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Seizure Predictors and Control After Microsurgical Resection of Supratentorial Arteriovenous Malformations in 440 Patients

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Abstract

Background—Seizures are a common symptom of supratentorial arteriovenous malformations (AVMs), and uncontrolled epilepsy can considerably reduce patient quality-of-life. Potential risk factors for epilepsy in patients with AVMs are poorly understood, and the importance of achieving seizure-freedom in their surgical treatment remains under-appreciated.

Objective—To characterize risks factors for pre-operative seizures and factors associated with post-operative seizure-freedom in patients with surgically resected supratentorial AVMs.

Methods—We analyzed prospectively-collected patient data for 440 patients who underwent microsurgical resection of supratentorial AVMs at our institution.

Results—Among 440 patients with supratentorial AVMs, 130 (30%) experienced pre-operative seizures, and 23 (18%) individuals with seizures progressed to medically refractory epilepsy. Seizures were associated with a history of AVM hemorrhage (RR 6.65, 95% CI 3.81-11.6), male gender (RR 2.07, 95% CI 1.26-3.39), and frontotemporal lesion location (RR 1.75, 95% CI 1.05-2.93). After resection, 96% of patients had a modified Engel class I outcome, characterized by seizure-freedom (80%) or only one post-operative seizure (16%) (mean follow-up 20.7 ± 2.3 months). Comparable rates of post-operative seizures were seen in patients with (7%) or without

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(3%) pre-operative seizures. AVMs with deep artery perforators were significantly associated with post-operative seizures (HR 4.35, 95% CI 1.61-11.7).

Conclusion—In the microsurgical treatment of supratentorial AVMs, hemorrhage, male gender, and frontotemporal location are associated with higher rates of pre-operative seizures, while deep artery perforators are associated with post-operative seizures. Achieving seizure-freedom is an important goal that can be achieved in the surgical treatment of AVMs, as epilepsy can significantly diminish patient quality-of-life.

Keywords

arteriovenous malformation; AVM; epilepsy; seizure; surgery

Introduction

Brain arteriovenous malformations (AVMs) are vascular lesions composed of tortuous anastomotic arteries and veins in brain parenchyma without intervening capillaries, resulting in arteriovenous shunting at a central nidus.[1, 2] This type of vascular malformation represents the most frequent cause of intracranial hemorrhage in young adults and children.[3, 4] The second most common presenting symptom of brain AVMs is seizures.[5, 6] While the causes of epileptogenesis in AVMs are not fully understood, proposed contributory mechanisms include cerebral ischemia from neighboring arteriovenous shunting, gliosis, demyelination, hemosiderin deposition, and kindling of excitatory synapses.[5, 7-10] Various studies have reported that between 12 to 57% of brain AVM patients suffer from seizures, and epilepsy sometimes persists even after surgical resection of the lesion.[11-16] When uncontrolled, epilepsy may result in significant morbidity and diminished quality-of-life.[7, 17-19] However, the importance of seizure control is often under-appreciated in the surgical treatment of AVMs, as most clinical studies and neurosurgical practices focus primarily on the hemorrhage risk associated with these lesions.[1, 20, 21] Factors associated with seizures in AVM patients, and of seizure-freedom after surgical resection, remain incompletely understood due to patient diversity and small sample sizes in many studies.

Here we report the largest, to our knowledge, clinical series examining seizures in patients with surgically resected supratentorial brain AVMs. We retrospectively reviewed prospectively-collected clinical data for 440 patients who underwent surgical resection of a supratentorial AVM at our institution, and analyzed factors associated with pre- and post-operative seizures in this population.

Methods

Study population and data collection

We examined data for 440 patients (age, 1-82 years) who underwent surgery at the University of California, San Francisco (UCSF), for treatment of supratentorial brain AVMs between 1997 and 2010. All research protocols were approved by the University of California, San Francisco, Institutional Review Board for Human Research. Data were obtained from an ongoing registry of AVM patients treated at our institution, maintained prospectively as part of the UCSF Brain AVM Study Project. These data include patient demographics, clinical presentation, surgical details, neuroimaging findings, AVM characteristics, therapeutic management, outcome, as well as seizure-related history, including seizure onset, type, and seizure control on medication. Medically refractory epilepsy was defined by continued seizures after trial of ≥ 2 anti-epileptic drugs (AEDs). Patients received pre-operative neuroimaging, including catheter angiography, and lesion size, location, and involvement of eloquent brain regions were recorded for each AVM. The presumed eloquent areas consisted of the sensorimotor strip (precentral and postcentral gyri), dominant hemisphere perisylvian language areas (superotemporal, inferofrontal, and inferoparietal areas), the basal ganglia/internal capsule, thalamus, and calcarine occipital cortex. AVMs were graded using the Spetzler-Martin scale[22] and the supplementary AVM grading scale, which uses parameters described by our group, including patient age, history of hemorrhage, and nidal diffuseness.[23-25] 85 infratentorial AVMs surgically treated at our institution were excluded.

Surgery and pre-operative treatment

AVM patients were treated using a multimodal approach, including open surgery, embolization, and stereotactic radiosurgery, after considering all therapeutic options with a multidisciplinary team consisting of neurosurgeons, neurologists, interventional neuroradiologists, and radiation oncologists. Only individuals who underwent surgical resection as part of their overall management were included in this study. Surgical procedures were performed by our senior author (MTL), utilizing a microsurgical approach with the main goal of minimizing transgression of normal brain parenchyma *en route* to the AVM. When possible, transsulcal, transsylvian, and/or other approaches through subarachnoid spaces or fissures were used with minimal brain retraction. Techniques used to approach lesions involving posterior midline structures have been previously described in detail.[26] Stealth intraoperative neuronavigation (Medtronic, Minneapolis, MN) was used to assist with localization. Intraoperative functional mapping was used when there was concern about proximity to eloquent brain areas. Invasive pre-operative diagnostics (i.e., implanted depth or grid electrodes) were not performed.

222 patients (50%) received pre-operative endovascular AVM embolization, typically during the 2 weeks preceding surgery, using polyvinyl alcohol (PVA) particles and Onyx® non-adhesive liquid embolic agent (ev3 Inc., Plymouth, MN). 21 patients (5%) underwent stereotactic radiosurgery prior to surgical resection. Except in three individuals who had radiosurgery outside of our institution, all radiosurgery patients were treated with the Leksell Gamma Knife models U, B, or C (Elekta, Stockholm, Sweden) using existing planning software. Our radiosurgical techniques for AVM treatment have been previously detailed.[27]

Outcomes

The modified Rankin Scale (mRS) was utilized to estimate both pre-operative (within 5 days immediately preceding surgery) and post-operative (within 1 week after surgery) neurological disability, with outcomes assessed by the research nurse for the cerebrovascular service and by the senior author. A modified version of the Engel classification system[28] was used to stratify post-operative outcomes into patients who had 0 or only 1 post-operative seizure (modified Engel class I) versus those who experienced multiple post-operative seizures (modified Engel class II-IV) as of their last follow-up. Seizure-freedom versus recurrence was assessed at post-operative follow-up appointments, and was not verified by an independent neurologist. Patients with pre-operative seizures were on AEDs pre-operatively, and remained on these medications post-operatively, but AEDs were not used as prophylaxis in patients without a history of seizures. Post-operative follow-up duration was 20.7 ± 2.3 (mean ± SEM) months, ranging from 6 months to 10 years. Peri-operative complications were recorded, including intra-operative aneurysm rupture, post-operative intracerebral or intraventricular hemorrhage, post-operative subdural or epidural hematoma, and post-operative arterial or venous infarct. Gross-total versus incomplete AVM resection was confirmed by intraoperative observation and post-operative imaging, including formal angiography to determine complete nidal obliteration.

Statistical analysis

To analyze factors associated pre-operative seizures and post-operative seizure control, we used Fisher's exact test for categorical variables (e.g., gender) and an unpaired t-test for continuous variables (e.g., size). Prior to utilizing parametric tests, normality of data was verified and Levene's test for equality of variances was applied. For further analysis of pre-operative factors associated with seizures, significant factors from univariate analyses were entered into a multivariate logistic regression in a backwards fashion. Both Cox and Snell R-squared and Nagelkerke R-squared values were calculated to ensure goodness-of-fit of the applied model. Relative risks (RRs) were calculated with a 95% confidence interval (CI). For further analysis of post-operative factors associated with seizures, significant factors from univariate analyses were examined with Cox proportional-hazards regression analysis, hazard ratios (HRs) were calculated with a 95% CI, and time to first post-operative seizure was plotted using Kaplan-Meier analysis. Multivariate analysis was not done for post-operative seizure data, as a significant association with seizure outcome was only observed for a single variable. Patients who died peri-operatively were excluded from post-operative seizure analyses. Pre- and post-operative mRS scores were compared to seizure status using Fisher's exact test. Statistical significance was assessed at $P < 0.05$. All statistical analyses were performed using SPSS version 17 (IBM, Somers, NY).

Results

The 440 patients with a surgically resected supratentorial AVM had a mean age of 37 years (range 1-82), of whom 48% were female. A total of 130 (30%) experienced pre-operative seizures. Of these individuals, 98 (75%) had seizures as their presenting symptom, and 23 (18%) progressed to medically refractory epilepsy (Figure 1).

Factors associated with pre-operative seizures

Several variables were evaluated for possible association with pre-operative seizures across all 440 patients (Table 1). No age differences were observed between individuals who did or did not have seizures, but seizures were more common in males (34%) than females (25%; $P = 0.04$). Lesions confined to the left versus right hemisphere resulted in similar rates of seizures (32-34%), but lesions located primarily in the frontal or temporal lobes were more likely to be associated with seizures (39% and 34%, respectively) than AVMs in other locations (9%, P < 0.001).

While overall Spetzler-Martin grade was not associated with seizures (P = 0.50), we did find that the mean AVM size was greater in patients with seizures (3.1 ± 0.1 cm) than in those without seizures (2.4 ± 0.1 cm, P < 0.001). Also, lesions with any deep venous drainage (not exclusive) were less likely (26%) to be associated with seizures than AVMs without deep drainage (37%, P = 0.04), but regional eloquence was not related to seizures. Supplementary parameters previously described by our group were also analyzed (Table 1). Patients with a history of AVM hemorrhage had a dramatically higher rate of seizures (43%) than those without hemorrhage (13%, P < 0.001). However, neither nidal diffuseness or deep arterial perforator supply were associated with varied seizure rates.

On multivariate analysis, pre-operative seizures were significantly associated with a history of AVM hemorrhage (RR 6.65, 95% CI 3.81-11.6), male gender (RR 1.07, 95% CI 1.26-3.39), and frontotemporal lesion location (RR 1.75, 95% CI 1.05-2.93) (Table 2).

Factors associated with post-operative seizures

Post-operative seizures were evaluated in 416 patients who did not die peri-operatively (Table 3). Of these, 399 (96%) achieved a modified Engel class I outcome, experiencing either no post-operative seizures (80%) or only 1 post-operative seizures (16%), while 17 (4%) patients had multiple seizures. Modified Engel class I outcome was achieved by 117 (93%) of the 126 patients who did have pre-operative seizures, and 282 (97%) of the 290 individuals who did not have pre-operative seizures, suggesting that pre-operative seizures were not significantly associated with post-operative seizure outcome (P = 0.06, Table 3). None of the factors associated with pre-operative seizures (Tables 1, 2) were also associated with post-operative seizures (Table 3). Also, outcomes did not vary significantly by pre-operative treatment or seizure characteristics, AVM obliteration extent, or peri-operative complications (including intra-operative rupture, post-operative hemorrhage, or post-operative infarct) (Table 3). However, individuals harboring AVMs with deep artery perforators experienced significantly worse seizure outcomes after surgery (84% modified Engel class I outcome, with 66% having no seizures) compared to those without deep artery perforators (97% modified Engel class I outcome, with 82% having no seizures) (P < 0.001, Table 3).

Cox regression analysis was performed to investigate the influence of deep artery perforators on post-operative seizures, and Kaplan-Meier plots were generated to reflect time to first post-operative seizure (Figure 2). Overall, AVMs with deep artery perforators were significantly associated with post-operative seizures (HR 4.35, 95% CI 1.61-11.7). This result did not change appreciably when controlling for whether or not patients had pre-operative seizures (data not shown).

Neurological outcomes

Finally, we asked whether there is an association between seizures and neurological disability before or after surgery (Figure 3). Pre-operative mRS scores were calculated ≤ 5 days preceding surgery and post-operative scores were assessed within 1 week after surgery.

Prior to surgery, patients with seizures were less likely (20%) to have marked neurological disability (mRS ≥ 3) than patients without seizures (58%, $P < 0.001$) (Figure 3A). However, no significant difference in post-operative disability was observed between patients who did or did not have seizures after surgery ($P = 0.26$) (Figure 3B). Overall, 76% of patients were neurologically improved or the same after surgery, while 24% were worse or had died, with no differences by seizure outcome ($P = 0.89$) (Figure 3C). 24 patients (5.5%) died in the peri-operative period.

Discussion

Seizures are the second most common presenting symptom of brain AVMs, and uncontrolled epilepsy can considerably reduce patient quality-of-life.[5, 6] However, the risk factors for epilepsy in AVMs are poorly understood, and the importance of achieving seizure-freedom in their surgical treatment remains under-appreciated, as most clinical studies focus on the risk of hemorrhage associated with these lesions. The present study represents the largest, to our knowledge, clinical series examining seizures in patients with surgically treated supratentorial AVMs. Among 440 patients, 30% suffered from seizures pre-operatively, and 23 patients progressed to medically refractory epilepsy. Seizures were more common in individuals with less pre-operative neurological disability. After microsurgical AVM resection, a modified Engel class I outcome, characterized by either complete seizure-freedom or only 1 post-operative seizure, was observed in 93% of individuals who did have pre-operative seizures, and 97% of those who did not have pre-operative seizures. Furthermore, 21 patients (91%) with medically refractory epilepsy before surgery achieved a favorable post-operative seizure outcome. This suggests that good seizure outcomes can often be achieved in the microsurgical treatment of AVMs causing seizures, even with lesions associated with medically refractory epilepsy. A history of hemorrhage was most strongly associated with pre-operative seizures, and a lack of AVM deep artery perforators was associated with post-operative seizure control.

Several factors associated with pre-operative seizures were also identified. A history of AVM hemorrhage was strongly associated with seizures, suggesting that the irritating effects of extravasated blood products in parenchyma may contribute to epileptogenicity in these patients. As recent evidence suggests that AVM patients with history of hemorrhage achieve greater post-operative improvement over their pre-operative neurological status compared to individuals without previous hemorrhage,[24, 25] surgical treatment of ruptured lesions should be considered, both to prevent re-rupture and to improve seizure control. Pre-operative seizures were also more common with lesions ≥ 3 cm and in AVMs in the frontotemporal region. These findings are not surprising, as such lesions have a larger area of contact between AVM and neocortical parenchyma at greatest risk for seizures, and they also confirm similar observations by previous investigators.[14-16, 29-31]

None of the risk factors for pre-operative seizures were also associated with post-operative seizure outcome, and outcomes were not significantly affected by peri-operative complications (including intra-operative rupture, post-operative hemorrhage, or post-operative infarct). However, AVMs with deep artery perforators were associated with post-operative seizures, whether or not patients had seizures pre-operatively. While the reason for this association is not known, it is possible that the additional microsurgical dissection required to isolate deep artery perforators from parenchyma has an irritative effect in surrounding brain, making post-operative seizures somewhat more likely.

A critical consideration in the treatment of AVMs is obliteration extent. One previous investigation found higher rates of seizure recurrence with incomplete AVM obliteration after surgery,[14] and the risk of post-operative hemorrhage with residual nidus has been well documented.[32-34] We did not observe a relationship between incomplete obliteration and post-operative seizure recurrence, suggesting that seizure-freedom is possible even in the setting of residual AVM. Nevertheless, it is clear that achieving complete AVM obliteration is an important goal in approaching these lesions to avoid subsequent morbidity related to hemorrhage.

We did not observe a relationship between pre-operative duration of seizures and post-operative seizure outcome in AVM patients, which is consistent with findings by previous investigators.[35] While a longer duration of seizures predisposes to less favorable seizure outcome in other causes of lesional epilepsy, such as low-grade tumors,[36] there is no evidence to suggest a similar relationship with AVMs.

Finally, we observed a 3% incidence of > 1 new post-operative seizures in patients without pre-operative seizures, which is somewhat lower than the 6-22% incidence of new seizures after surgery reported in the literature.[5, 13, 37-39] Given the risk of post-operative seizures inherent to neurosurgical procedures involving craniotomy,[40-42] this raises the question of whether prophylactic AEDs are warranted in AVM surgery. While it is not our standard practice to utilize prophylactic post-operative AEDs in patients without a history of seizures, further study addressing this question may be warranted.

There are several limitations to the present study. As we retrospectively reviewed data from our prospectively collected clinical database, no factors were controlled or randomized, and restriction of our analysis to one institution likely allows selection bias. Seizure-freedom versus recurrence was assessed at post-operative follow-up appointments, and was not verified by an independent neurologist, which may also allow bias in outcome reporting. Information regarding AED agent, dose, or duration was not included in our database, and patients with multiple post-operative seizures (Engel class II-IV) were not stratified into a specific Engel class. Thus, further study into AED utilization in post-operative AVM patients of different Engel class outcomes is warranted. Specific seizure type and frequency were also not recorded prospectively beyond the presence of no seizures, a single seizure, or multiple seizures. As our focus was intentionally restricted to seizures in microsurgically treated AVM patients, post-operative seizure rates were not compared to those in untreated patients or individuals who received embolization or radiosurgery alone. A large, multi-centered prospective trial comparing seizure outcomes by various treatment modalities – along with detailed assessment of seizure type, frequency, and AED agents – will be important going forward. Nevertheless, our study does provide insight into factors associated with pre-operative and post-operative seizures that will be useful in guiding physician-patient discussions regarding treatment decisions and expected outcomes.

Conclusion

Seizures are common in patients with brain AVMs, particularly in those with a history of hemorrhage, and can significantly impact quality-of-life. Seizures are associated with larger AVMs in frontotemporal regions, many of them unruptured, so careful patient selection with Spetzler-Martin and supplementary grading is important. In our series, AVM resection resulted in seizure control in 93% of patients with pre-operative seizures, with an incidence of new post-operative seizures of only 3%. While we do not advocate surgical resection of AVMs simply for the purpose of seizure control (prevention of intracranial hemorrhage or re-hemorrhage remains the most important operative consideration), our data do suggest that good seizure outcomes can be achieve in the microsurgical treatment of these lesions.

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Appendix

The authors have provided insight into the issue of seizure control in a large series of patients with supratentorial arteriovenous malformations that were resected. There are a few central questions that this study answers. If you are having seizures due to an AVM, how likely you are you to be with excellent seizure control (Engel Class 1) after surgery? The answer is estimate to be 93% if you had any seizure preoperatively and 91% if your seizures were medically refractory prior to surgery. Conversely, if you are seizure free before surgery, how likely are you to be seizure free after surgery? The answer is estimated to be 97%. This should be reassuring to many patients who have experienced seizures due to AVM's are weighing treatment options. Interestingly, a newly identified factor that predisposed patients to developing post-operative seizures was the presence of deep perforators.

There are criticisms that could be levied against the report such as the failure to have an independent observer assessment of seizure status. Despite this criticism, the report does provide useful information and I congratulate the authors for taking the time to study their patients and report the findings to us.

Bob Carter, La Jolla, California

Although seizures are a common presenting symptom of arteriovenous malformations (AVMs), there have been few studies evaluating the risk of post-operative epilepsy following microsurgical resection. This large series of 440 patients, treated over 13 years at a high volume center by a skilled surgeon, easily provides the most definitive data to date on the topic. As was expected, the vast majority of patients with pre-operative seizures were relieved of their seizures post-operatively, while nearly all patients without seizures before surgery (97%) did not develop them following microsurgical resection. Furthermore, seizures were more common in men, those with AVMs located in the frontal or temporal lobe, larger lesions, and in patients with prior AVM rupture. Overall, this study demonstrates excellent outcomes in regard to seizure control after surgical resection. However, a review of the neurologic outcomes highlights the difficulties in successfully treating these complex lesions. Even with an experienced surgeon, Modified Rankin scores at one week after surgery demonstrated over one-quarter of patients were neurologically worse compared to before surgery, and over 5% of patients died during the peri-operative period (it must be stated, however, that 10% of the AVMs treated in this series were Spetzler-Martin grade IV or V). This study further suggests that surgical resection is an excellent treatment option both for seizure control and in reducing the risk of hemorrhage, but surgical resection remains associated with high morbidity and mortality even in modern operating theaters, highlighting the importance of patient selection for surgery given individual patient symptoms, lesion grade and complexity. The authors have provided the neurosurgical community with useful data that will help guide the management of patients with AVMs and should be congratulated for their efforts.

Kyle M. Fargen, Brian L. Hoh, Gainesville, Florida

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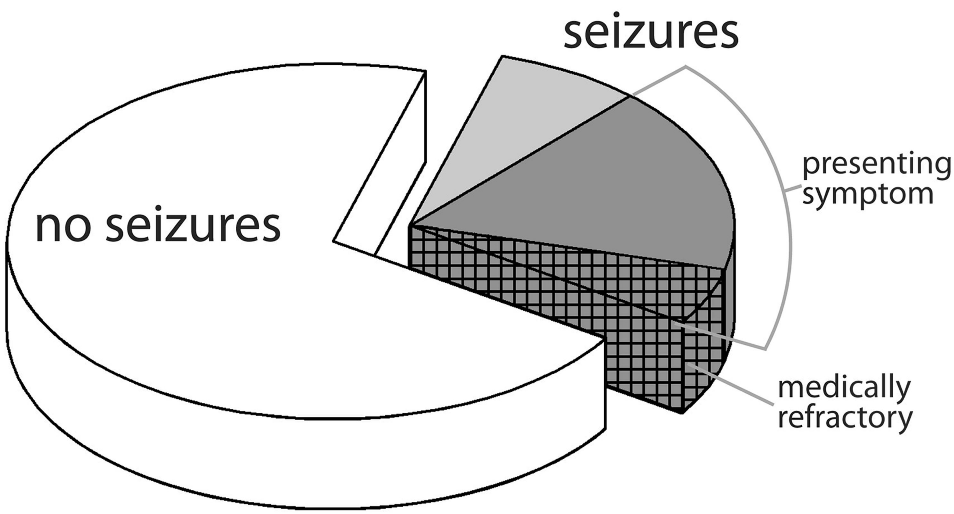

Figure 1. Incidence of pre-operative seizures among 440 patients with surgically treated supratentorial AVMs

Among 440 patients, 130 (30%) had seizures before surgery (explanted gray segments). Of these 130 patients, seizure was the presenting symptom in 98 (75%) individuals (dark grey segments), and 23 patients (18%) progressed to medically refractory epilepsy (checkered segment). All patients with medically refractory epilepsy initially presented with seizures.

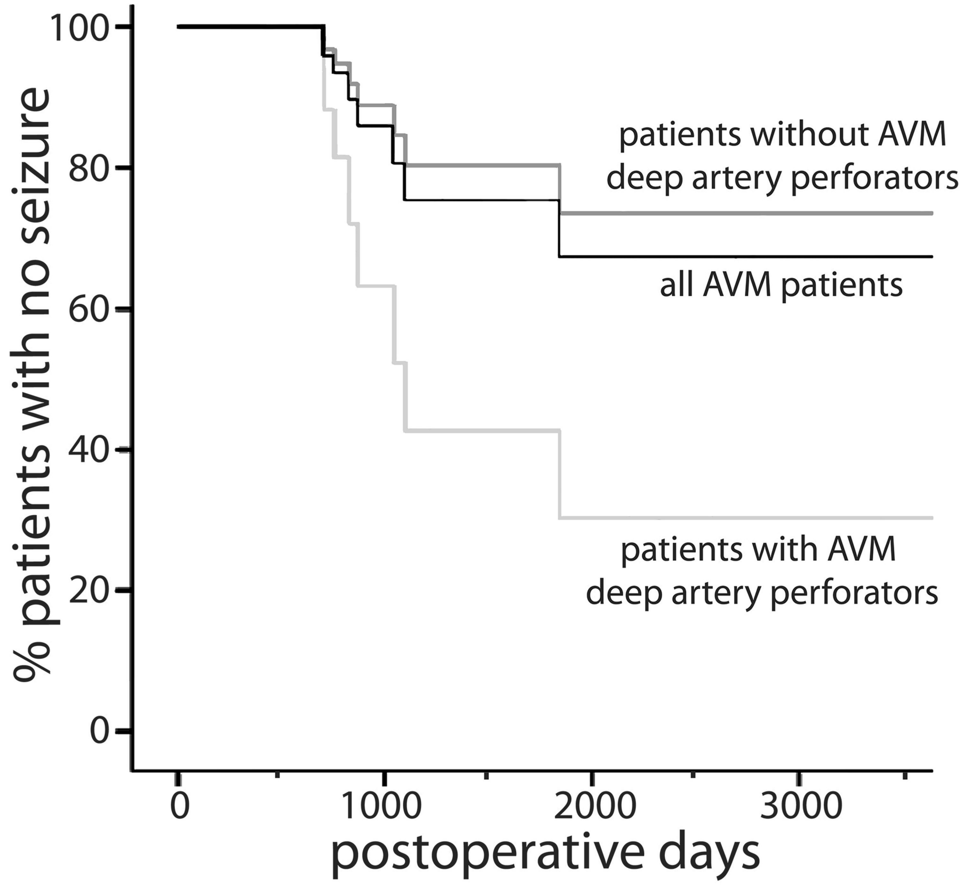

Figure 2. Post-operative seizures among patients harboring AVMs with or without deep artery perforators

Time to first seizure is plotted for all post-operative AVM patients (black line), those harboring AVMs with deep artery perforators (light gray line), and those harboring AVMs without deep artery perforators (dark gray line). Overall, AVMs with deep arterial perforators were significantly associated with post-operative seizures (HR 4.35, 95% CI 1.61-11.7). Patients who died peri-operatively are excluded.

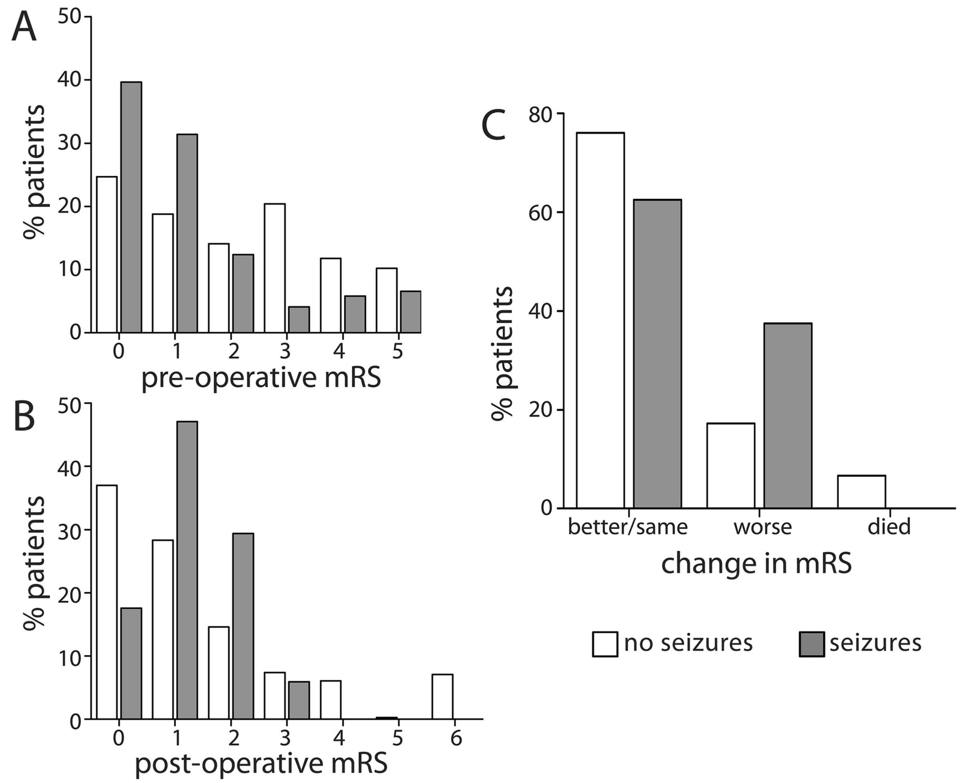

Figure 3. Pre-operative and post-operative disability among patients with and without seizures
(**A**) Prior to surgery, patients with seizures were less likely (20%) to have significant neurological disability (mRS ≥ 3) than patients without seizures (58%) ($P < 0.001$, chi-square). (**B**) Post-operatively, no difference in disability was observed between seizure-free patients versus those with continued or new seizures ($P = 0.26$, chi-square). 13% of patients had significant disability (mRS 3-5) and 24 patients (5.5%) had died (mRS 6). (C) After surgery, 76% of patients had either the same or improved mRS score, while 24% had greater disability or had died, with no significant difference observed by post-operative seizure status ($P = 0.89$, chi-square). Neurological disability was measured using the modified Rankin scale (mRS).

Table 1
Pre-operative seizure characteristics of all AVM patients

		No seizures	Seizures	P value
Age	*years*	37.5 ± 1.0	36.6 ± 1.5	0.59
Gender	Male	148 (66)	77 (34)	0.04 *
	Female	160 (75)	53 (25)	
Side	Left	128 (66)	66 (34)	0.43
	Right	117 (68)	54 (32)	
	Crosses midline	3 (100)	0 (0)	
Location	Cortical	206 (67)	101 (33)	0.50
	Cortical + SubC	35 (66)	18 (34)	
Lobe	Frontal	84 (61)	54 (39)	< 0.001 *
	Temporal	63 (66)	33 (34)	
	Parietal	50 (70)	21 (30)	
	Occipital	36 (78)	10 (22)	
	Multiple	77 (87)	12 (13)	
Grade	Grade I	51 (70)	22 (30)	0.50
	Grade II	107 (71)	43 (29)	
	Grade III	86 (66)	45 (34)	
	Grade IV	26 (62)	16 (38)	
	Grade V	3 (100)	0 (0)	
Size	*cm*	2.4 ± 0.1	3.1 ± 0.1	< 0.001 *
Deep venous drainage	Yes	100 (74)	35 (26)	0.04 *
	No	151 (63)	87 (37)	
Eloquence	Eloquent	161 (67)	79 (33)	0.58
	Non-eloquent	111 (70)	47 (30)	
Hemorrhage	Yes	138 (57)	104 (43)	< 0.001 *
	No	174 (87)	26 (13)	
Nidal diffuseness	Diffuse	27 (60)	18 (40)	0.23
	Not diffuse	215 (70)	93 (30)	
Deep artery perforators	Yes	27 (60)	18 (40)	0.13
	No	215 (70)	93 (30)	
TOTAL		310 (71)	130 (29)	

P values represent Fisher's exact test for categorical variables and t-test for continuous variables.

*Significant value (P ≤ 0.05). SubC = subcortical.

Table 2

Factors associated with pre-operative seizures in AVM patients

	RR	95% CI	*p* value
Female gender	2.07	1.26-3.39	< 0.01 *
Frontotemporal location	1.75	1.05-2.93	0.03 *
Size ≥ 3 cm	1.55	0.95-2.53	0.08
Lack of deep venous drainage	1.28	0.76-2.16	0.36
History of AVM hemorrhage	6.65	3.81-11.6	< 0.001 *

Results of multivariate logistic regression analysis. Larger relative risk (RR) indicates higher likelihood of pre-operative seizures.

* Significant value (P ≤ 0.05). CI = confidence interval.

Table 3

Post-operative seizures

		Engel class I outcome			Engel class II-IV outcome Multiple seizures	P value
		0 seizures	1 seizure	Total (0 or 1 seizure)		
Age	*years*	36.8 ± 1.0	35.0 ± 2.0	36.5 ± 0.9	33.4 ± 3.4	0.14
Gender	Male	161 (77)	41 (19)	202 (96)	8 (4)	0.81
	Female	170 (83)	25 (12)	195 (96)	9 (4)	
Side	Left	136 (75)	32 (18)	168 (93)	12 (7)	0.29
	Right	130 (80)	28 (17)	158 (97)	5 (3)	
	Crosses midline	2 (100)	0 (0)	2 (100)	0 (0)	
Location	Cortical	233 (80)	42 (15)	275 (95)	15 (5)	0.99
	Cortical + SubC	30 (63)	16 (33)	46 (96)	2 (4)	
Lobe	Frontal	94 (73)	29 (23)	123 (96)	5 (4)	0.10
	Temporal	67 (73)	17 (19)	84 (92)	7 (8)	
	Parietal	55 (85)	8 (12)	63 (97)	2 (3)	
	Occipital	38 (84)	4 (9)	42 (93)	3 (7)	
	Multiple	79 (91)	8 (9)	87 (100)	0 (0)	
Grade	Grade I	58 (81)	13 (18)	71 (99)	1 (1)	0.69
	Grade II	115 (81)	20 (14)	135 (95)	7 (5)	
	Grade III	93 (75)	23 (19)	116 (94)	7 (6)	
	Grade IV	29 (79)	6 (16)	35 (95)	2 (5)	
Size	Grade V	2 (100)	0 (0)	2 (100)	0 (0)	
	cm	2.5 ± 0.1	2.8 ± 0.2	2.5 ± 0.1	3.3 ± 0.4	0.96
Deep venous drainage	Yes	102 (82)	17 (13)	119 (95)	6 (5)	0.99
	No	171 (76)	43 (19)	214 (95)	11 (5)	
Eloquence	Eloquent	176 (79)	38 (17)	214 (96)	10 (4)	0.99
	Non-eloquent	119 (79)	25 (16)	144 (95)	7 (5)	
Hemorrhage	Yes	177 (77)	40 (18)	217 (95)	12 (5)	0.22
	No	156 (83)	26 (14)	182 (97)	5 (3)	
Nidal diffuseness	Diffuse	32 (76)	8 (19)	40 (95)	2 (5)	
	Not diffuse	233 (81)	42 (14)	275 (95)	14 (5)	

		Engel class I outcome			Engel class II-IV outcome Multiple seizures	P value
		0 seizures	1 seizure	Total (0 or 1 seizure)		
Deep artery perforators	Yes	30 (66)	8 (18)	38 (84)	7 (16)	<0.001 *
	No	303 (82)	58 (15)	361 (97)	10 (3)	
Pre-operative treatment	Embolization	161 (78)	32 (16)	193 (94)	13 (6)	0.06
	Radiosurgery	18 (86)	2 (9)	20 (95)	1 (5)	
	None	154 (81)	32 (17)	186 (98)	3 (2)	
Pre-operative seizures	Yes	76 (60)	41 (33)	117 (93)	9 (7)	0.06
	No	257 (89)	25 (8)	282 (97)	8 (3)	
Duration seizures	*weeks*	2.5 ± 0.1	2.8 ± 0.2	147 ± 36	121 ± 110	0.96
Seizures controlled on medication	Yes	62 (59)	36 (34)	98 (93)	7 (7)	0.64
	No	14 (67)	5 (24)	19 (91)	2 (9)	
Seizure type	Partial only	41 (50)	33 (40)	74 (90)	8 (10)	0.16
	Generalized	35 (80)	8 (18)	43 (98)	1 (2)	
Obliteration extent	Complete	322 (80)	64 (16)	386 (96)	17 (4)	0.99
	Incomplete	11 (85)	2 (15)	13 (100)	0 (0)	
Complication	Yes	16 (80)	4 (20)	20 (100)	0 (0)	
	No	317 (80)	62 (0)	379 (96)	17 (4)	
TOTAL		333 (80)	66 (16)	399 (96)	17 (4)	

P values represent Fisher's exact test for categorical variables and t-test for continuous variables, comparing patients with Engel I (0 or 1 seizure) versus Engel II-IV (multiple seizures) outcomes. Peri-operative deaths are excluded.

* Significant value ($P \leq 0.05$). SubC = subcortical.