patients require dual therapy with aspirin and clopidogrel. In a recent review of 24 cases of unruptured fusiform aneurysms that were treated with PED, Monteith et al.\textsuperscript{16} encountered only 1 aneurysm (4.5%) that had increased in size over a median follow-up period of 6 months. Aneurysm obliteration and remodeling of the parent vessel to close to a normal anatomical configuration occurred in 59.1% of cases in their series. Similar to our findings, most of the fusiform aneurysms treated with the PED by these authors were in the anterior circulation (70%). They reported a major complication rate of 16.7% related to aneurysm treatment and 1 death (4.2%). Long-term follow-up data are needed to better evaluate the usefulness of this technology for management of fusiform and dolichoectatic aneurysms.\textsuperscript{14,18}

The specific management of complex fusiform aneurysms is often tailored for each patient on the basis of the aneurysm’s location, size, configuration, and flow characteristics.\textsuperscript{1,16,18} The heterogeneity in presentation and management of these aneurysms makes estimation of rebleeding and recurrence rates difficult.\textsuperscript{1,3–5,11} In the current study, with 3 late recurrences, all several years after the initial surgery, we found an overall risk of recurrence of 2% annually. This underlines the importance of rigorous, long-term radiographic follow-up studies in the treatment of patients with intracranial aneurysms. Clipped aneurysms are known to sometimes rebleed or recur decades after the initial treatment.\textsuperscript{19,21} Our median follow-up period of 3 years, the relatively small sample size of this cohort, and the retrospective nature of this review limit our conclusions. Furthermore, it is difficult to draw general conclusions given the heterogeneity of the presentation of patients with these complex lesions. Despite these limitations, our experience constitutes the largest contemporary series on these formidable lesions.

**Conclusions**

The treatment of fusiform intracranial aneurysms remains challenging. The ideal treatment of fusiform and
dolichoectatic aneurysms involving the entire vessel wall must be investigated on a case-by-case basis. Treatment is based on anatomical properties, such as aneurysm size, type, and location, as well as on dynamic flow properties, such as availability of collateral flow or the response to balloon test occlusion. Although some of these aneurysms may be amenable to primary clipping and clip reconstruction, alternative microsurgical and endovascular treatment modalities are often required for the management of these complex lesions. Microsurgical alternatives include clipping, microvascular bypass and aneurysm trapping, proximal or distal parent vessel occlusion, or aneurysmorrhaphy and aneurysm excision followed by end-to-end anastomosis if complete clipping is not possible. These techniques can be performed with acceptable morbidity and mortality rates and low rates of early rebleeding and recurrence. Long-term angiographic follow-up is recommended.

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References


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Conception and design: Safavi-Abbasi, Kalani, Spetzler. Drafting of the article: all authors. Reviewed submitted version of manuscript: all authors. Study supervision: Spetzler.

Supplemental Information


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