Pediatric intracranial arteriovenous malformations: a single-center experience

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OBJECTIVE Intracranial arteriovenous malformations (AVMs) are a common cause of intracranial hemorrhage in children. Exploring outcomes of treatment and factors that predict recurrence may help guide the management of pediatric AVMs. In this study, the authors review a single-center experience with pediatric AVMs, aiming to identify factors contributing to recurrence and areas for improvement in treatment.

METHODS A single-center retrospective review of patients ages 0–18 years with AVMs in the period from 2005 to 2018 was conducted. Demographic, clinical, and radiographic data were collected and examined to compare the clinical and functional outcomes of patients managed with and those managed without open microsurgical resection.

RESULTS One hundred five patients were diagnosed and treated during the study period. Fifty (47.6%) had been treated surgically and 35 (33.3%) nonsurgically, and 20 (19%) had been treated primarily at an outside institution and thus were excluded from further analysis. Of the 50 treated surgically, 92% had complete obliteration on postoperative imaging, with the remaining patients having residual AVM and undergoing re-resection or SRS, ultimately resulting in a 96% radiographic cure rate. The surgically treated patients were followed up for an average of 3.34 years. Eighty-two percent had a modified Rankin Scale (mRS) score of 0–2. There was a recurrence rate of 12%, with the time to recurrence averaging 327.86 days (range 85–596 days). Of the 35 patients managed without open surgery, 77% underwent serial imaging surveillance, 20% underwent endovascular embolization, and 3% underwent stereotactic radiosurgery. Radiographic cure was seen in 6% of those treated nonsurgically, and all had undergone endovascular treatment alone. The nonsurgically treated patients were followed up for an average of 2.14 years. Eighty percent had an mRS score of 0–2.

CONCLUSIONS The data revealed that patients with lower-grade AVMs treated surgically and those with higher-grade AVMs managed without surgery have good functional and clinical outcomes. A high rate of recurrence was noted, and the possible contributing factors were explored. The authors encourage further study into mechanisms to reduce AVM recurrence in pediatric patients and look forward to advances in the medical management of lesions that are considered unresectable.

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KEYWORDS cerebral arteriovenous malformations; pediatrics; recurrence; outcomes; vascular disorders

CEREBRAL arteriovenous malformations (AVMs) are lesions of abnormal vascular connections that occur in the brain in approximately 10–18 cases per 100,000 people.²¹ AVMs can remain asymptomatic for years or can lead to seizures or rupture, which can result in devastating intracranial hemorrhage and life-long disability. Ruptured AVMs account for a much higher proportion of spontaneous intracranial hemorrhages in pediatric patients than in adults, that is, 30%–50% compared to

1.4%–2%, respectively.⁷ With untreated AVMs, the annual risk of rupture in children is 4.4%–5.5%, and that risk is significantly reduced after treatment.^{7,9} This reduction supports the role of early intervention in the management of pediatric intracranial AVMs.

Current methods for managing intracranial AVMs include resection, endovascular embolization, radiosurgery, or a combination of these modalities.^{7,9,11,12} While surgery remains the gold-standard therapy for immediate angio-

ABBREVIATIONS AVM = arteriovenous malformation; mRS = modified Rankin Scale; SRS = stereotactic radiosurgery.

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graphic resolution of low-grade intracranial AVMs, many high-grade lesions are not amenable to this therapeutic modality because of their high-risk features or eloquent location.^{7,9,26} Endovascular therapy via embolization can be used to treat or reduce the flow of large AVMs in multiple stages, aiming for cure or rendering the lesion more amenable to surgery or radiosurgery. Complete radiographic resolution following embolization therapy alone has been estimated to occur in 10%–40% of AVMs treated endovascularly.^{4,29} Additionally, stereotactic radiosurgery (SRS) is another primary or adjunctive treatment method with a 60%–70% obliteration rate⁶ after involution, which occurs over a period of at least 12–24 months following treatment.³⁰ The SRS cure rate is highly dependent on lesion size; thus, SRS is typically used for small or residual lesions located in surgically inaccessible locations.

While these three modalities can be used independently, they can be also used in combination to provide the best chance of complete obliteration of the AVM. Multimodal treatment is largely dependent on the characteristics of the AVM and is therefore individualized based on parameters such as lesion size, feeding vessels, and location.^{7,9,11,12}

We aimed to examine the Texas Children's Hospital experience with pediatric intracranial AVMs to highlight the use of individualized multimodal treatments and their outcomes in this population. We present our institutional experience with pediatric ruptured and unruptured AVMs across 13 years. We describe treatment using various therapies with the aim to better understand clinical and functional outcomes in pediatric AVMs treated surgically or nonsurgically. Additionally, we aim to identify which factors may contribute to AVM recurrence in this pediatric patient population and to single out areas for improvement in treatment modalities and options for patients with limited conventional treatments. We hypothesize that outcomes in this cohort are favorable across treatment modalities and that there are unique characteristics of AVMs that contribute to recurrence.

Methods

A retrospective chart review of all patients who had been seen and treated for intracranial AVMs at Texas Children's Hospital in the period from 2005 to 2018 was conducted with institutional review board approval. Subjects were included if they had a radiographic or pathological diagnosis of intracranial AVM, were younger than 18 years old, and had been seen at our institution for conservative treatment, endovascular treatment, radiosurgery, or surgical management of an AVM. Any subjects who had undergone primary treatment of any type at an outside facility prior to transfer to Texas Children's Hospital for further care were excluded from this study. Clinical and radiographic variables collected included demographic and descriptive data regarding AVM characteristics and treatment. Primary outcomes were AVM obliteration, recurrence, and functional outcomes as assessed using the modified Rankin Scale (mRS) for neurological disabilities at the last follow-up.

Data were analyzed using IBM SPSS Statistics version 26 (IBM Corp.). Comparisons were made using chi-

square or Fisher's exact tests for categorical variables and independent-samples t-tests or one-way ANOVA for continuous variables. Correlations were assessed using Pearson's *r* test. Results were considered significant at the $p < 0.05$ level; all comparisons were two-tailed.

Results

Of the 105 patients identified at our institution, 50 had undergone surgical treatment and 35 had undergone nonsurgical treatment defined as serial surveillance, radiosurgery, or endovascular therapy alone. Twenty patients had received some or all of their treatment at external facilities and had been transferred to our institution for further management; these patients were excluded from this study.

The surgical group was older than the nonsurgical group, with a mean age of 9.82 years compared to 4.09 years ($p = 0.63$; Table 1). The groups were both predominantly Hispanic with similar sex distributions. The nonsurgical group had a higher rate of concomitant AVMs or AVM syndromes, including hereditary hemorrhagic telangiectasia and Wyburn-Mason syndrome, than the nonsurgical group, though the difference was not statistically significant ($p = 0.11$). There was a wide range of locations and sizes of AVMs among both groups; however, lesions treated surgically were more commonly located in the frontal, temporal, and parietal lobes, whereas lesions in the nonsurgical group were located more commonly in the deep structures, including the basal ganglia, thalamus, brainstem, corpus callosum, or intraventricular region ($p = 0.01$). The average nidus size was larger in the nonsurgical group, 3.95 cm compared to 2.42 cm in the surgical group ($p = 0.01$). Additionally, the nonsurgical group more commonly had lesions in eloquent locations ($p = 0.01$), with deep venous drainage ($p = 0.01$), with higher Spetzler-Martin²⁷ ($p = 0.01$) or Lawton-Young¹⁶ ($p = 0.01$) grades, with a diffuse nidus ($p = 0.01$), and with more feeding arteries to the lesion ($p = 0.01$).

Seventy-two percent of those treated surgically had presented with rupture, and the most common presenting symptom in this group was headache (60%; Table 2). Patients in the nonsurgical group also most commonly presented with headache (49%) or had lesions that were incidentally found (32%). Presenting symptoms had occurred for a similar duration in the two groups ($p = 0.11$).

The outcomes of those with surgically treated AVMs are listed in Table 3. Thirty-two percent of these patients had undergone preoperative embolization, with a median of 1 embolization procedure (range 1–4) and a 12.5% complete obliteration rate after preoperative embolization. Following resection, this group had a 92% complete resection rate on immediate postoperative imaging; 8% were found to have residual AVM after surgery. Of the 4 patients with residual AVM, one underwent radiosurgery for treatment of the residual lesion; the other 3 patients underwent repeat surgery, with one having preoperative embolization prior to the repeat resection. Two underwent re-resection within a week of the initial resection, and the patient who underwent re-resection in a delayed fashion had incomplete medical records, so the reason for

TABLE 1. Descriptive characteristics by treatment group

Variable	Surgical	Nonsurgical	p Value
No. of patients	50	35	
Age in yrs			
Mean	9.82	4.09	0.63*
Range	2–17	1–17	
Sex (%)			0.84†
Male	52	54	
Female	48	46	
Race/ethnicity (%)			0.23‡
White	40	26	
African American	4	6	
Hispanic	56	60	
Asian	0	6	
Other/unknown	0	3	
Presence of other AVMs or AVM syndromes			0.11†
Hereditary hemorrhagic telangiectasia	4	3	0.29‡
Wyburn-Mason syndrome	0	3	
History of AVM in other location	0	6	
Concern for syndrome, undiagnosed	0	3	
AVM characteristics			
Laterality (%)			0.11†
Rt	58	51	
Lt	42	40	
Bilat	0	9	
Lobe (%)			0.01‡
Frontal	40	20	
Temporal	24	26	
Parietal	26	9	
Occipital	8	14	
Holoheispheric	0	9	
Deep§	0	43	
Cerebellum	12	3	
Size of nidus			
Mean in cm	2	4	0.01*
0–3 cm (%)	70	29	0.01†
3–6 cm (%)	20	49	
>6 cm (%)	4	20	
Unknown (%)	6	3	
Eloquent location (%)	24	69	0.01†
Deep venous drainage (%)	24	69	0.01†
SM grade (%)			0.01‡
I	38	9	
II	40	17	
III	6	20	
IV	8	37	
V	0	14	
Unknown	8	3	
Diffuse nidus (%)	36	80	0.01†

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TABLE 1. Descriptive characteristics by treatment group

Variable	Surgical	Nonsurgical	p Value
AVM characteristics (<i>continued</i>)			
LY grade (%)			0.01‡
I	46	9	
II	40	31	
III	8	57	
Unknown	6	3	
Mean no. of feeding arteries	1.43	2.21	0.01*
Signs of prior hemorrhage (%)	12	3	0.23†
Presence of intranidal aneurysm (%)	30	26	0.64†
Venous outlet obstruction (%)	6	11	0.45†

LY = Lawton-Young; SM = Spetzler-Martin.

Boldface type indicates statistical significance.

* p value derived from independent samples t-test.

† p value derived from Fisher's exact test.

‡ p value derived from chi-square test.

§ Deep is defined as a location in the basal ganglia, thalamus, brainstem, corpus callosum, or intraventricular region.

the delayed re-resection is unknown, but it occurred 14 months after the initial resection. All 4 patients with residual AVM had complete obliteration on the most recent follow-up imaging. The surgical patients were followed up for an average of 3.34 years. A recurrence rate of 12% was noted in this group, with the time to recurrence averaging 327.86 days (range 85–596 days). Recurrence was defined as the interval development of AVM after postoperative imaging had demonstrated no appreciable residual AVM. Of the 6 patients with AVM recurrence, one had two recurrence episodes. Of the 7 episodes of recurrence, 6 were treated with redo craniotomy for AVM resection with one patient undergoing radiosurgery for treatment of the recurrence. All but 2 patients had complete obliteration of the recurrent AVM on the most recent follow-up imaging. Of the 50 patients treated surgically, 96% had radio-

graphic cure at the last follow-up. The 2 patients who did not have radiographic cure had recurrent AVM; one was treated with radiosurgery, with a small residual nidus followed conservatively, and the other patient was followed up conservatively for a new small recurrence after having undergone two redo craniotomies for resection of the recurrent AVM. The decision for conservative management was based on shared decision-making with the families. Looking more closely at the group with recurrence, we noted that the patients were predominantly males of various ethnic and racial backgrounds, more commonly presented with rupture, had frontal or temporal nidus locations, and their nidi had one feeding artery, were typically smaller than 3 cm in size, were not typically deep or eloquently located, and were more diffuse. While the number of recurrences was too small to detect statistically significant differences, there were some subjective commonalities among the patients, namely nidus location, size, and diffusivity.

Postoperative complications included neurological deficits, wound complications, and hydrocephalus or CSF leakage. Neurological deficits in the surgically treated group included hemiparesis, ataxia, cranial neuropathies, cognitive impairment, speech delay, and visual field deficits. Eighty-two percent of the surgically treated patients had an mRS score of 0–2 at the last follow-up, indicating functional independence.

The outcomes of patients in the nonsurgical group are listed in Table 4. Seventy-seven percent underwent serial surveillance, 20% underwent endovascular embolization, and 3% underwent SRS. Among those who underwent embolization, the median number of embolization procedures was 3 (range 1–6) with a complete obliteration rate of 14% after embolization alone. Complications of embolization included AVM rupture or delayed hemorrhage, hydrocephalus, and neurological deficits. There was no difference in the overall complication rate between the

TABLE 2. Clinical presentation of patients by treatment group

Variable	Surgical	Nonsurgical	p Value
No. of patients	50	35	
Rupture (%)	72	29	0.01*
Headache (%)	60	49	0.08*
Weakness (%)	14	17	0.84*
Speech disturbances (%)	2	11	1.00†
Visual disturbances (%)	4	11	0.39†
Imbalance (%)	20	3	0.44†
Dysphagia (%)	0	11	—
Incidental finding (%)	12	32	0.02†
Mean duration of symptoms in wks	6.01	19.68	0.11‡

Boldface type indicates statistical significance.

* p value derived from chi-square test.

† p value derived from Fisher's exact test.

‡ p value derived from paired-samples t-test.

TABLE 3. Surgical group AVM outcomes

Variable	Value
Preop embolization (%)	32
Median no. of embolization procedures (range)	1 (1–4)
Complete obliteration after embolization (%)	12.50
Complete resection postoperatively (%)	92
Postop complications (%)	
Neurological deficit	10
Hydrocephalus, CSF leakage, pseudomeningocele	4
Wound complication*	4
Residual AVM (%)†	8
Recurrent AVM (%)‡	12
Time to recurrence in days	
Range	85–596
Mean	327.86
Additional procedures (%)	34
Preop EVD placement	24
Preop decompressive craniectomy	8
Hematoma evacuation	8
Other (wound revision, ICP monitor)	6
Length of FU in yrs	
Range	0–11.75
Mean	3.34
Radiographic cure at FU (%)	96
Functional outcome (%)	
Functionally independent (mRS score 0–2)	82
Functionally dependent (mRS score 3–6)	6
Unknown mRS score	12

EVD = external ventricular drain; FU = follow-up; ICP = intracranial pressure.

* Wound complication is defined as wound infection, wound dehiscence, or bone flap resorption.

† Residual AVM was defined by the presence of residual AVM on postoperative imaging. Recurrent AVM was defined by the interval development of AVM after postoperative imaging demonstrated no residual AVM.

‡ One patient had two episodes of recurrence, and that patient is counted here once, but each episode's time to recurrence is included.

two treatment groups ($p < 0.65$). Neurological deficits in the nonsurgical group included hemiparesis, cognitive impairment, speech delay, and visual field deficits. None of the patients who experienced complete obliteration with embolization had a recurrence in the follow-up period. The nonsurgical patients were followed up for an average of 2.14 years. Radiographic cure was seen in 6% of the nonsurgical group, and all had undergone endovascular treatment alone. There were higher rates of radiographic cure in the surgical group than in the nonsurgical group (96% vs 6%, $p < 0.01$). Delayed hemorrhage or AVM rupture was seen in 6% of the nonsurgical group throughout the follow-up. At the most recent follow-up, 80% of the patients in the nonsurgical group had an mRS score of 0–2, indicating functional independence. There was no difference in the last mRS score ($p < 0.11$) or functional independence ($p < 1.00$) between the treatment groups.

TABLE 4. Nonsurgical group AVM outcomes

Variable	Value
Treatment modality (%)	
Endovascular embolization	20
SRS	3
Serial surveillance	77
Embolization (n = 7)	
Median no. of embolization procedures (range)	3 (1–6)
Complete obliteration after embolization (%)	14
Complications (%)	
AVM rupture or delayed hemorrhage	6
Hydrocephalus, CSF leakage, pseudomeningocele	6
Neurological deficit	3
Additional procedures (%)	
EVD placement	17
Decompressive craniectomy	6
Hematoma evacuation	3
Other (wound revision, ICP monitor, VPS)	9
Length of FU in yrs	
Range	0–12
Mean	2.14
Radiographic cure at FU (%)	6
Functional outcome (%)	
Functionally independent (mRS score 0–2)	80
Functionally dependent (mRS score 3–6)	6
Unknown mRS score	14

n = number; VPS = ventriculoperitoneal shunt.

Discussion

This study represents a large series of pediatric intracranial AVMs. We found an overall radiographic cure of 96% for those treated surgically and 6% for those in the nonsurgical group. These rates are comparable to those quoted in the literature and underscore the success and benefit of surgical intervention.

We characterized functional outcomes using the mRS, with a score of 0–2 indicating functional independence. Both groups, surgical and nonsurgical, had good neurological functional outcomes, with 82% and 80%, respectively, having mRS scores of 0–2. This outcome corresponds with those in previous reports supporting improvement after treatment³¹ and indicates that an overwhelming majority of pediatric patients have functional independence after treatment, whether surgical or nonsurgical, with good outcomes.

AVM Recurrence: When, How, and Why?

Most notably, we found a recurrence rate of 12% among those who had undergone resection, with the time to recurrence averaging roughly 12 months; no recurrence was seen in the 6% of patients cured with nonsurgical treatment. A recent systematic review of 14 case reports and 16 case series examined the risk factors and timing for recurrence of resected brain AVMs, finding a 2.7% rate of

recurrence in adult cases and a 9.5%–14% rate of recurrence in pediatric cases, with an average time to recurrence of 4.2 years.²⁶ Lang et al. assessed 28 pediatric patients treated with AVM resection and noted a recurrence in 14.3% of them, occurring 50–60 weeks after the initial resection, with the recurrence risk identified as 0.07 per person-year.¹⁵ Interestingly, these authors also correlated a lower compactness score with AVM recurrence.¹⁵ Looking more closely at the group that experienced a recurrence in our study, we noted that most had a diffuse nidus as well, although the number of recurrences was not sufficiently powered to demonstrate statistical significance. Therefore, it is possible that diffuse AVMs may have a higher propensity for recurrence, or perhaps there was an occult residual lesion that could not be visualized on the immediate postoperative angiogram, as opposed to a true recurrence.

Given the relatively high rate of recurrence after complete resection, a deeper understanding of why this occurs and how to minimize recurrence is imperative. Among the AVMs that did recur, we found a higher prevalence in males and among patients who had presented with AVM rupture, had frontal or temporal nidus locations, had one nidus-feeding artery, had an AVM smaller than 3 cm in size, and had a more diffuse nidus. None of the patients with residual AVMs had a recurrence, although one patient had a recurrence twice. While these results bear no statistical significance, subjective findings may help guide future study, and comparisons with the literature can help inform management. A systematic review revealed that AVM recurrence in pediatric populations varies across a wide range of time, from 3 months to 17 years postresection, with an average time to recurrence of 4.82 years.¹⁴ Authors of this review also stratified recurrence according to whether or not patients underwent active follow-up imaging and found an earlier rate of detection among those undergoing surveillance, with a time to recurrence of 3.56 compared to 8.86 years. Moreover, those who did not have imaging follow-up had a higher risk of presenting with AVM rupture. These findings highlight the need for long-term follow-up and serial surveillance in pediatric patients with a history of intracranial AVM, with clear roles for detecting clinical and radiographic changes and critically evaluating conservative management versus treatment at each follow-up.

The literature on AVMs in adults reports a recurrence rate of approximately 2%–4%.^{13,26} The reason for the higher rate of recurrence among the pediatric AVM population is not fully understood, although multiple theories have been postulated. The concept of early postoperative changes hiding residual AVM which later presents as a recurrence is one such theory.²² Other authors have proposed that there are different angiogenic attributes of pediatric AVMs that foster vascular proliferation and subsequent recurrence.²⁵ Additionally, the angioarchitecture of pediatric AVMs differs from that of adult AVMs, with exclusive deep venous drainage higher in pediatric populations and deep venous drainage associated with AVM recurrence.^{1,2,10} Moreover, some pediatric AVMs have a more diffuse architecture, perhaps predisposing to occult areas, which can foster a future recurrence.¹⁵ Going forward, we

aim to understand the attributes of pediatric AVMs that lead to increased recurrences by looking at tissue pathology and genetic markers as possible means to elucidate this pathology and pathophysiology and perhaps open new avenues of treatment in the years to come. We also look forward to future large-volume studies sufficiently powered to explore associations with recurrences to further guide treatment.

The Role of SRS

One treatment modality used in a limited fashion in our study was SRS. This procedure was developed by Leskell in 1951 to destroy lesions inaccessible via open surgery by delivering beams of radiation to a designated brain area.¹⁷ It was first applied to intracranial AVMs in 1972.²⁸ Currently, SRS remains one of the mainstays of primary and adjunctive therapy for inaccessible AVMs. SRS is most effective in treating small AVMs (< 3 cm or < 10 cm³ in volume).⁶ The mechanism by which SRS causes AVM involution remains unclear, but it is thought to be similar to the formation of an atherosclerotic plaque wherein damage to the surrounding vessel walls stimulates proliferation of smooth muscle cells, which leads to narrowing and eventual occlusion of the vessel.³⁰ Relatedly, the resolution of AVMs treated with SRS is delayed by several months to years, with complete obliteration seen at a minimum of 12–18 months in multiple adult series.⁶ Despite the delay in AVM resolution after SRS treatment, many studies support the use of SRS in pediatric AVMs, touting good obliteration rates of 60%–95%.^{20,24} After treatment with an average radiation dose of 20 Gy and stratification by AVM size, obliteration rates of 80% in AVM lesions smaller than 3 ml and 64.7% in lesions 3–10 ml were seen.¹⁸

Our clinical practice favors the resection of all accessible lesions in noneloquent areas. For lesions located in deep, eloquent, or inaccessible areas of the brain, conservative treatment with serial surveillance is favored (77% of nonsurgically treated patients in our study underwent imaging surveillance). Very few patients underwent embolization alone, and even fewer underwent SRS. Endovascular embolization of complex AVMs can change flow dynamics, increasing the rupture risk if the lesion is not completely embolized.⁵ Radiosurgery can help target deep remnants of the AVM adjacent to structures such as the internal capsule and thalamus.²³ If the AVM is only partially obliterated with radiosurgery, studies have suggested that the rupture risk may be similar to the natural history of 2.6% per year.⁸ Additionally, in ARUBA (A Randomized Trial of Unruptured Brain Arteriovenous Malformations), which compared the risk of death and symptomatic stroke in adult patients with unruptured cerebral AVMs randomly assigned to medical management or medical management plus intervention, including neurosurgical, endovascular, or radiotherapy procedures, researchers found a significantly lower risk of death and neurological disability at 30 months' follow-up in the medical management group (15.1% vs 46.2%).¹⁹ While the ARUBA findings are not generalizable to pediatric populations, based on an extrapolation of its findings and for the reasons aforementioned, we propose serial surveillance as a viable option in patients with high-grade unresectable lesions.

Additional Future Directions

The nonsurgical cohort in our study comprised mostly patients with deep, diffuse, large, eloquent high-grade lesions with more feeding arteries, venous outflow obstruction, and deep venous drainage. This cohort was also associated with a higher proportion of multiple AVMs or AVM-associated syndromes. Despite a low cure rate in this group (6% compared to 96%), our study demonstrated comparable functional and clinical outcomes in the patients treated nonsurgically and surgically. We recognize that the majority of patients in the nonsurgical cohort were treated with serial surveillance, which inherently will not lead to a cure, unless spontaneous regression occurs. While our findings underscore the importance of patient selection when determining treatment modality, we also believe that these findings highlight a subset of pediatric patients with high-grade, unresectable AVMs that would benefit from further study to delineate alternative treatment modalities where conventional modalities offer limited benefit. We hope for advances in the medical management of AVMs and look toward understanding the genetics, molecular biology, and immunohistopathology of these lesions to find targets for medical treatments in the future.

Study Limitations

Limitations of this study include the small number of patients in each group and lack of power to assess statistical significance between smaller subgroups with stratification. With an increased sample size, more subtle differences between treatment modalities and clinical as well as functional outcomes could be better explored. Because of the low numbers of recurrences and residual lesions in our study, significant statistical analysis comparing associations with the rate of recurrence or residual lesions could not be performed. Given the retrospective study design, causality when assessing recurrence or residual lesions could not be assessed; prospective randomized control trials would be best to establish temporality and assess causality. Additionally, the single-institution retrospective design applied in our study reflects the practice variations of treating clinicians' choices, limiting our ability to assess, through a larger volume, patients treated using all types of modalities. Moreover, though the mRS is a validated scoring system commonly used to assess functional neurological outcomes, the scale is designed for adults and has not been validated in children,³ thereby making assessment of functional outcome challenging to definitively gauge in this patient population with the mRS score functioning as a proxy.

Conclusions

In sum, our study examined a sizable cohort of pediatric patients diagnosed with and treated for intracranial AVMs. We found that patients with lower-grade AVMs treated surgically and patients with higher-grade AVMs managed without surgery have good functional and clinical outcomes. We identified a high rate of recurrence and explored possible contributing factors. We hope that further examination of these factors and outcomes can better delineate the attributes of pediatric AVMs that lead to

delayed and high rates of recurrence, and we look forward to future studies investigating the underlying reasons. We encourage further study into mechanisms to reduce AVM recurrence and look forward to advances in the medical management of lesions considered to be unresectable.

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Disclosures

Dr. Kan is a consultant for Stryker and Cerenovus.

Author Contributions

Conception and design: Lam, LoPresti. Acquisition of data: LoPresti, Pyarali. Analysis and interpretation of data: LoPresti, Ravindra, Goethe. Drafting the article: LoPresti, Pyarali. Critically revising the article: Lam, LoPresti, Ravindra, Gadgil, Wagner, Kan. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Lam. Statistical analysis: LoPresti, Goethe. Administrative/technical/material support: Lam, Kan. Study supervision: Lam, Ravindra, Kan.

Supplemental Information

Previous Presentations

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