Microsurgical Treatment of Pediatric Intracranial Aneurysms: Long-term Angiographic and Clinical Outcomes

BACKGROUND: Pediatric aneurysms are rare and complex to treat. Long-term angiographic and clinical data after microsurgical or endovascular therapies are lacking.

OBJECTIVE: To study the clinical and radiographic outcomes in aneurysms in pediatric patients treated with microsurgery.

METHODS: Between 1989 and 2005, 48 patients ≤ 18 years of age (28 boys, 20 girls; mean age, 12.3 years) were treated for intracranial aneurysms. Patient charts were reviewed retrospectively for age, presentation, type and location of aneurysm(s), surgical approach, complications, and clinical and angiographic outcomes. Rates of aneurysm recurrence and de novo formation were calculated.

RESULTS: Seventy-two aneurysms were treated. Presentations included incidental aneurysm (35%), aneurysmal subarachnoid hemorrhage (17%), stroke (13%), and traumatic subarachnoid hemorrhage (10%). Location was anterior circulation in 76% and posterior circulation in 24%. Twenty-eight (39%) were fusiform/dissecting, and 16 (23%) were giant. Most aneurysms were clipped directly. A vascular bypass with parent-vessel occlusion was used to treat 13 aneurysms (18%). Hypothermic circulatory arrest was used to treat 10 aneurysms (14%), all involving the basilar artery. The perioperative morbidity rate was 25%. There were no deaths. The long-term morbidity rate was 14%, and the mortality rate was 3%. Clinical outcome was favorable in 92% and 94% at discharge and follow-up, respectively (mean, 59 months; median, 32 months). At angiographic follow-up (mean, 53 months; median, 32 months), the annual recurrence rate was 2.6%, and the annual rate of de novo formation or growth was 7.8%.

CONCLUSION: Pediatric aneurysms require complex microsurgical techniques to achieve favorable outcomes. They leave higher rates of recurrence and de novo formation or growth than their adult counterparts, which mandates lifelong follow-up.

ABBREVIATIONS: ICA, internal carotid artery; MCA, middle cerebral artery; SAH, subarachnoid hemorrhage
and angiographic follow-up for pediatric intracranial aneurysms is lacking.

We therefore reviewed the long-term angiographic and clinical outcomes of intracranial aneurysms in 48 pediatric patients treated primarily with microsurgical techniques. Combined with 16 patients previously reported from this institution,9 this series represents the largest experience with these rare complex lesions from a single institution.

MATERIALS AND METHODS

Patient Population

All patients were treated by the neurovascular team (R.F.S. and J.M.Z.) at the Barrow Neurological Institute, St Joseph’s Hospital, Phoenix, Arizona. We searched a prospectively maintained surgical database from 1989 to 2005 for pediatric patients ≤18 years of age who underwent a craniotomy for the treatment of an intracranial aneurysm. Forty-eight patients (28 boys, 20 girls; male-to-female ratio, 4:1; mean age, 12.3 years) underwent 53 surgical procedures during separate hospitalizations for the treatment of 72 intracranial aneurysms. Sixteen patients harboring 20 aneurysms treated before 1989 were reported previously9 and were not included in this series. None of the patients in the current series had undergone endovascular treatment for their treated aneurysm. One patient had undergone prior microsurgical treatment for the same aneurysm.

The patients’ hospital and office records were reviewed retrospectively for age at admission, presenting symptoms, type and location of aneurysm(s), surgical approach, complications, clinical outcomes at discharge and follow-up, and angiographic outcomes at discharge and follow-up. Neuroradiology reports were reviewed to record angiographic follow-up results when available. Clinical follow-up (mean, 59.4 months; median, 31.5 months; range, 1-216 months) was available in 53 patients (75%). Angiographic follow-up (mean, 53.2 months; median, 31.5 months; range, 1-216 months) was available in 26 patients (54%). Despite attempts at contact, 12 patients (25%) were lost to follow-up.

Aneurysms were classified as fusiform/dissecting, infectious/mycotic, traumatic/iatrogenic, or saccular.10 Aneurysms > 2.5 cm were categorized as giant. The perioperative period was defined as time spent in the hospital and up to 1 month after hospital discharge.

Calculation of Annual Rates of Aneurysm Recurrence and De Novo Formation

Aneurysm recurrence was defined as growth of an aneurysm that had been treated previously. De novo aneurysm formation was defined as the formation of a new aneurysm or growth of an existing aneurysm at a site remote to the treated aneurysm. The annual percentage rates were determined by dividing the number of clinical events (recurrence or de novo formation) by the number of patient-years of observation for the population.11

RESULTS

A summary of each pediatric patient treated with microsurgical technique is presented in Table 1.

Demographics and Presentation

In 17 patients (35%), the aneurysm was discovered incidentally (Table 2). Neurological deficits were present in 22 patients (46%). Sixteen patients (35%) presented with hemorrhage. Subarachnoid hemorrhage (SAH) was related to the aneurysm in 8 patients (17%) and was traumatic in 5 patients (10%). Six patients (13%) presented with stroke. Two patients (4%) developed iatrogenic pseudoaneurysms from intracranial surgery. Aneurysms were thought to be flow related in 3 patients with a coexisting arteriovenous malformation.

Aneurysm Characteristics

Fifteen patients (31%) harbored multiple aneurysms. Aneurysms most frequently involved the anterior circulation (55, 76%) with the following distribution (Table 3): internal carotid artery (ICA), 28%; middle cerebral artery (MCA), 18%, anterior choroidal artery, 10%; and anterior cerebral artery, 10%. The basilar artery (13%) was the most frequent site involved in the posterior circulation, which overall harbored 17 aneurysms (24%). Of the 72 aneurysms, 32 (45%) were saccular and 28 (39%) were fusiform/dissecting (Table 4). Sixteen aneurysms (22%), including 1 recurrent lesion, were giant. Seven aneurysms (10%) were traumatic: 5 related to blunt head trauma and 2 to iatrogenic causes after intracranial surgery. Of the 5 mycotic aneurysms (7%), 1 recurred as a giant fusiform/dissecting type.

Surgical Technique

All patients underwent standard craniotomy procedures based on the location of their aneurysm(s) (Table 1). Primary clipping was used to treat 48 aneurysms (67%). Thirteen aneurysms (18%) were treated with bypass techniques, one of which was performed as a bailout technique for an avulsed aneurysm during clipping. Five aneurysms (7%) were clip wrapped, and 3 (4%) were wrapped. Two aneurysms (3%) were excised, and 1 thrombectomy (1%) was performed. Hypothermic cardiac standstill was performed in 10 procedures (19%), and all of these aneurysms involved the basilar artery.

Morbidity and Mortality

There were no deaths in the perioperative period. Perioperative complications were noted in patients after 12 procedures (23%; Table 5). One patient each required a craniotomy for an epidural hematoma and a cerebellar hematoma. After an intracranial bypass procedure, 2 patients were returned to the operating room to reopen an occluded graft. The graft remained occluded in one of these patients. The aneurysm ruptured intraoperatively in 2 patients, both of whom were treated successfully. Two patients developed hydrocephalus: 1 from endovascular treatment of a coexisting vein of Galen malformation and 1 from postoperative ventriculitis.

At the last follow-up, 1 patient (1%) died of presumed rehemorrhage of his treated aneurysm. Two patients underwent placement of a ventriculoperitoneal shunt, and 3 had permanent neurological deficits. The long-term morbidity and mortality rate was 17%.

Clinical Follow-up

In our series, 48 patients underwent 53 procedures at separate admissions, and all patients were discharged from the hospital.
Based on the Glasgow Outcome Scale, 49 discharges (92%) had a good outcome, and 4 (8%) had a poor outcome (Table 6). Thirty-six patients (75%) had clinical follow-up > 1 month after their original surgery (mean, 59.4 months; median, 41 months; range, 1-226 months). At last follow up, 34 patients (94%) had a Glasgow Outcome Scale score of 4 or 5. One patient with a residual aneurysm on postoperative angiography died 13 months after surgery of cerebral hemorrhage as reported by his family. Three patients have neurological deficits (1 has increased spasticity after resection of an arteriovenous malformation, 1 has trouble with fine motor skills, and 1 has mild hemiparesis). One patient is confined to a long-term care facility.

Angiographic Follow-up

Altogether, 49 postoperative catheter angiograms were performed after 53 microsurgical procedures for the treatment of 67 aneurysms. Eight patients had a residual aneurysm, which included 2 wrapped aneurysms and 2 with perforators arising from the residual. As noted, 1 patient died. One patient with a residual aneurysm was lost to follow-up. One patient underwent coiling of the residual aneurysm. The remaining 5 patients have been stable. Angiography indicates that microsurgical treatment was successful in 63 of 67 aneurysms (94%).

Long-term angiographic follow-up was available for 26 patients (54%) with 35 aneurysms treated with microsurgical techniques. During the 115.3 years of follow-up, 3 of the 67 patients had 3 recurrences (8.6%) as early as 5 months and as late as 10 years. Therefore, the annual risk of recurrence was 2.6%. None of the patients with a recurrence had a residual aneurysm on postoperative angiography. One patient with a recurrence was treated surgically, and angiography at 36 months confirmed complete occlusion of the aneurysm. Two patients underwent endovascular intervention (twice each for the same aneurysm). If one were to presume that the death at 13 months was attributed to recurrence of the patient’s residual aneurysm, then the annual risk of recurrence would be 3.5% and the annual risk of hemorrhage would be 0.6%.

Three patients had de novo aneurysms (6 new and 3 that grew, 9 of 35 or 7.8%) over the cumulative follow-up period of 115.3 years (range, 5-216 months). Two patients whose aneurysm grew had a history of multiple aneurysms. Therefore, the annual risk of de novo aneurysm formation or growth was 2.6%. All patients underwent treatment of their new aneurysms.

CASE EXAMPLES

Case 1

After a motor vehicle accident, a 13-year-old boy (patient 2) who sustained severe blunt head trauma and atlantoaxial dislocation had a Glasgow Coma Scale score of 4. Computed tomography (CT) of the head revealed contusions, hydrocephalus, and Fisher grade 3 SAH in the preoptic and basal cisterns. He underwent craniovertebral stabilization with Steimann pin fixation. Cerebral angiography showed a traumatic dissecting aneurysm of the basilar apex (Figure 1A and B). The aneurysm was clipped under hypothermic cardiac arrest. Postoperative angiography showed slight small residual filling of the aneurysm (Figure 1C). Given the patient’s poor medical condition, the residual was coiled by the endovascular team. No residual was visible on final angiography (Figure 1D). After a protracted hospital course, the patient was discharged to a long-term care facility with a Glasgow Coma Scale of 7. At last follow-up, he was dependent for his activities of daily living at the care facility.

Case 2

A 17-year-old female (patient 3) who was 22 weeks pregnant presented with the worst headache of her life. CT showed SAH and angiography revealed an 8-mm saccular aneurysm involving the left posterior communicating artery (Figure 2A and 2B). She underwent a left petro- craniotomy, and her aneurysm was clipped. She was discharged with no neurological deficits. Follow-up angiograms obtained 5 and 10 years later showed no residual or new aneurysms. At 15 years, however, new aneurysms involving the right ICA and right posterior communicating artery were detected on angiography. At her 18-year follow-up, these 2 aneurysms had enlarged and a new aneurysm was present on the left cavernous ICA segment (Figure 2C through 2E). Surgical treatment was recommended.

Case 3

As reported previously,12 a 7-month-old boy (patient 32) who had been evaluated for viral meningitis and discharged 2 weeks earlier presented with increased irritability, lethargy, and hemiparesis. CT showed a large hematoma in the left sylvian fissure (Figure 3A). An angiogram of left ICA showed 2 aneurysms, 1 at the bifurcation of the MCA and 1 on the distal MCA (Figure 3B). At surgery, both lesions were identified as giant thrombosed mycotic aneurysms (2.5 and 3.5 cm, respectively) with cultures positive for Streptococcus salivarius. The proximal aneurysm was clipped and the distal aneurysm was trapped. Angiography done in the immediate postoperative period and 3 weeks later showed complete obliteration of aneurysms. He was treated with antibiotics, and his hemiparesis had improved dramatically by discharge.

Eleven years later, the patient developed nausea and vomiting. Imaging studies showed a recurrent giant aneurysm of the left MCA (Figure 3C and 3D). He underwent a left petrocraniotomy with a common carotid artery—MCA bypass with a radial artery graft and clip occlusion of the parent vessel (Figure 3E and 3F). Postoperatively, he had no deficits and was discharged from the hospital. A CT angiogram at 36 months showed complete occlusion of the aneurysm. The patient continued to do well at his 6-year follow-up visit.

DISCUSSION

Much is known about the pathophysiology and treatment outcomes for intracranial aneurysms in adults. However, the same is not true for the pediatric population because of the rarity of these lesions in children. During the period of 1989 to 2005, pediatric aneurysms represented 1% of aneurysms treated at our institution. Given their rarity, most of the published series are small, which makes it difficult to make rational conclusions and treatment recommendations for this subset of population. Given the life expectancy of children, curing these lesions should be the ultimate goal. Therefore, the ideal modality of treatment in this population is one associated with low rate of operative morbidity and
| Patient | Age/Sex | GCS | Presentation | Deficits | Location | Type | Approach |
|---------|---------|-----|--------------|----------|----------|------|----------|
| 1       | 10 y/F  | 15  | Stroke/ophthalmoplegia | CN III/hemiparesis | L ICA (cav and clinoidal) | Saccular | L OZ     |
| 2       | 13 y/M  | 4   | TSAH | Decerebrate posture | BA | Traumatic dissecting BA | R OZ |
| 3       | 16 y/M  | 15  | SAH  | None | L A1 | Mycotic (endocarditis) | L OZ |
| 4       | 13 y/M  | 15  | SAH  | None | Mid BA | Fusiform/dissecting | L transcochlear subtemporal far lateral |
| 5       | 18 y/M  | 15  | Incidental/football concussion | None | L ICA | Fusiform/dissecting | L OZ |
| 6       | 14 y/M  | 15  | Seizure/AVM | None | R A1/anterior temporal/AChA | Saccular | R mini OZ |
| 7       | 12 y/F  | 15  | Incidental/HA | None | BA | Fusiform/dissecting | R far lateral |
| 8       | 13 y/F  | 15  | CN VII HP | R ICA | Fusiform/dissecting | R OZ |
| 9       | 17 y/F  | 15  | SAH/pregnancy | None | L PCoA | Saccular | L pterional |
| 10      | 16 y/F  | 15  | Incidental | None | R AICA | Saccular | R RS |
| 11      | 15 y/M  | 15  | Incidental/concussion | None | L MCA | Giant dissecting/fusiform | L OZ |
| 12      | 14 y/F  | 15  | Seizure | None | L MCA | Giant dissecting/fusiform | L OZ |
| 13      | 5 y/F   | 15  | TSAH | Localize UES | BA Apex | Traumatic pseudoaneurysm | L OZ |
| 14      | 14 y/F  | 13  | ICH HP | L MCA | Fusiform/dissecting | L temporal |
| 15      | 9 y/M   | 15  | Incidental previous AVM resection | None | R ICA | Fusiform/dissecting | L OZ |
| 16      | 13 y/M  | 7   | ICH CN III/hemiplegia | R AChA | Giant saccular | R pterional |
| 17      | 13 y/F  | 15  | Tremor | None | L ICA (A1 + M1)/L AChA | Fusiform/dissecting | L OZ |
| 18      | 9 y/M   | 15  | Basal ganglia Stroke drift | L clinoid ICA/L PCoA | Fusiform/dissecting | L OZ |
| 19      | 13 y/M  | 15  | Incidental/assault | None | R MCA | Giant fusiform/dissecting | R pterional |
| 20      | 10 y/M  | 15  | Incidental | None | Basilar (P1 + PCoA) | Fusiform/dissecting | R OZ/EC-IC bypass/staged |
| Technique                                      | GOS at DC | Complications/ New Deficits | Postoperative Angiography | Residual? | Clinical Follow-up, mo | Follow-up GOS | Angiographic Follow-up, mo | Angiography Result |
|------------------------------------------------|-----------|----------------------------|---------------------------|-----------|-----------------------|--------------|---------------------------|-------------------|
| EC-IC/radial artery/PV occlusion               | 4         | Same as preop              | Y                         | N         |                       |              |                           |                   |
| Standstill/clip                                | 3         | E4M2Vt extends all ext     | Y                         | Y (coiled)| 13                    | 3            |                           |                   |
| Clip                                           | 5         | Intraop rupture            | Y                         | N         | 15                    | 5            |                           |                   |
| Standstill/clip                                | 3         | Cerebellar IPH/R VI/ locked in/withdraws all extremities | Y                         | Y         | 13                    | 1            |                           |                   |
| Clip w/cotton reinforcement                    | 5         | None                       | Y                         | N         | 112                   | 5            | 36                        | Stable            |
| Clip                                           | 5         | None                       | Y                         | N         | 28                    | 5            |                           |                   |
| Standstill/thrombectomy and clip occlusion     | 4         | R HP/facial droop/trach but talking | Y                         | N         | 15                    | 5            | 13                        | Stable distal BA/increase R ICA |
| Clip/cervical ICA-MCA bypass/saphenous vein    | 5         | Occlusion of graft/thrombectomy | Y                         | N         | 23                    |              | MRA, no residual          |                   |
| Excision                                       |           | Same as preop localizing/R HP | Y                         | N         | 40                    | 4            |                           |                   |
| Clip                                           | 5         | None                       | Y                         | N         | 226                   | 5            | 216                       | Stable/new R ICA/PCoA |
| Clip                                           | 5         | R VI diplopia              | Y                         | N         | 90                    | 5            | 36                        | Stable            |
| Clip                                           | 5         | None                       | Y                         | N         | 78                    | 5            | 22                        | Stable            |
| Proximal clip/PV occlusion/STA-MCA             | 5         | None                       | Y                         | N         | 108                   | 5            | 60                        | No residual/STA-MCA bypass patent |
| Standstill/clip                                | 5         | L facial droop             | Y                         | N         | 5                     | 5            |                           |                   |
| Clip/wrap                                      | 5         | None                       | Y                         | N         | 37                    | 5            | 1                         | Stable residual (wrap) |
| Clip/wrap                                      | 5         | None                       | Y                         | Y         | 71                    | 5            | 9                         | CTA stable        |
| Clip                                           | 4         | Left HP                    | Y                         | N         |                       |              |                           |                   |
| Wrap ICA/clip AChA choroidal                   | 5         | None                       | Y                         | N         | 4                     | 5            | 16                        | CTA stable        |
| Muslin wrap ICA/clip L PCoA                    | 5         | Mild L VII/lacunar stroke  | Y                         | N         | 132                   | 5            | 96                        | Stable            |
| PV clip occlusion anterior temporal-to-distal MCA bypass | 5       | None                       | Y                         | N         |                       |              |                           |                   |
| PV clip occlusion/ cervical ICA-MCA bypass/saphenous vein | 5       | Mild HP graft occlusion treated with TPA/neck hematoma evacuation | Y           | N         |                       |              |                           |                   |
| Patient | Age/Sex | GCS | Presentation | Deficits | Location | Type | Approach |
|---------|---------|-----|--------------|----------|----------|------|----------|
| 21      | 12 y/M  | 15  | Incidental/concussion | None | L ICA terminus | Giant/fusiform dissecting | L orbitocranial |
| 22      | 9 y/M   | 15  | Stroke | HP | L AChA | Fusiform/dissecting | L MOZ |
| 23      | 17 y/F  | 7   | SAH | Hemiplegia | L ICA terminus/R A1 | Saccular | L OZ |
| 24      | 5 y/M   | 8   | SAH | Localize UES | R V4 | Giant saccular | R far lateral |
| 25      | 12 y/F  | 15  | Incidental/tremor grade V AVM | HP | R MCA | Saccular/AVM feeder aneurysm | R pterional |
| 26      | 14 y/M  | 15  | HA incidental | None | L MCA | Giant fusiform/dissecting | L pterional staged |
| 27      | 18 y/F  | 14  | TSAH | CN VII/VIII | R ophthalmic ICA | Traumatic pseudoaneurysm | R pterional |
| 28      | 16 y/M  | 14  | SAH | None | L ICA terminus | Saccular | L OZ |
| 29      | 18 y/F  | 5   | TSAH | Decorticate posture | L pericallosal | Traumatic pseudoaneurysm | Bi frontoparietal |
| 30      | 18 y/F  | 15  | Seizure | None | R ACA (azygos) | Dolichoectatic blebs | R OZ |
| 31      | 4 y/M   | 15  | Irritable/papilledema | None | L Ant frontal opercular branch | Giant saccular---thrombosed | L pterional |
| 32      | 8 mo/M  | 14  | Stroke | Hemiplegia | L MCA (proximal and distal) | Mycotic | L pterional |
| 33      | 5 y/M   | 15  | SAH | CN VII HP | L V4 | Fusiform/dissecting | L far lateral with VA occlusion, PICA-PICA bypass |
| 34      | 8 y/F   | 15  | Diplopia | None | Mid BA | Fusiform/dissecting | L far lateral |
| 35      | 6 y/M   | 15  | Iatrogenic/tumor resection | CN VI/VII | L cav ICA | Traumatic pseudoaneurysm | L OZ |
| 36      | 18 y/M  | 15  | Incidental/vein of Galen malformation | Nystagmus | ACoA L ICA, clinoidal L ICA terminus | Saccular | L OZ |
| 37      | 11 y/M  | 14  | Stroke/blindness/ophthalmoplegia | CN II/III/IV/VI | L ICA | Fusiform/dissecting | L pterional |

| 11 y    | BA      | Fusiform/dissecting | R OZ |
| 13 y    | BA recurrence | R OZ coil embolization |
| Technique | GOS at DC | Complications/ New Deficits | Postoperative Angiography | Residual? | Clinical Follow-up, mo | Follow-up GOS | Angiographic Follow-up, mo | Angiography Result |
|-----------|-----------|-----------------------------|---------------------------|-----------|------------------------|--------------|---------------------------|-------------------|
| Clip      | 5         | R partial III               | Y                         | N         | 30                     | 5            | 30                        | Stable            |
| Clip      | 4         | L HP                        |                           |           |                        |              |                           |                   |
| Clip      | 4         | Transient foot drop        | Y                         | N         | 36                     | 5            | 28                        | Stable            |
| Standstill/clip | 5   | Mild cognitive deficits    | Y                         | N         | 70                     | 5            | 33                        | No residual        |
| Clip      | 4         | Stable L HP                | Y                         | N         | 42                     | 5            | 8                         | No residual        |
| PV clip occlusion/ double STA-MCA bypass | 5 | None                        | Y                         | N/patent bypass | 60        | 5            | 155                      | Stable/no aneurysm |
| Wrap      | 5         | Confusion/L VII and VIII from skull base fractures | Y | Y (wrapped) | 1         | 5            | 3                         | Stable/wrapped    |
| Clip      | 5         | None                        | Y                         | N         | 4                      | 5            | 3                         | No residual        |
| Clip      | None      | N                           |                           |           |                        |              |                           |                   |
| Clip      | 4         | Transient aphasia/improved to walking and talking |                           |           | 42                     | 5            | 42                        | Stable            |
| Clips     | 5         | None                        | Y                         | N         | 35                     | 5            | 30                        | Stable            |
| Excision end-to-end anastomosis | 5 | None                        | Y                         | N         | 14                     | 5            | 14                        | MRA--- no residual |
| Clip      | 4         | Stable preoperative hemiparesis | Y                     | N         | 120                    | 5            | 120                       | Recurrence         |
| PV clip occlusion/ CCA-MCA bypass |           |                             |                           |           | 72                     | 5            | 36                        | No residual        |
| VA occlusion/ PICA-PICA bypass | 5 | None                        | Y                         | N/patent bypass |           |              |                           |                   |
| Standstill/clip | 5 | L VI palsy                  | Y                         | Y/small between clips | 132       | 5            | 132                      | Stable/no residual |
| Clip      | 5         | L monococular blindness/mild R | HP/persistent L VII and VI palsy | Y        | N         |              |                           |                   |
| Clip      | 5         | Hydrocephalus from vein of Galen/VP shunt | Y                        | N         |              |              |                           |                   |
| L ICA-MCA bypass/saphenous vein | 5 | Graft occlusion treated with TPA/epidural hematoma L blindness ophthalmoplegia from presentation | Y | N/graft occluded |           |              |                           | 5                 |
| Standstill/clip | 5 | Periocular cellulitis       | Y                         | N         | 10                     | 5            |                           |                   |
| Attempted R EC-IC bypass/coil embolized | 4 | R hemiparesis from embolization | Y/postembolization | 79        | 5            | 79                        | Stable/patent bypass |

Continues
| Patient | Age/Sex | GCS | Presentation | Deficits | Location | Type | Approach |
|---------|---------|-----|--------------|----------|----------|------|----------|
| 38      | 18 y/F  | 13  | Thrombosis/brainstem dysfunction/postpartum HA | Quadriplegia | L VBJ | Fusiform/dissecting | R far lateral |
| 39      | 15 y/M  | 15  | Iatrogenic/IVH from depth wire placement | None | L ICA terminus | Traumatic pseudoaneurysm | R temporal |
| 40      | 4 y/M   | 15  | Seizure | None | L MCA x 2 | Fusiform/dissecting + saccular | L OZ |
| 41      | 18 y/M  | 15  | Incidental | None | L PCoA/L AChA L Clin ICA/R A1 | Saccular but L ICA was fusiform | L OZ |
| 42      | 7 y/M   | 15  | Incidental/HA | None | R MCA/R ICA terminus | Saccular | R MOZ |
| 43      | 6 y/M   | 15  | SAH | None | R AICA | Saccular | R RS |
| 44      | 14 y/M  | 15  | Incidental | None | VB J | Fusiform/dissecting | L pterional + L far lateral |
| 45      | 18 y/F  | 15  | Incidental/HA/Hx of Kawasaki disease | None | L clinoid ICA | Fusiform/dissecting | L pterional |
| 46      | 14/F    | 15  | ICH/endocarditis | Aphasia, HP | L MCA | Giant mycotic---thrombosed | L pterional |
| 47      | 16 y/F  | 15  | Incidental | CN III | L BA (P1 + SCA) R P2 | Fusiform/dissecting | L OZ |
| 48      | 15 y/M  | 15  | Incidental after trauma | None | L ICA | Fusiform/dissecting | L OZ |

*ACA, anterior cerebral artery; AChA, anterior choroidal artery; ACoA, anterior communicating artery; AICA, anterior inferior cerebellar artery; ASAH, aneurysmal SAH; AVM, arteriovenous malformation; BA, basilar artery; C dif, Clostridium difficile; CCA, common carotid artery; CN, cranial nerve; CTA, computed tomographic angiogram; ECA, external carotid artery; EC-IC, extracranial-intracranial; EVD, external ventricular drain; FL, far lateral; HA, headache; HP, hemiparesis; Hx, history; ICA, internal carotid artery; IPH, intraparenchymal
| Technique | GOS at DC | Complications/ New Deficits | Postoperative Angiography | Residual? | Clinical Follow-up, mo | Follow-up GOS | Angiographic Follow-up, mo | Angiography Result |
|-----------|----------|-------------------------------|---------------------------|----------|-----------------------|--------------|--------------------------|-------------------|
| Thrombectomy/ cotton packing | 2 | Stable preoperative quadriplegia |  | Y | Y (clip-wrapped) | 26 | 5 |  |
| Clip-wrap | 5 | Partial L III | Y | N | patent bypass | 73 | 5 |  |
| Clip of giant/clip of smaller M2 but rupture of neck/ M2-ant temp artery bypass | 5 | None | Y | N | patent bypass | 37 | 5 |  |
| Clip/ICA-clip wrapped | 5 | Sickle cell crisis was transfused | Y | N |  |
| Clip | 5 | None | Y | N | severe narrowing of M1 with thrombus treated with Aggrastat on postop angio | 64 | 5 |  |
| Standstill/clip | 5 | Intraop rupture with cerebellar herniation/ EVD infection/VPS/R VI/mild R VII/trace HP and dysmetria | Y | N | patent bypass |  |
| L ICA-M2 saphenous vein bypass followed by BA occlusion above aneurysm and bilateral VA occlusion above PICAs | 5 | Right groin pseudo-aneurysm/transient hydrocephalus/C diff colitis/Gram-negative bacteremia | Y | N | patent bypass |  |
| Wrap | 5 | None | 124 | 5 | 120 | Stable |  |
| Clip with cotton reinforcement/ STA onlay | 4 | Stable right hemiparesis from admission | Y | N |  |
| Standstill/clip | 5 | Stable preop L III palsy | Y | Y | small residual to keep P1 patent | 18 | 5 |  |
| Standstill/clip | 5 | R posterior internal capsule ischemia with slight L UE weakness that improved | Y | Y | small BA residual to keep thalamoperforate patent |  |
| Clip trapping/EC-IC saphenous bypass | 5 | None | Y | N |  |

hematoma; L, left; MCA, middle cerebral artery; MOZ, modified OZ; MRA, magnetic resonance angiogram; OZ, orbitozygomatic; PCA, posterior cerebral artery; PCoA, posterior communicating artery; PICA, posterior inferior cerebellar artery; R, right; RS, retrosigmoid; SAH, subarachnoid hemorrhage; SCA, superior cerebellar artery; STA, superficial temporal artery; TPA, tissue plasminogen activator; TSAH, traumatic SAH; UE, upper extremity; VA, vertebral artery; VBJ, vertebrobasilar junction; VPS, ventriculoperitoneal shunt.
mortality. Treatment should confer both an immediate and long-term cure. An angiographic follow-up is essential in determining the long-term effectiveness of any treatment for aneurysms. Until recently, such information was lacking for both the microsurgical and endovascular treatment of pediatric aneurysms.7,10

Demographics

There is a male preponderance for aneurysms in the pediatric population. Some series suggest that age at presentation seems to follow a bimodal distribution with an earlier peak from birth to 6 years of age and a later peak from 8 years of age to adolescence.1 Most of our patients (73%) presented during the second decade of life. The incidence of aneurysmal SAH has ranged from 54% to 95%,5 which is considerably higher than the 17% in our series. In our series, 62% of the aneurysms were symptomatic. As reported in literature, underlying causes in our series included iatrogenic, trauma, arteriovenous malformation—flow related, and infection. The differences between our series and previous reports may reflect referral patterns to the respective institutions involved.

### TABLE 2. Presentation of Pediatric Patients With Aneurysm

| Symptoms          | n | % |
|-------------------|---|---|
| Incidental        | 17| 35|
| ASAH              | 8 | 17|
| Stroke            | 6 | 13|
| TSAH              | 5 | 10|
| Seizure           | 4 | 8 |
| ICH               | 3 | 6 |
| Iatrogenic        | 2 | 4 |
| Mass effect       | 2 | 4 |
| Tremor            | 1 | 2 |

*ASAH, aneurysmal subarachnoid hemorrhage; ICH, intracerebral hematoma; TSAH, traumatic SAH.

### TABLE 3. Distribution of 72 Aneurysms in 48 Pediatric Patients

| Location                     | n | % |
|------------------------------|---|---|
| Anterior circulation         |   |   |
| Internal carotid artery      | 20| 28|
| Anterior cerebral artery     | 7 | 10|
| Anterior communicating artery| 1 | 1 |
| Anterior choroidal artery    | 7 | 10|
| Pericallosal artery          | 1 | 1 |
| Anterior temporal artery     | 1 | 1 |
| Posterior communicating artery| 4 | 6 |
| Middle cerebral artery       | 13| 18|
| Posterior circulation        |   |   |
| Basilar artery               | 9 | 13|
| Anterior inferior cerebellar artery| 2 | 3 |
| Vertebral (V4 segment) artery| 2 | 3 |
| Vertebobasilar junction      | 2 | 3 |
| Posterior cerebral artery    | 2 | 3 |

### TABLE 4. Aneurysms Categorized by Type

| Type                      | n | % |
|---------------------------|---|---|
| Saccular                  | 28| 39|
| Giant saccular            | 4 | 6 |
| Fusiform/dissecting       | 16| 22|
| Giant fusiform/dissecting | 12| 17|
| Traumatic                 | 7 | 10|
| Myotic                    | 5 | 7 |

### TABLE 5. Immediate and Long-term Complications in 48 Pediatric Patients With Aneurysms

| Complication                          | Postoperative | Follow-up |
|---------------------------------------|---------------|-----------|
| Death                                 | 0             | 1         |
| Epidural hematoma                     |               |           |
| Cerebellar hematoma                   | 1             |           |
| Ischemia/stroke                       | 2             |           |
| Graft occlusion                       | 2             |           |
| New cranial nerve deficit             | 2             |           |
| Persistent deficits                   |               | 3         |
| Hydrocephalus                         | 2             |           |
| Ventriculoperitoneal shunt            |               | 2         |
| Groin pseudoaneurysm                  | 1             |           |
| Periocular cellulitis                 | 1             |           |
| Ventriculitis                         |               | 1         |

*Thirteen of 53 procedures (25%).

*Six of 36 procedures (17%).

### TABLE 6. Clinical Outcomes Based on Glasgow Outcome Scale

| GOS Score | GOS at Discharge, No. Patients | GOS at Follow-up, No. Patients |
|-----------|--------------------------------|-------------------------------|
| 5         | 40                             | 33                            |
| 4         | 9                              | 1                             |
| 3         | 1                              | 1                             |
| 2         | 3                              | 0                             |
| 1         | 0                              | 1                             |

*GOS, Glasgow Outcome Scale
Aneurysm Distribution and Characteristics

In our series, the anterior circulation (76%) was the most frequent site of aneurysm formation. The posterior circulation harbored 24% of the lesions. In a review by Aryan et al, posterior circulation aneurysms in children were 3-fold higher than in adults (21% vs 7%).

Compared with adult aneurysms, giant and/or complex aneurysms are common in the pediatric population. In general, giant and fusiform/dissecting aneurysms warrant treatment because of their poor prognosis if left untreated. They pose risks for both bleeding and embolic stroke. Fusiform/dissecting aneurysms composed 39% of our series, 60% of which were in the anterior circulation compared with 45% as reported by Lasjaunias et al. Giant aneurysms were present in 23% of cases. Both findings are higher than in adults and reflect the high incidence of complex lesions in the pediatric population and the need for their effective treatment.

Surgical Technique

Pediatric aneurysms are diverse and often require complicated treatment. A high percentage of pediatric patients require specialized or innovative procedures compared with their adult counterparts, a majority of whom can be treated successfully with direct clip occlusion. In our current series, patients were treated by direct clipping, revascularization with flow diversion, and wrapping.

As suggested by Ferguson, the pathogenesis of aneurysm formation in adults represents an initial defect, with injury to the internal elastic membrane of the vessel wall by hemodynamic forces. Arterial branch points of vessels are most susceptible to such injury. The result is the development of solitary saccular aneurysms in both adults and adolescents. These lesions become symptomatic from SAH and are treated by direct clipping of the aneurysm or by endovascular techniques.

Compared with saccular aneurysms, fusiform/dissecting aneurysms are slightly different entities. They often represent acute and subacute or chronic recurrent dissections of the vessel wall after an intimal tear. If left untreated, they often enlarge and become symptomatic with mass effect or embolic stroke and, less frequently, with hemorrhage. Such aneurysms are amenable to treatment by redirecting blood flow through the aneurysm, which can be accomplished by clip reconstruction of the vessel lumen or by trapping the aneurysm with revascularization if necessary.

In our series, a significant portion (17%) of the aneurysms required treatment via bypass techniques coupled with parent vessel occlusion. This technique was also used as a bailout technique in one patient when the neck of the aneurysm avulsed during clipping. If such techniques are used, the surgeon must ensure that a
A 7-month-old boy presented with lethargy. A, computed tomography of the head shows a large hematoma in the left sylvian fissure. B, left internal carotid artery (ICA) angiogram shows 2 proximal and distal MCA aneurysms (arrows), which were clipped with no postoperative residual. Anterior (C) and lateral (D) projections of the left ICA angiogram 12 years later show a recurrent giant middle cerebral artery (MCA) aneurysm (arrow), which was treated with an ICA-to-MCA radial artery bypass with proximal occlusion of the parent vessel. Three-month postoperative angiograms showed occlusion of the aneurysm (E) and good filling of the distal MCA branches via the bypass (F). Figure 3A and 3C through 3F used with permission from Barrow Neurological Institute. Figure 3B from Lee KS, Liu SS, Spetzler RF, Rekate HL. Intracranial mycotic aneurysm in an infant: report of a case. Neurosurgery. 1990;26(1):129-33. Used with permission from Lippincott Williams and Wilkins.

graft is patent. Graft thrombosis occurred in 2 patients during the perioperative period, and 1 graft remained occluded despite attempts to open it. Aneurysms not amenable to clipping or endovascular techniques could be treated via wrapping techniques, which seem to confer long-term efficacy.14

The utility of hypothermic circulatory arrest for treatment of intracranial aneurysms is well established15 and has been reported previously in 2 pediatric patients with giant vertebrobasilar aneurysms16 from our institution. We used this technique in 9 patients to treat 10 aneurysms (15%), all of which involved the basilar artery and were thought not to be amenable to revascularization. Pediatric patients represented 10.2% of all cardiac standstill procedures at our institution.17 Cardiac standstill was chosen for treatment because of the size of the aneurysm and its location in the posterior fossa. However, with the advances in endovascular techniques, coupled with our increased use of revascularization and alteration of flow strategies for complex posterior fossa aneurysms, cardiac standstill is rarely used today.

**Treatment Outcomes**

Some series have reported surgical mortality rates as high as 22%5 and favorable outcomes as low as 44%.8 Poor outcomes have been attributed to preoperative neurological status. In our series, the perioperative mortality rate was zero. Outcome was favorable (Glasgow Outcome Scale score, 5 or 4) in 92% of our patients at discharge and in 94% at the last follow-up. Patients who presented with aneurysmal SAH had a good grade (Hunt and Hess I and II) and thus a favorable outcome. At the last follow-up, 1 patient died of presumed rehemorrhage 13 months after treatment, creating an annual hemorrhage risk of 0.6%. The rate of treatment-related morbidity and mortality was 23% in the perioperative period and 9% at the last follow-up.

Angiographic outcomes are essential to evaluate the efficacy of either endovascular or microsurgical treatment of aneurysms. Sanai et al7 reported 13 pediatric patients treated with microsurgical techniques with angiographic follow-up; their reported rate of aneurysm obliteration was 94%. In comparison, our complete obliteration rate on postoperative angiography was 88% (8 residuals of 67 aneurysms treated). This rate, however, includes 2 aneurysms that were wrapped and 2 with perforators arising from the residual aneurysms, which would thus show as residuals on angiography.

Sanai et al7 reported no recurrences in the microsurgical arm of their study. However, we observed 3 recurrences on angiographic follow-up of 35 aneurysms. The recurrence rate was therefore 8.6% with a 2.6% annual risk of recurrence. This rate is 6 times higher than that reported by David et al11 in a predominantly adult population after microsurgical clipping of an aneurysm (recurrence rate, 1.5%; annual risk of recurrence, 0.5%). In our series, the presence of residual aneurysm did not predict a recurrence, and none of the recurrences were associated with a residual on immediate postoperative angiography. Nine de novo aneurysms formed or grew in 3 patients; therefore, the annual risk was 7.8% per year compared to 1.8% for adults.11 One patient was treated
for a left posterior communicating artery aneurysm and had normal angiography at the 5-year follow-up, but 3 new aneurysms were present on the contralateral ICA at the 18-year follow-up. This delayed appearance of de novo lesions supports the necessity of following these patients well into adulthood.

### Endovascular Treatment

After microsurgical treatment of their aneurysm, 3 patients underwent adjuvant endovascular treatments. One patient was treated for a residual after clipping of a traumatic basilar apex aneurysm. After microsurgical treatment, 2 patients underwent 2 endovascular procedures each to treat a recurrence. Scarring precluded further surgery in 1 patient. The presence of parent vessel narrowing at the clip site made stent/coiling a better treatment choice in another patient. The availability of endovascular treatments made it possible for further treatment of these recurrences when microsurgery was not feasible.

### Treatment Choices

Some authors have advocated endovascular treatment of pediatric aneurysms over microsurgical treatment\(^7\) despite the lack of angiographic evidence of efficacy and long-term durability to support such recommendation. Sanai et al\(^7\) addressed the long-term durability of both treatment modalities and reported an obliteration rate of 82% and a recurrence rate of 14% after endovascular management in 16 patients compared with 94% and 0%, respectively, after microsurgery in 13 patients. They suggested that microsurgical therapy may confer better long-term durability compared with endovascular therapy. Our results suggest otherwise. We observed a recurrence rate of 8.6% (range, 5-120 months) after microsurgery, and the rate of de novo formation, which occurred as late as 18 years, was 12%. These differences could be attributed to the larger number of patients in our series. Our results show that both modalities of treatment achieve similar results.

The treatment of pediatric cerebral aneurysms poses several challenges. The aneurysms are often complex and require advanced microsurgical and/or endovascular techniques. The risks of recurrence and de novo formation in children are much higher than in the adult population, which is a major concern given the life expectancy of children. The ideal treatment of choice is one that cures the lesion in the long term and should be chosen on an individual basis. In the hands of a skilled neurovascular surgeon, both short-term and long-term favorable outcomes can be achieved.

### Limitations

Our series reflects a significant referral pattern because a large number of cases were semielective. Our good outcomes may reflect selection bias because only patients deemed to be surgical candidates were included. Our rates of recurrence and formation of de novo aneurysms represent best-case scenarios because only 54% of our patients had angiographic follow-up. Given the high rates of aneurysm recurrence and de novo formation in the pediatric population, clinical outcomes from only 75% of the patients may be inadequate. It is imperative that neurosurgeons follow these patients carefully, as we hope to do.

### CONCLUSIONS

Pediatric aneurysms are rare and complex lesions. They often require advanced surgical techniques and a skilled neurovascular team to achieve good outcomes. In children, microsurgical treatment may be equivalent to or better than endovascular management for conferring long-term durability and protection. We advocate lifetime vigilance and angiographic follow-up, with magnetic resonance angiography if possible, because the annual risks of hemorrhage (0.6%), recurrence (2.6%), and de novo formation (7.8%) are high.

### Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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COMMENTS

This is a very large retrospective review of pediatric aneurysms, all treated with microsurgical techniques. The basic conclusions are well known: Pediatric aneurysms are often large, distal, multiple, and difficult. The authors seem biased against endovascular treatment, even though it was used as salvage in 3 of their cases.

These aneurysms are quite difficult to treat, as shown by the high morbidity rate cited in this article. The tendency is to use endovascular techniques more frequently. Stenting might be considered rather than wrapping for fusiform aneurysms, and certainly coiling should be considered for posterior circulation (mainly basilar) aneurysms, as in patient 1 in this report. The major value of this report is that it will serve as a historical baseline against which more contemporary series incorporating endovascular techniques can be compared.

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