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Does eloquence subtype influence outcome following arteriovenous malformation surgery?

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Abstract

OBJECTIVE—Although numerous arteriovenous malformation (AVM) grading scales consider eloquence in risk assessment, none differentiate the types of eloquence. The purpose of this study was to determine if eloquence subtype affects clinical outcome.

METHODS—This is a retrospective review of a prospectively collected clinical database of brain AVMs treated with microsurgery in the period from 1997 to 2017. The only inclusion criterion for this study was the presence of eloquence as defined by the Spetzler-Martin grading scale. Eloquence was preoperatively categorized by radiologists. Poor outcome was defined as a modified Rankin Scale (mRS) score 3–6, and worsening clinical status was defined as an increase in the mRS score at follow-up. Logistic regression analyses were performed.

RESULTS—Two hundred forty-one patients (49.4% female; average age 33.9 years) with eloquent brain AVMs were included in this review. Of the AVMs (average size 2.7 cm), 54.4% presented with hemorrhage, 46.2% had deep venous drainage, and 17.0% were diffuse. The most common eloquence type was sensorimotor (46.1%), followed by visual (27.0%) and language (22.0%). Treatments included microsurgery alone (32.8%), microsurgery plus embolization (51.9%), microsurgery plus radiosurgery (7.9%), and all three modalities (7.5%). Motor mapping was used in 9% of sensorimotor AVM cases, and awake speech mapping was used in 13.2% of AVMs with language eloquence. Complications occurred in 24 patients (10%). At the last follow-up (average 24 months), 71.4% of the patients were unchanged or improved and 16.6% had a poor outcome. There was no statistically significant difference in the baseline patient and AVM characteristics among the different subtypes of eloquence. In a multivariate analysis, in comparison to visual eloquence, both sensorimotor (OR 7.4, $p = 0.004$) and language (OR 6.5, $p = 0.015$) eloquence were associated with poor outcomes. Additionally, older age (OR 1.31, $p = 0.016$) and larger AVM size (OR 1.37, $p = 0.034$) were associated with poor outcomes.

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Disclosures
The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

CONCLUSIONS—Unlike visual eloquence, sensorimotor and language eloquence were associated with worse clinical outcomes after the resection of eloquent AVMs. This nuance in AVM eloquence demands consideration before deciding on microsurgical intervention, especially when numerical grading systems produce a score near the borderline between operative and nonoperative management.

Keywords

arteriovenous malformation; brain eloquence; modified Rankin Scale; Spetzler-Martin grading system; Lawton-Young grading system; patient selection; risk prediction; vascular disorders

Brain arteriovenous malformations (AVMs) are a heterogeneous group of intracranial vascular lesions that have a number of different management paradigms, including observation, microsurgery, radiosurgery, embolization, and, most commonly, a combination of approaches. A number of different grading scales have been developed to better understand outcomes following microsurgery,[16,25,26] radiosurgery,[22,23,28,30] and embolization.[4,5,19] The grading scales are used to understand treatment risk and to select patients for a given treatment. The most commonly used microsurgery grading scale is the Spetzler-Martin (SM) scale,[25] which grades AVMs on a scale from 1 to 5 based on size, venous drainage, and eloquence.

While the majority of these grading scales take brain eloquence into account, none of them differentiate the types of eloquence. One exception may be the radiosurgery-based grading system,[22,23] which accounts for AVM location, a surrogate for eloquence type. Thus, a patient with an AVM in the motor strip, for example, may receive the same grade as a patient with an AVM in the optic radiations. Damage to these structures can result in very different neurological deficits with potentially variable impact on overall clinical outcome. There has been some interest in the lesion-to-eloquence distance (LED),[11,12] but a study assessing the risk of resection in specific eloquence types is lacking. The purpose of this study was to determine how eloquence type affects clinical outcome. We hypothesized that the resection of AVMs that have sensorimotor eloquence can result in worse clinical outcomes than the resection of AVMs that have language, visual, or coordination eloquence.

Methods

Institutional review board approval was obtained to perform this study, which was a retrospective review of a prospectively collected clinical database of brain AVMs treated with microsurgery by the senior author at the University of California, San Francisco, in the period from August 1997 to March 2017. The only study inclusion criterion was the presence of eloquence as defined by the SM grading scale. Arteriovenous malformations that spanned multiple areas of eloquence (n = 8) were excluded. Two AVMs located in the corpus callosum were also excluded. Following exclusions, 241 patients with eloquent AVMs were identified for evaluation, which represents 30% of the total 804 AVMs resected by the senior author during the study period. Preoperatively, all patients underwent complete neurological examination, and a baseline modified Rankin Scale (mRS) score was assigned. All patients underwent CT scanning, MRI, and catheter angiography. Patients with AVMs in or near motor or sensory cortex also underwent functional MRI (fMRI) and/or magnetic source imaging (MSI). Patients with AVMs in the language cortex underwent language testing (naming, counting, reading, and verbal fluency tests) conducted by a neuropsychologist. Baseline patient and AVM data were collected by research coordinators. The AVMs were graded using both the SM scale and the Lawton-Young supplementary grading scale.[16] The following types/locations of eloquence were recorded in the database (Fig. 1): sensorimotor, language, visual, thalamic, internal capsule, basal ganglia, corpus callosum, insular, brainstem, deep cerebellar nuclei, and cerebellar peduncle. Eloquence was determined by radiologists based on preoperative MRI and angiography. For the purposes of comparison in our study, eloquence was grouped as follows: 1) sensorimotor (sensorimotor cortex, thalamus, internal capsule, basal ganglia, and brainstem), 2) visual, 3) language, and 4) coordination (deep cerebellar nuclei and cerebellar peduncle).

An overall treatment strategy for each patient was designed by a multidisciplinary team. Because data were derived from the senior author's surgical database, the overwhelming approach was surgical in nature with the goal of obtaining complete resection with or without supplemental treatments (embolization, radiation). Patients with AVMs less than 10 mm from the motor or language cortex, as determined by fMRI and/or MSI, and with normal neuropsychological language testing (> 90% proficiency) were selected for intraoperative brain mapping.[6] Imaging outcome was based on digital subtraction angiography in the vast majority of cases and on MRI in a very small number of cases. Clinical outcome was measured using the mRS. Assessments were performed by trained research coordinators under the supervision of the study neurologist. Our protocol for patients with complete re-section involved a follow-up evaluation every 6 months up to 2 years postsurgery. Patients with residual AVM were monitored annually until cure and then 2 years thereafter. Some patients were lost to follow-up. Poor outcome was defined as an mRS score 3–6 at follow-up. Worsening clinical status was defined as an increase in the mRS score at follow-up compared to the preoperative assessment.

Statistical Analysis

Patient demographic and clinical data were aggregated in Microsoft Excel (version 16, Microsoft Corp.), and statistical analyses were performed using Stata/SE 15 (StataCorp). Univariate analysis was performed to first assess the unadjusted associations of preoperative risk factors with worsened postoperative mRS score and poor outcomes as primary outcomes. To obtain adjusted risk estimates, clinically relevant variables based on previous studies (age, history of hemorrhage, AVM size, deep drainage, and diffuseness)[16,25] were included in multivariate logistic regression models. Types of eloquence were included as a single categorical variable with four values: sensorimotor, visual, language, and coordination. This model adjusted for the log of follow-up time to account for the interval from procedure to outcome assessment; this was included as a confounding variable since patients with a longer follow-up time may have better outcomes with more time to recover from surgery.

We then created another multivariate logistic regression model without types of eloquence as independent variables and compared it to the model with types of eloquence using a likelihood ratio test. All other variables (age, history of hemorrhage, AVM size, deep drainage, diffuseness, log follow-up time) remained the same between the two models. Statistical significance was established at the alpha level of $p = 0.05$. Calculations based on the cohort size to detect a 20% outcome difference for the mRS score change and poor outcome groups resulted in a power of 0.30 and 0.13, respectively; to detect a 40% outcome difference, calculations showed a power of 0.81 and 0.38, respectively.

Results

Patient and AVM Characteristics

Two hundred forty-one patients with eloquent brain AVMs were included in this review. Baseline patient and AVM characteristics are displayed in Table 1. Half the patients were female (49.4%), and the mean age at diagnosis was 33.9 years. Over half (54.4%) of the patients presented with AVM hemorrhage. The mean AVM size was 2.7 cm, and the majority of AVMs (98.3%) were 6 cm or less in size. Nearly half of the AVMs had deep venous drainage (45.6%), and a minority were diffuse (17.0%). The most common SM grade was III (46.1%), and the most common supplemented grade was 6 (34.9%). The most common eloquence type was sensorimotor (46.1%), followed by visual (27.0%) and language (22.0%). Specifically, among cortical sensorimotor AVMs (n = 77), there were 29 in the motor cortex, 31 in the sensory cortex, and 17 spanning both cortices.

Treatment and Outcome

Treatment and outcome information is displayed in Table 2. All patients were treated surgically, with 32.8% having microsurgery only, 51.9% having microsurgery with preoperative embolization, 7.9% having microsurgery and radiosurgery, and 7.5% undergoing all three treatment modalities. Of the AVMs with sensorimotor eloquence, motor mapping was performed in 9 cortically based cases (8.1%) and 1 brainstem case (0.9%). Of the AVMs with language eloquence, awake speech mapping was performed in 7 cases (13.2%). Complications occurred in 24 patients (10%). The vast majority of patients (97%) underwent postoperative angiography. Eight patients without a postoperative angiogram had an MR image. Complete AVM resection was achieved in 86.7% of patients. The average time to last follow-up was 24 months. At the last follow-up, 83.4% had a good clinical outcome (mRS score 0–2), 16.6% had a poor outcome (mRS 3–6), and 3.3% were deceased (mRS score 6). Compared to the preoperative state, 44.0% of patients had an improved mRS score, 27.4% had a stable score, and 28.6% had a worse score.

Impact of Eloquence on Clinical Outcome

There was no statistically significant difference in the baseline patient and AVM characteristics among the different subtypes of eloquence (Table 3). Complications were more common in AVM cases with coordination eloquence ($p = 0.008$).

In our univariate analysis (Table 4), AVM size ($p = 0.045$), preoperative hemorrhage ($p = 0.003$), and supplemented grade ($p = 0.003$) were all associated with worsening clinical status. The SM grade ($p = 0.037$) and eloquence subtype ($p = 0.017$) were both associated with a poor outcome. Among the patients with visual eloquence, 4.6% had a poor outcome. In comparison, 22.5% of those with sensorimotor eloquence, 17% of those with language eloquence, and 25% of those with coordination eloquence had poor outcomes. In a subgroup analysis of cortical motor AVMs (n = 29) compared to cortical sensory AVMs (n = 31), there were no statistically significant differences in either worsening clinical status (p = 0.185) or poor outcome (p = 0.655).

In our multivariate analysis (Table 5), older age (OR 1.25, p = 0.012), larger AVM size (OR 1.3, p = 0.022), and preoperative hemorrhage (OR 0.46, p = 0.012) were all associated with worsening clinical status. Similarly, older age (OR 1.31, p = 0.016) and larger AVM size (OR 1.37, p = 0.034) were associated with a poor outcome. In comparison to visual eloquence, both sensorimotor (OR 7.4, p = 0.004) and language (OR 6.5, p = 0.015) eloquence were associated with a poor outcome. While coordination eloquence had a higher risk of a poor outcome, this relationship was not statistically significant (OR 4.5, p = 0.145).

Discussion

Main Findings

Our study confirms our hypothesis that AVM eloquence subtype does, in fact, have an influence on outcome following resection. We hypothesized that sensorimotor eloquence would have a greater association with poor outcome than the other eloquence subtypes. We found that both sensorimotor and language eloquence have associations with poor outcome in comparison to visual eloquence. Our results suggest that although eloquent AVMs of the sensorimotor or language cortex may receive the same SM or supplemented grade as an otherwise equivalent AVM of the visual cortex, the risk of a poor outcome may be higher with the former.

In addition, we found that an older patient age and a larger AVM size both have associations with worsening clinical status and poor outcome, according to Lawton-Young and SM grading. Preoperative hemorrhage was protective against a worsening clinical status, which likely reflects the damage already done by the hemorrhage, not the treatment. This factor has been explored in detail in the supplemented grading system. Our results regarding coordination eloquence are likely difficult to interpret given the small number of patients and higher rate of complications in this subgroup.

Classifications of AVM

Microsurgical resection of brain AVM requires careful patient selection to avoid postoperative surgical complications and poor neurological outcomes. The wide heterogeneity of AVMs with respect to their size, anatomy, location, and patient characteristics further complicates the surgical decision-making process.[7,9,14] In recent decades, numerous classification schemes have been developed to predict the risks of AVM treatment.[4,5,16,19,22,23,25,26,28,30] Grading systems can be helpful by inviting the educated clinical gestalt of operative risk by a surgeon to be compared to an objective number that summarizes known risk factors based on large sample sizes.

First introduced in 1986, the SM grading system—a five-point scheme based on AVM size, eloquence, and deep venous drainage—is accepted as the predominant scale in predicting postoperative outcomes.[25] As research elucidated more factors contributing to AVM surgical risks,[3,15,24,27] several improvements have been proposed to increase the predictive value of the SM grading system and refine surgical patient selection.[26] One such augmentation of the SM system was the Lawton-Young supplementary grading system.[16] This supplementary system is analogous to the five-tier model of the SM system and assigns points to three additional categories: patient age, history of hemorrhage, and AVM compactness. The combined SM and supplementary grading system (or supplemented SM grade) has been shown to accurately predict neurological outcomes after AVM surgery in a multicenter cohort study of 1009 patients.[13] Our multivariate analysis, which found associations between older age, larger AVM size, or unruptured AVM status and worsening clinical status after treatment, is consistent with the previous SM and Lawton-Young supplementary grading scales. Alternative AVM classification schemes have included factors such as the Hunt and Hess grade,[8] AVM volume,[22] feeding artery supply,[8,21] and other hemodynamic factors.[21]

Some authors have broken the SM grades into components to better understand which AVMs within a given grade harbor more or less surgical risk. For instance, Lawton demonstrated that among grade III AVMs, the S1V1E1 subtype behaved similarly to grade II AVMs with a lower surgical risk, whereas the S2V0E1 subtype behaved more like high-grade AVMs with a higher surgical risk.[14] Pandey et al. demonstrated similar results in that small, grade III AVM cases (S1V1E1) had the lowest risk of developing new neurological deficits.[20] Together, these studies suggest that size may be the most important factor among grade III AVMs. Most recently, Hung et al. performed the same analysis for grade II AVMs and found that the S2V0E0 subtype had the best outcome, whereas the S1V1E0 sub-type had the worst outcome,[9] suggesting that deep venous drainage portends a worse outcome than eloquence for grade II AVMs. Even with numerous grading scales in hand, it has been shown in an online survey that there is wide variation in clinicians' opinions on which patient and/or AVM characteristics are most important for decisions regarding treatment or trial enrollment.[2]

Eloquence

Most classification systems recognize eloquence of the brain region adjacent to the nidus as an important factor and incorporate it. However, none of the grading scales differentiate the various types of eloquence: motor, speech, coordination, sensation, and vision. While the modified Pittsburgh radiosurgery-based AVM grading system accounts for location,[22] the assigned points do not differ between eloquence types specifically.

One element of eloquence that has been studied is lesion-to-eloquence distance (LED).[10–12,18] Jiao et al. recently proposed a modified grading scale in which the LED is taken into account.[12] All patients in their study underwent fMRI and diffusion tensor imaging (DTI) to determine exactly where areas of eloquence were located. An LED of 4.95 mm was the cutoff for a worsened mRS score. These findings, together with our own, suggest that more extensive functional imaging and/or tractography will be necessary to refine eloquence grading beyond what can be done with angiography and MRI. The authors evaluated a number of different grading scales based on different combinations of patient and AVM factors and found that their so-called HDVL scale—which includes hemorrhagic presentation, diffuseness, deep venous drainage, and LED—outperformed other scales and was significantly more predictive than the SM scale. This HDVL scale can be viewed as a variation of the supplemented SM grading system, which combines SM and Lawton-Young grades, with the addition of LED to measure eloquence.

Finally, certain techniques can be employed to better handle AVMs that reside within eloquent tissue. Gabarrós et al. reported on the use of language and motor mapping in a number of patients from the same database.[6] The practice was used infrequently (2.8%) but allowed the surgeon to identify functional cortex, guide dissection through normal cortex to the nidus, and limit the extent of resection in certain cases. Arteriovenous malformations can be completely dissected with occlusion of the arterial supply and then left in situ to preserve venous drainage and limit dissection in eloquent tissue. These authors concluded that indications for speech and motor mapping include preoperative functional imaging that identifies the language/motor cortex adjacent to the AVM, larger AVMs with higher SM grades, and patients presenting with unruptured AVMs without deficits. In our study, mapping was used approximately 10% of the time among AVMs with sensorimotor or language eloquence.

Our present study demonstrates that eloquence subtype does, in fact, affect outcome and that AVMs with sensorimotor and language eloquence have a greater association with a poor outcome. This nuance in AVM eloquence demands careful consideration before deciding on microsurgical intervention, especially when numerical grading systems produce a score near the borderline between operative and nonoperative management.

Study Limitations

First, the database only includes surgically treated AVMs. Difficult-to-treat eloquent AVMs with an anticipated poor outcome with resection were almost certainly selected out. Conversely, some patients with difficult-to-treat eloquent AVMs and anticipated increases in the mRS score knowingly opted in for the sake of curative AVM resection. For example, some patients with AVMs in visual cortex or sensory cortex decided to proceed with surgery because the expected visual field deficits or numbness were acceptable and preferable to the risks of AVM rupture. Therefore, surgeon and patient selection biases impact the surgical results.

Second, because a single surgeon operated on all of the AVMs, the findings may not generalize to other surgeons. Similarly, the judicious use of speech and motor mapping by the senior author may have prevented devastating deficits and ultimately impacted clinical outcomes. Third, assigning eloquence based on anatomical location may be flawed methodologically. For instance, it has been shown that eloquence can shift or translocate in the presence of AVMs[17,29] and, as discussed above, the distance from the AVM to eloquence may be the more important factor.

Conclusions

The majority of AVMs are treated with multimodality therapy. Unlike visual eloquence, sensorimotor and language eloquence were associated with worse clinical outcomes after the resection of eloquent AVMs. This nuance in AVM eloquence demands consideration before deciding on microsurgical intervention, especially when numerical grading systems produce a score near the borderline between operative and nonoperative management.

ABBREVIATIONS

AVM	arteriovenous malformation
fMRI	functional MRI
LED	lesion-to-eloquence distance
mRS	modified Rankin Scale
MSI	magnetic source imaging
SM	Spetzler-Martin

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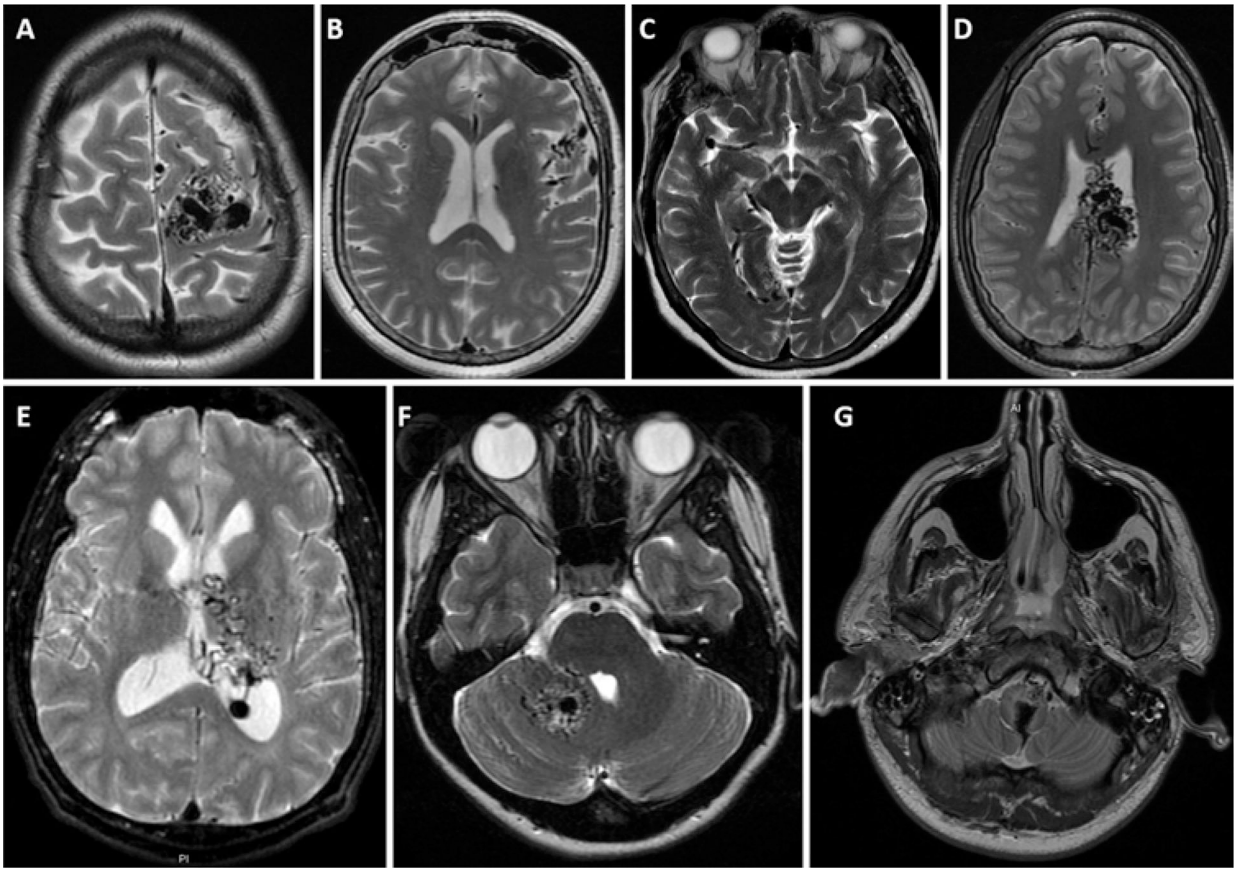

FIG. 1.
Images featuring examples of eloquence subtypes: sensorimotor (**A**), language (**B**), vision (**C**), corpus callosum (**D**), thalamic (**E**), deep cerebellar nuclei (**F**), and brainstem (**G**).

TABLE 1.

Baseline patient and AVM characteristics

Variable	No.
No. of patients	241
Mean age in yrs	33.9 ± 16.1
Age group	
Under 20 yrs	56 (23.2)
20–40 yrs	99 (41.1)
Over 40 yrs	86 (35.7)
Sex	
F	119 (49.4)
M	122 (50.6)
Mean AVM size in cm	2.7 ± 1.4
AVM size	
Under 3 cm	141 (58.5)
3–6 cm	96 (39.8)
Over 6 cm	4 (1.7)
Hemorrhage	131 (54.4)
Deep drainage	110 (45.6)
Diffuseness	41 (17.0)
Mean SM grade	2.9 ± 0.8
SM grade	
II	80 (33.2)
III	111 (46.1)
IV	47 (19.5)
V	3 (1.2)
Mean supplemented grade	5.7 ± 1.2
Supplemented grade	
3	5 (2.1)
4	31 (12.9)
5	67 (27.8)
6	84 (34.9)
7	38 (15.8)
8	11 (4.6)
9	5 (2.1)
AVM location/eloquence	
Sensorimotor eloquence	111 (46.1)
Sensorimotor cortex	77 (32.0)
Internal capsule	2 (0.8)
Basal ganglia	6 (2.5)

Variable	No.
Thalamus	13 (5.4)
Brainstem	13 (5.4)
Visual eloquence	65 (27.0)
Language eloquence	53 (22.0)
Coordination eloquence	12 (5.0)
Cerebellar peduncle	8 (3.3)
Deep cerebellar nuclei	4 (1.7)

Values are expressed as the mean ± standard deviation or as the number of patients (%).

TABLE 2.

Treatment and outcome information

Variable	No. (%)
No. of patients	241
Treatment	
Surgery alone	79 (32.8)
Surgery & embolization	125 (51.9)
Surgery & radiosurgery	19 (7.9)
Surgery, embolization, & radiosurgery	18 (7.5)
Complications	24 (10.0)
Hemorrhagic	13 (5.4)
Ischemic	5 (2.1)
Infectious	6 (2.5)
mRS score at last FU	
0–2	201 (83.4)
3–5	32 (13.3)
6	8 (3.3)
Change in mRS score	
Improved	106 (44.0)
Stable	66 (27.4)
Worse	69 (28.6)
Mean FU duration in mos	24

FU = follow-up.

TABLE 3.

Comparison of eloquence subtypes

Variable	Sensorimotor (n = 111)	Visual (n = 65)	Language (n = 53)	Coordination (n = 12)	p Value
Age (yrs)	33.4 ± 16.6	31.0 ± 14.9	36.5 ± 15.3	41.3 ± 19.8	0.531
Male sex (%)	49.6	52.3	50.9	50.0	0.988
AVM size (cm)	2.7 ± 1.3	2.8 ± 1.5	2.8 ± 1.3	2.7 ± 1.6	0.495
Deep drainage (%)	49.6	46.2	32.1	66.7	0.080
Hemorrhage (%)	58.6	55.4	43.4	58.3	0.326
Diffuseness (%)	16.2	15.4	15.1	41.7	0.140
Mean SM grade	2.9 ± 0.7	2.9 ± 0.8	2.8 ± 0.8	3.3 ± 0.8	0.487
Mean supplemental grade	5.6 ± 1.1	5.7 ± 1.3	5.8 ± 1.3	6.4 ± 1.2	0.295
Treatment (%)					0.091
Surgery alone	34.2	30.8	30.2	41.7	
Surgery & embolization	42.3	60.0	60.4	58.3	
Surgery & radiosurgery	11.7	3.1	7.6	0.0	
Surgery, embolization, & radiosurgery	11.7	6.2	1.9	0.0	
Complete resection (%)	84.7	90.8	84.9	91.7	0.630
Complications (%)	12.6	0.0	13.2	25.0	**0.008**

n = number of cases.

Boldface type indicates statistical significance.

TABLE 4.

Univariate analysis of predictors of postoperative mRS score increase and poor outcome

Variable	No mRS Score Increase	mRS Score Increase	p Value	Good Outcome (mRS score 0–2)	Poor Outcome (mRS score 3–6)	p Value
No. of patients	172	69		201	40	
Age group, no. of patients (%)			0.061			0.610
Under 20 yrs	45 (80.4)	11 (19.6)		48 (85.7)	8 (14.3)	
20–40 yrs	73 (73.7)	26 (26.3)		84 (84.8)	15 (15.2)	
Over 40 yrs	54 (62.8)	32 (37.2)		69 (80.2)	17 (19.8)	
AVM size, no. of patients (%)			**0.045**			0.163
Under 3 cm	109 (77.3)	32 (22.7)		123 (87.2)	18 (12.8)	
3–6 cm	61 (63.5)	35 (36.5)		75 (78.1)	21 (21.9)	
Over 6 cm	2 (50.0)	2 (50.0)		3 (75.0)	1 (25.0)	
Hemorrhage, no. of patients (%)	104 (79.4)	27 (20.6)	**0.003**	106 (80.9)	25 (19.1)	0.258
Deep drainage, no. of patients (%)	81 (73.6)	29 (26.4)	0.476	87 (79.1)	23 (20.9)	0.099
Diffuseness, no. of patients (%)	28 (68.3)	13 (31.7)	0.632	31 (75.6)	10 (24.4)	0.141
SM grade, no. of patients (%)			0.347			**0.037**
II	61 (76.3)	19 (23.8)		73 (91.3)	7 (8.8)	
III	77 (69.4)	34 (30.6)		91 (82.0)	20 (18.0)	
IV	33 (70.2)	14 (29.8)		34 (72.3)	13 (27.7)	
V	1 (33.3)	2 (66.7)		3 (100.0)	0 (0.0)	
Supplemented grade (%)			**0.003**			0.242
3	5 (100.0)	0 (0.0)		5 (100.0)	0 (0.0)	
4	27 (87.1)	4 (12.9)		27 (87.1)	4 (12.9)	
5	52 (77.6)	15 (22.4)		58 (86.6)	9 (13.4)	
6	61 (72.6)	23 (27.4)		71 (84.5)	13 (15.5)	
7	20 (52.6)	18 (47.4)		27 (71.1)	11 (28.9)	
8	4 (36.4)	7 (63.6)		8 (72.7)	3 (27.3)	
9	3 (60.0)	2 (40.0)		5 (100.0)	0 (0.0)	
Eloquence subtype, no. of patients (%)			0.685			**0.017**

Variable	No mRS Score Increase	mRS Score Increase	p Value	Good Outcome (mRS score 0–2)	Poor Outcome (mRS score 3–6)	p Value
Sensorimotor *	82 (73.9)	29 (26.1)		86 (77.5)	25 (22.5)	
Visual	45 (69.2)	20 (30.8)		62 (95.4)	3 (4.6)	
Language	38 (71.7)	15 (28.3)		44 (83.0)	9 (17.0)	
Coordination †	7 (58.3)	5 (41.7)		9 (75.0)	3 (25.0)	

Boldface type indicates statistical significance.

* Subtype includes sensorimotor cortex, internal capsule, basal ganglia, thalamus, and brainstem.

† Subtype includes deep cerebellar nuclei and cerebellar peduncle.

TABLE 5.

Multivariate analysis of predictors of postoperative mRS score increase and poor outcome*

	mRS Increase		Poor Outcome (mRS score 3–6)	
Variable	**OR (95% CI)**	**p Value**	**OR (95% CI)**	**p Value**
Eloquence				
Visual	1.000	Reference	1.000	Reference
Sensorimotor†	0.734 (0.356, 1.511)	0.401	7.393 (1.895, 28.843)	**0.004**
Language	0.686 (0.291, 1.616)	0.389	6.495 (1.438, 29.346)	**0.015**
Coordination‡	1.272 (0.323, 5.007)	0.731	4.543 (0.592, 34.870)	0.145
Older age (by decade)	1.250 (1.060, 1.460)	**0.012**	1.310 (1.060, 1.570)	**0.016**
Larger AVM size (per cm)	1.307 (1.040, 1.642)	**0.022**	1.372 (1.024, 1.837)	**0.034**
Deep drainage	0.858 (0.457, 1.614)	0.636	1.814 (0.801, 4.108)	0.153
Diffuseness	1.081 (0.485, 2.407)	0.849	2.127 (0.811, 5.577)	0.125
Preop hemorrhage	0.459 (0.249, 0.843)	**0.012**	1.98 (0.865, 4.533)	0.106
Log(FU)	0.611 (0.395, 0.946)	**0.027**	0.273 (0.159, 0.470)	**<0.001**

Boldface type indicates statistical significance.

*Multivariate analysis is a multiple logistic regression model adjusting for time between surgery and last mRS score assessment.

†Subtype includes sensorimotor cortex, internal capsule, basal ganglia, thalamus, and brainstem.

‡Subtype includes deep cerebellar nuclei and cerebellar peduncle.