Surgical Neurology International

OPEN ACCESS

For entire Editorial Board visit : http://www.surgicalneurologyint.com

Editor: **James I. Ausman**, MD, PhD University of California, Los Angeles, CA, USA

Original Article

A proposed grading system for endovascular treatment of cerebral arteriovenous malformations: Buffalo score

Travis M. Dumont[1,5,7], Peter Kan[1,5,8], Kenneth V. Snyder[1,2,3,4,5], L. Nelson Hopkins[1,3,4,5,6], Adnan H. Siddiqui[1,3-6], Elad I. Levy[1,3,4,5]

[1]Departments of Neurosurgery, [2]Neurology, and [3]Radiology, School of Medicine and Biomedical Sciences, [4]Toshiba Stroke and Vascular Research Center, University at Buffalo, State University of New York, [5]Department of Neurosurgery, Gates Vascular Institute, Kaleida Health, [6]Jacobs Institute, Buffalo, New York, [7]Division of Neurosurgery, Department of Surgery, The University of Arizona, Tucson, Arizona, [8]Department of Neurosurgery, University of South Florida, Tampa, Florida, USA

E-mail: Travis M Dumont - tdumont@surgery.arizona.edu; Peter Kan - pkan@health.usf.edu; Kenneth V Snyder - ksnyder@ubns.com; L. Nelson Hopkins - lnhbuffns@aol.com; Adnan H Siddiqui - asiddiqui@ubns.com; *Elad I. Levy - elevy@ubns.com
*Corresponding Author

Received: 18 November 13 Accepted: 05 September 14 Published: 07 January 15

This article may be cited as:
Dumont TM, Kan P, Snyder KV, Hopkins LN, Siddiqui AH, Levy EI. A proposed grading system for endovascular treatment of cerebral arteriovenous malformations: Buffalo score. Surg Neurol Int 2015;6:3.
Available FREE in open access from: http://www.surgicalneurologyint.com/text.asp?2015/6/1/3/148847

Abstract

Background: The Spetzler–Martin arteriovenous malformation (AVM) grading system has proven to be useful in guiding treatment of cerebral AVMs with craniotomy. It is based on anatomical characteristics each of which makes surgical resection of an AVM more difficult, namely, deep venous drainage, eloquence of surrounding tissue, and large nidus size. A higher score correlates with more complications after treatment. Although this grading system has proven reliable over time, it does not reflect the major determinants of risk associated with endovascular treatment. The authors developed a grading system unique to endovascular treatment of cerebral AVMs.

Methods: The proposed grading system accounts for the principal AVM anatomical and physiological features that make endovascular embolization more difficult and, thus, the likelihood of complications greater. These include number of arterial pedicles, diameter of arterial pedicles, and eloquent location of AVM nidus. The proposed grading system was retrospectively applied to 50 patients undergoing endovascular AVM embolization, and its ability to predict complications was compared to the Spetzler–Martin grading system.

Results: Perioperative complications among the 50 patients included 4 major and 9 minor complications. The proposed grading system was predictive of complication risk, with an increasing rate of perioperative complications associated with an increasing AVM grade. An improved correlation of perioperative complication incidence was noted with the proposed system ($P = 0.002$), when compared with the Spetzler–Martin grading system ($P = 0.33$).

Conclusion: This grading system for the endovascular treatment of AVMs is simple, easily reproduced, and clinically valuable.

Key Words: Cerebral arteriovenous malformations, complications, endovascular glue embolization

Access this article online

Website: www.surgicalneurologyint.com

DOI: 10.4103/2152-7806.148847

Quick Response Code:

INTRODUCTION

The arteriovenous malformation (AVM) grading system introduced by Spetzler and Martin in 1986[9] has proven to be useful in guiding treatment of cerebral AVMs with craniotomy.[2] It is based on anatomical characteristics, each of which makes surgical resection of an AVM more likely to result in complications, including deep venous drainage, eloquence of surrounding tissue, and nidus size. A higher Spetzler–Martin score correlates with more complications after treatment.

Although this grading system has proven reliable over time and even in prediction of deficits after endovascular treatment,[5] it does not reflect the major anatomical issues at hand in conjunction with endovascular treatment.[1,3] This is relevant, given advancements in endovascular and radiosurgical treatments that have made multimodal treatment of AVMs favorable over surgical resection alone.[10] To account for this, a separate grading system for radiosurgical treatment has been devised,[7,8] and another grading system for endovascular treatment has been suggested, although this system has not been applied or validated.[1]

A grading system to estimate the risks of endovascular treatment of AVMs should take into account the anatomical difficulties unique to that therapeutic approach. We propose a grading system, the Buffalo score, that accounts for the principal anatomical and functional AVM features that we have observed to make endovascular embolization procedures more difficult and prone to complication. Such features include the number and diameter of arterial pedicles and the anatomical (functional) location of the AVM nidus.

METHODS

Description of the grading system

Important features of AVM embolization

Endovascular treatment of an AVM requires microcatheter selection of an artery feeding directly into the AVM. A liquid embolic agent is then delivered directly into the AVM directed at embolization of the abnormal vasculature. Hazards of treatment come from selective catheterization of the targeted artery or embolization of arterial supply to normal brain tissue. The proposed grading system is based on a combination of factors that make the likelihood of complication greater: Number of arterial pedicles, diameter of arterial pedicles, and eloquent location of the AVM nidus. These factors were chosen based on the operative experience of the authors and others and are discussed in detail.

Graded variables

Number of arterial pedicles

The number of arterial pedicles is estimated based on angiography. The number of arterial pedicles is determined to be 1-2, 3-4, or 5 or more and is based on an estimation of the number of arterial pedicles contributing flow into the AVM nidus. Embolization of each arterial pedicle essentially comprises a separate surgical approach as, with each embolization, the microcatheter must be removed and replaced for another arterial pedicle embolization. Whether performed during one prolonged procedure or in staged fashion, each microcatheterization and embolization carries technical risks of arterial dissection or wire perforation, as well as potential neurological damage. Thus, with an increasing number of arterial pedicles, the risk of procedural complications increases.

Arterial pedicle diameter

The diameter of arterial pedicles is estimated on the basis of angiography. Arterial pedicles are determined to be mostly large (diameter >1 mm) or small (diameter ≤1 mm). This measurement is assessed at a distal segment of the arterial pedicle, within 1 cm of the AVM nidus. A smaller vessel caliber will make catheterization-related complication more likely, as a more delicate vessel is more prone to injury during wire manipulation. In addition, reflux of glue polymer may be more likely, with less penetration into the AVM nidus owing to blood flow demand.

Eloquent location

Eloquent location of the AVM nidus is determined based on nidus location on angiography and correlated to noninvasive magnetic resonance imaging. Eloquent location of the AVM nidus is defined according to the grading system of Spetzler–Martin.[9] Any portion of the AVM nidus located within the motor or sensory cortex areas, including language and vision, as well as deep eloquent areas comprising the hypothalamus, thalamus, brainstem, and cerebellar peduncles, is considered eloquent in location. With arterial embolization of an AVM, embolysate may be inadvertently injected to a nearby or en passage vessel supplying normal brain. Such inadvertent embolization is more likely to cause a neurological deficit if the AVM is situated in eloquent cortex.

Determination of grade

The grade of the AVM is calculated by determining the individual scores of arterial pedicle number, arterial pedicle diameter, and eloquent brain location. A numerical value is assigned to each of the categories [Table 1], and the grade is determined by summing the points assigned to each category. The lowest possible score is Grade I; such a lesion would have a single, large arterial pedicle in noneloquent cortex. The highest possible score is Grade V; such a lesion would have five or more arterial pedicles, mostly ≤1 mm in diameter and be located within eloquent cortex. Other gradations comprise variations of arterial pedicle number (N), pedicle diameter (D), and eloquence of adjacent cortex

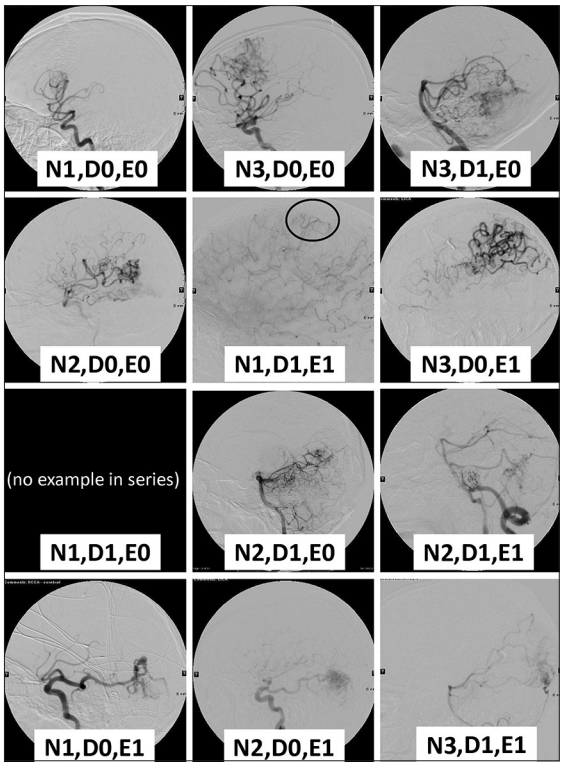

Figure 1: Lateral views of early arterial phase angiograms display examples of possible grades from the series of 50 patients retrospectively tested with the proposed grading system. No patients treated had an arteriovenous malformation (AVM) with 1 or 2 small vessels and noneloquence of adjacent brain, and thus an example of this is not shown. N: Number (of arterial pedicles); D: Diameter (of arterial pedicles); E0: Noneloquence; E1: Eloquence

(E). Angiograms displaying examples of the grades of the proposed system are shown in Figure 1. Schematic representations of the features and grades of the proposed system and the Spetzler–Martin scheme are provided in Figure 2a and b, respectively, for the purpose of comparison.

Application of the grading system

To test the predictive value of this grading scale, we conducted a retrospective analysis of 50 consecutive cases of AVMs in which patients were treated at our hospital between January 2006 and December 2011. Embolization was performed with the intention of cure in all cases, although in most cases this was not possible. We attempted catheterization and obliteration of all AVM pedicles until cure was achieved or when the treating physician felt that the risk of endovascular treatment was outweighed by the potential benefit, in which case adjunctive treatment with stereotactic radiosurgery or surgical resection was performed. At our hospital, endovascular embolization of one or two pedicles is generally performed at 6-week intervals for patients requiring multiple embolization procedures. Patients were generally treated under conscious sedation unless patient safety mandated intubation for the procedure. A superselective Wada test is performed to assess the eloquence of each pedicle prior to embolization, as previously described.[11] Liquid embolic agents are used for nearly all arterial pedicles embolized. At our hospital, we favor Onyx (Covidien, Mansfield MA) as the

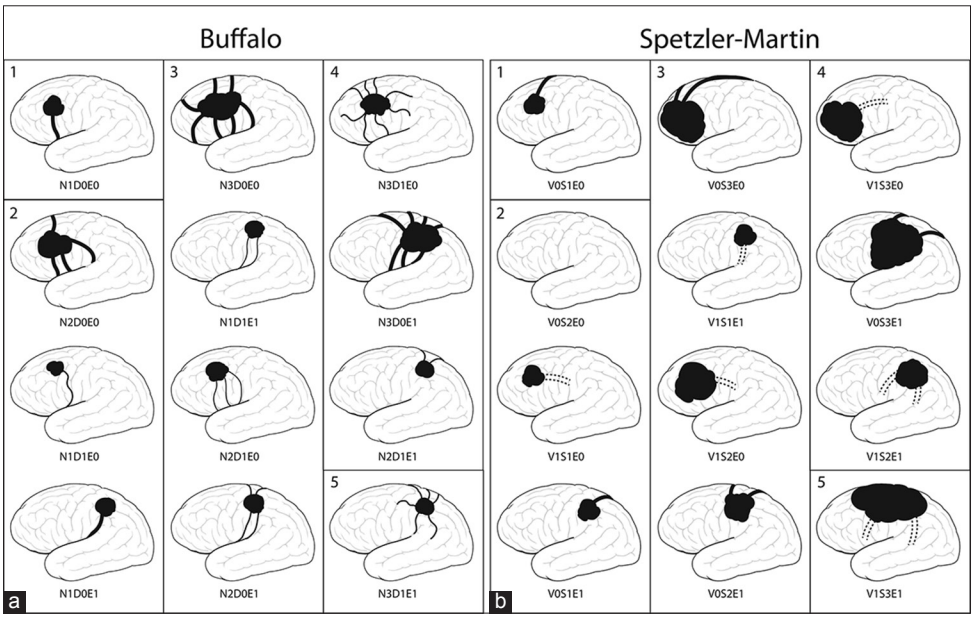

Figure 2: (a) The Buffalo system takes into account the following features: Number of arterial pedicles (N), diameter of those pedicles (D), and eloquent location (E). This schematic representation of supratentorial AVMs provides examples of different AVM types and the grade (1-5) determined by summing the points for each graded feature. In this figure, arterial pedicles and nidus are represented by black lines and shading, respectively. A higher complication incidence would be expected for patients with a higher score. See also Table 1. (b) The Spetzler–Martin system takes into account the features of venous drainage (V), size (S), and eloquence (E). This schematic representation of supratentorial AVMs provides examples of different AVM types and the grade (1-5) determined by summing the points for each graded feature. In this schematic, the AVM nidus is represented with black shading and draining veins are represented with lines (dashed lines represent deep drainage whereas solid lines represent superficial drainage). A higher complication incidence would be expected for patients with a higher score. See also table 1

liquid embolic agent of choice; however, we frequently employ n-butyl cyanoacrylate (NBCA) in cases where the microcatheter is not delivered into an ideally distal position proximal to the AVM nidus, as we have had superior penetration of the AVM nidus with NBCA in this setting. Patients presenting with AVM-related hemorrhage were treated during the presenting hospitalization if high-flow characteristics, such as a prenidal aneurysm, associated arteriovenous fistula, or venous outlet stenosis, were encountered on angiography (defined below).

Each AVM was graded according to the Spetzler–Martin scheme[9] as well as the proposed grading scale [Table 1]. All patients underwent biplane cerebral digital subtraction angiography, and graded variables were derived from preoperative imaging. AVM nidus size, venous drainage pattern, and eloquence were calculated based on the criteria of the Spetzler–Martin grading system.[9] Number of arterial pedicles and pedicle diameter were estimated based on angiography, and classified according to the proposed grading system. Other relevant or potentially relevant clinical variables analyzed include age,[3] presentation (presence of hemorrhage or seizure at time of initial presentation), presence of neurological deficits at the time of the initial embolization procedure,[3] and abnormal angioarchitectural structures.[4] Abnormal angioarchitectural structures included prenidal aneurysm, fistulous or "high-flow" component[4] (defined according to the criteria of Yuki *et al.*),[13] or venous outlet stenosis (defined as >50% narrowing of a draining vein on cerebral angiography). Other demographic data and anatomical characteristics previously noted to be correlated with perioperative complications or morbidity were noted and included age,[3] perioperative hemorrhage,[6] and lack of neurological deficit at baseline.[3] All complications, including intraoperative and postoperative events, were noted and tabulated for each grade for both grading systems and reported as a percentage. Complications were arbitrarily deemed "major" complications if the result was a permanent neurological deficit or death. Other complications were considered "minor" complications and were temporary.

Table 1: Determination of cerebral arteriovenous malformation grade according to the proposed (Buffalo) grading system

Graded feature	Points assigned
Number of arterial pedicles	
1 or 2	1
3 or 4	2
5 or more	3
Diameter of arterial pedicles	
Most>1 mm	0
Most≤1 mm	1
Nidus location	
Noneloquent	0
Eloquent	1

AVM grade= [number] + [diameter] + [nidus location]

Spetzler-Martin classification of cerebral arteriovenous malformations

Graded feature	Points assigned
Size	
Small (<3 cm)	1
Medium (3-6 cm)	2
Large (>6 cm)	3
Eloquence of adjacent brain	
Noneloquent	0
Eloquent	1
Venous drainage pattern	
Superficial only	0
Deep	1

AVM Grade = [size] + [eloquence] + [venous drainage]; that is [1, 2, or 3] + [0 or 1]+ [0 or 1]. Adapted from Spetzler RF, Martin NA: A proposed grading system for arteriovenous malformations. *J Neurosurgery* 65:478, 1986. AVM: Arteriovenous malformation

Complete obliteration of the AVM was defined as no evident contrast filling of preexistent AVM nidus and absence of early venous draining on a catheter angiogram that was performed at least 3 months after the last embolization. Cases without complete obliteration were assessed for percentage of embolization of the original nidus by two of the authors (TMD and PK). As this is a somewhat subjective measurement, no statistical assessment was made with respect to this outcome, although this data is provided as an approximate measure of completeness of obliteration in the series.

Independent variables and the grading systems were analyzed for predictive value of complications and tested for statistical significance with Fisher's Exact test or analysis of variance. Independent variables found to be significant to $P < 0.20$ were included in a multivariate analysis. Data were analyzed with SAS 9.2 (SAS Institute Inc., Cary, NC). The local institutional review board approved this study.

The test group consisted of 50 consecutive patients treated with endovascular AVM embolization [Table 2]. Most patients were men (54%), with varied presentation overall (including hemorrhage in 44% and seizure in 27%). Endovascular embolization with a goal of AVM obliteration was performed in all patients. A total of 194 arterial pedicles were embolized in 177 procedures, with an additional 21 planned pedicle embolizations aborted for the following reasons: Inadequate catheter position (14 cases), patient inability to cooperate (3 cases), positive Wada test (3 cases), or iatrogenic vessel injury (1 case). Embolic material used in the completed procedures was Onyx (78% of cases), NBCA (56% of cases), and detachable coils (4% of cases). The median number of pedicles embolized was 3.5, with a minimum of 1 pedicle (in 8 patients) and a maximum of 11 pedicles (in 1 patient). In the course of treatment of these

Table 2: Details of the test cases

Case	Age (years), gender	Pres. with hemorrhage	Pres. with neuro. deficit	Atypical features	Size (S-M)	Drainage (S-M)	Eloquence (S-M)	Pedicle diameter (Buffalo)	Pedicle no. (Buffalo)	Total S-M	Total Buffalo	Embolysate (s)	Complication	Complete obliteration
1	37, M	No	Yes	No	3	0	1	1	3	4	5	Onyx, NBCA	None	Yes
2	44, M	Yes	Yes	No	1	0	0	1	2	1	3	Onyx	(Minor) arterial dissection without neuro. deficit	Yes
3	62, M	Yes	No	No	1	0	0	0	2	1	2	NBCA	None	No
4	37, M	No	No	No	2	0	0	0	1	2	1	Onyx, NBCA	None	No
5	18, F	No	No	No	3	1	0	1	3	4	4	Onyx, NBCA	None	No
6	49, F	No	No	No	3	0	0	1	3	3	4	NBCA	(Minor) perforation of arterial pedicle without neuro. deficit	No
7	56, F	Yes	No	Aneurysm	2	1	0	1	3	3	4	Coil, Onyx	(Minor) neuro. deficit, resolved	No
8	43, F	No	No	No	3	1	1	0	1	5	2	NBCA	None	No
9	21, M	Yes	Yes	No	3	1	1	0	3	5	4	NBCA	(Minor) arterial dissection without neuro. deficit	No
10	23, M	No	No	Fistula	3	0	1	0	2	4	3	Onyx, NBCA	None	No
11	45, F	Yes	Yes	No	2	0	0	0	1	2	1	Onyx	None	No
12	29, F	No	No	No	2	0	0	0	1	2	1	Onyx, NBCA	None	No
13	30, F	Yes	No	No	2	1	0	0	2	3	2	Onyx, NBCA	None	No
14	38, M	No	No	No	2	0	1	0	3	3	4	Onyx, NBCA	None	No
15	40, M	No	No	No	3	1	1	1	3	5	5	Onyx, NBCA	(Major) hemorrhage resulting in death	No
16	45, M	Yes	Yes	Fistula	1	0	1	0	1	2	2	NBCA	None	No
17	49, M	No	No	No	3	0	1	0	3	4	4	Onyx, NBCA	(Major) right-hand weakness	No
18	50, F	Yes	Yes	No	2	0	0	1	2	2	3	Onyx, NBCA	None	No
19	39, M	No	No	No	2	1	0	0	2	3	2	Onyx	None	No
20	51, F	Yes	Yes	No	3	1	0	0	3	4	3	Onyx	None	No
21	57, M	No	Yes	Fistula	3	1	1	0	3	5	4	Onyx	None	No
22	34, F	No	No	No	2	0	1	0	2	3	3	Onyx	None	No
23	44, M	Yes	Yes	No	2	1	0	0	3	3	3	coil, Onyx	None	No
24	51, F	No	No	No	1	1	0	1	2	2	3	Onyx, NBCA	None	No

Contd....

Table 2: Contd....

Case	Age (years), gender	Pres. with hemorrhage	Pres. with neuro. deficit	Atypical features	Size (S-M)	Drainage (S-M)	Eloquence (S-M)	Pedicle diameter (Buffalo)	Pedicle no. (Buffalo)	Total S-M	Total Buffalo	Embolysate (s)	Complication	Complete obliteration
25	26, M	No	No	No	2	0	1	0	3	3	4	NBCA	(Minor) neuro. deficit, resolved	No
26	33, M	No	No	No	2	1	1	0	2	4	3	Onyx, NBCA	(Major) hemianopsia	No
27	51, F	No	No	No	2	1	0	0	2	3	2	NBCA	None	No
28	51, M	Yes	Yes	No	1	0	1	0	2	2	3	Onyx	None	No
29	49, F	No	No	No	2	0	0	1	3	2	4	NBCA	(Minor) arterial dissection without neuro. deficit	No
30	58, M	Yes	Yes	No	1	0	0	0	2	1	2	Onyx	None	No
31	34, F	No	No	No	3	1	0	1	3	4	4	Onyx, NBCA	None	No
32	59, F	No	No	No	1	1	0	0	1	2	1	Onyx	None	No
33	25, F	Yes	No	No	2	1	0	1	2	3	3	Onyx	None	No
34	19, F	Yes	Yes	No	1	0	0	0	3	1	3	Onyx	None	No
35	33, F	No	No	No	2	0	0	0	2	2	2	NBCA	None	No
36	19, M	No	No	No	3	0	0	1	3	3	4	Onyx, NBCA	None	No
37	30, F	No	No	No	3	1	1	0	3	5	4	Onyx	None	No
38	31, F	Yes	No	No	3	0	1	0	3	4	4	NBCA	(Minor) perforation of arterial pedicle without neuro. deficit	Yes
39	43, M	Yes	No	No	3	0	0	1	3	3	4	Onyx, NBCA	None	No
40	51, M	Yes	Yes	Aneurysm	3	1	0	0	2	4	2	Onyx	None	Yes
41	57, M	No	No	Outflow stenosis	2	0	0	1	3	2	4	Onyx	(Minor) neuro. deficit, resolved"	No
42	55, M	Yes	Yes	No	1	0	0	0	2	1	2	Onyx	None	No
43	18, M	No	No	No	2	0	1	1	2	2	4	Onyx, NBCA	None	No
44	52, F	No	No	No	2	1	0	1	1	3	2	NBCA	None	No
45	31, M	Yes	Yes	No	3	1	0	0	2	4	2	Onyx	None	No
46	19, M	No	No	No	3	0	1	1	3	4	5	Onyx	(Major) hemorrhage resulting in hemiparesis	No
47	55, F	Yes	Yes	Aneurysm	2	1	1	1	3	4	5	Onyx	(Minor) acute renal failure	No
48	83, M	Yes	Yes	No	1	1	0	0	3	2	3	Onyx	None	No
49	43, M	Yes	Yes	Aneurysm	2	0	0	1	2	2	3	Onyx, NBCA	None	Yes
50	20, F	No	No	No	3	1	0	0	3	4	3	Onyx	None	No

Buffalo: Buffalo (proposed) score, NBCA: N-butyl cyanoacrylate, neuro.: Neurologic, no.: Number, pres.: Presentation, S-M: Spetzler-Martin score, y: Year, Total S-M Score = size + drainage + eloquence, Total Buffalo score = pedicle diameter + pedicle no. + S-M eloquence, M: Male, F: Female

patients, a total of 13 complications were encountered, of which 4 were major and 9 were minor [Table 2].

Table 3: Univariate analysis of case features comparing cases with and without complications

Feature	Cases without complications (*n*=37)	Cases with complications (*n*=13)	*P* value
Age	40.8+14.7 y	40.7+13.4 y	1.00
Male	19 (51%)	8 (62%)	0.75
Hemorrhage at presentation	17 (46%)	5 (38%)	0.75
Neurologic deficits	15 (41%)	3 (23%)	0.33
S-M size			0.43
<3 cm	9 (24%)	1 (8%)	
3-6 cm	15 (41%)	6 (46%)	
>6 cm	13 (35%)	6 (46%)	
S-M deep drainage	18 (49%)	5 (38%)	0.74
S-M eloquence	10 (27%)	8 (62%)	**0.04**
Small pedicle diameter	11 (30%)	8 (62%)	**0.05**
Pedicle number			**0.01**
1 or 2	7 (19%)	0 (0%)	
3 or 4	17 (46%)	2 (15%)	
>5	13 (35%)	11 (85%)	
Atypical features	5 (14%)	3 (23%)	0.66

S-M: Spetzler-Martin grading system, y: Years. Bold font represents statistical significance

Table 4: Multivariate analysis of case features as correlates of procedural complications

Variable	Coefficient (B)	Standard error	Wald	*P* value	Odds ratio
Intercept	18	1.1	256	0	
Eloquence	1.93	0.92	4.4	**0.036**	6.90
Small pedicle diameter	1.69	0.92	3.32	0.068	5.35
3-4 pedicles	1.69	0.92	455	**<0.001**	3.42E+08
5 or more pedicles	19.7			**<0.001**	6.39E+07

Bold font designates statistical significance

RESULTS

In the test group, independent variables found to be correlated with complications included number of pedicles ($P = 0.01$), eloquent location ($P = 0.04$), and small pedicle diameter ($P = 0.05$) [Table 3]. In univariate analysis, these factors were found to be robust predictors for complication incidence. Features of the Spetzler–Martin grading system other than eloquent location,[9] namely, deep venous drainage ($P = 0.74$) and AVM diameter ($P = 0.43$), were not found to be independently correlated with perioperative complications. Several other independent variables previously noted to be correlated with perioperative complications by other authors were not found to be correlated with perioperative complications in the test group and included patient age in years ($P = 1.0$), lack of neurologic deficits at baseline ($P = 0.33$), and preprocedural hemorrhage ($P = 0.75$). Of additional note, no significant correlation to perioperative complications and abnormal angioarchitectural structures was found ($P = 0.66$). This is summarized in Table 3. In multivariate analysis, number of pedicles and eloquent location were found to be significant prediction variables for complications in the test group, whereas vessel diameter was not [Table 4].

The incidence of complications was tabulated for each AVM score [Table 5]. Complication rates were seen to increase with increasing grade in the proposed grading system ($P<0.0001$) but not the Spetzler–Martin system ($P = 0.28$). In the test cohort, the complication rate for each grade in the proposed scoring system is as follows: Grades 1 and 2, 0%; Grade 3, 14%; Grade 4, 50%; and Grade 5, 75%.

Complete obliteration was accomplished in 5 patients (10%), with >90% obliteration in 17 patients (34%) and >75% obliteration in 21 patients (42%) [Table 5]. Fifty

Table 5: Incidence of complications and endovascular cure tabulated according to arteriovenous malformation grading systems

Grade		Complications			Obliteration			
	N	Minor	Major	Overall complication rate/grade (%)	Complete	>75-99%	50-75%	<50%
Spetzler-Martin								
I	5	1	0	20	1	3	1	0
II	14	2	0	14	1	8	2	0
III	13	3	0	23	0	7	6	4
IV	14	2	3	38	3	1	5	3
V	5	1	1*	40	0	2	2	1
Proposed								
I	4	0	0	0	0	2	1	0
II	12	0	0	0	1	6	4	1
III	14	1	1	14	2	4	5	3
IV	16	7	1	50	1	8	5	2
V	4	1	2*	75	1	1	1	2

*includes 1 death. *N*: Number of patients

percent or more obliteration was obtained in all but eight cases. No obvious correlation between complete endovascular obliteration and Buffalo grade ($P = 0.51$) or Spetzler–Martin grade ($P = 0.99$) was evident. Definitive treatment included stereotactic radiosurgery in 27 patients and surgical resection in 14 patients. Four patients were not offered adjunctive therapies due to perceived futility.

DISCUSSION

The contemporary multimodality AVM treatment paradigm has resulted in new issues in operative management. In conjunction with surgical resection of an AVM, deep venous drainage, eloquence of surrounding tissue, and nidus size are of greatest import, and thus comprise the Spetzler–Martin grading system. In endovascular treatment, we have found the diameter of arterial pedicles, number of arterial pedicles, and eloquent nidus location to be of greatest significance for complications, and thus these variables comprise the proposed grading system. The proposed grading system is simple in design, based on angiographic and magnetic resonance features, and valuable in prediction of complications.

In this series, the value of the Spetzler–Martin grading system is reduplicated for AVM treatment, as the incidence of complications was greater in grades IV and V AVMs compared with lower-grade AVMs [Table 5]. However, a better correlation between grade and complications was noted in the proposed grading system. The utility of a new AVM grading system for endovascular treatment is in cases where the Spetzler–Martin grade is very high but the grade in the proposed grading system is low, or vice-versa. Two cases illustrate the utility of the proposed grading system. Case 29, with superficial drainage, intermediate nidus size (5 cm), and noneloquent location, is a Spetzler–Martin grade II AVM. However, with more than 5 mostly small arterial pedicles, it is a proposed grade IV AVM. A minor complication was encountered with incomplete embolization of this AVM. Thus, one could argue that with low risk for surgical resection (expected rate of minor deficit, 5%)[9] and relatively high risk with embolization (among the proposed grade IV patients in the present series: Incidence of major complication, 6%; incidence of any complication, 50%), surgical resection without embolization should have been performed preferentially. Conversely, Case 40 with noneloquent location, deep venous drainage, and diameter greater than 6 cm, is a Spetzler–Martin grade IV AVM. However, with only two large arterial pedicles, it is a proposed grade II AVM. This AVM was treated with two embolization procedures with complete obliteration without complication. Given its grade in the proposed system, the risk of neurological deficit or any complication is low (among the proposed grade II patients in the present series: Incidence of any complication, 0%) compared with the risk of surgery given its Spetzler–Martin grade (27% risk of any neurological deficit).[9]

The proposed grading system is based on the observed risk with endovascular treatment of AVMs. Simply stated, smaller vessels are more prone to injury with catheterization, a greater number of arterial pedicles produces more potential risk with each embolization, and eloquent location increases risk of neurological deficit. The actual size of the AVM nidus and venous drainage pattern of the AVM are of less importance during endovascular embolization but of chief importance during surgical resection. The proposed grading scheme provides a simple confluence of these concepts that will enable neurointerventionists to estimate the risk of endovascular AVM embolization.

Limitations

Limitations of the grading scheme include no prospective assessment to date and no evident correlation with complete endovascular obliteration. Of additional note, in multivariate analysis, the most relevant factor was number of arterial pedicles, whereas small pedicle diameter was not a significant factor in multivariate analysis (although it was in univariate analysis). We suspect this may be an artifact of small sample size (type II error), and we consider small vessel caliber as an important consideration when planning an embolization procedure as this feature when present typically results in more difficult microcatheterization. Furthermore, this experience is limited to a high-volume center and may not be accurate when applied universally. However, it should be noted that with the technology presently available for endovascular AVM embolization, the anticipated rate of complete obliteration is on the order of 10%.[12] Thus, a grading scheme to predict complete obliteration is of less importance. Prospective assessment of this grading scheme is planned.

CONCLUSION

The proposed grading system for endovascular treatment of cerebral AVMs is simple, easily reproduced, and clinically relevant.

ACKNOWLEDGMENTS

The authors thank Paul H. Dressel BFA for preparation of the illustrations and Debra J Zimmer for editorial assistance. Dr. Dumont and Dr. Kan: Nothing to disclose. Dr. Hopkins receives grant/research support from Toshiba; serves as a consultant to Abbott, Boston Scientific, Cordis, Micrus, and Silk Road; holds financial interests in AccessClosure, Augmenix, Boston Scientific, Claret Medical, Endomation, Micrus, and Valor Medical; holds a board/trustee/officer position with Access Closure and Claret Medical; serves on Abbott Vascular's speakers' bureau; and has received honoraria from Bard, Boston Scientific, Cleveland Clinic,

Complete Conference Management, Cordis, Memorial Health Care System, and SCAI. Dr. Levy has shareholder/ownership interests in Intratech Medical Ltd., and Blockade Medical LLC. He serves as a principal investigator for the Covidien US SWIFT PRIME Trials. He receives compensation from Abbott for carotid training for physicians. Dr. Siddiqui has received research grants from the National Institutes of Health (co-investigator: NINDS 1R01NS064592-01A1, Hemodynamic induction of pathologic remodeling leading to intracranial aneurysms and co-investigator NIBIB 5RO1EB002873-07, Micro-Radiographic Image for Neurovascular Interventions), and the University at Buffalo (Research Development Award) (none of the grants are directly related to the present work); holds financial interests in Hotspur, Intratech Medical, StimSox, Valor Medical, Blockade Medical, and Lazarus Effect; serves as a consultant to Blockade Medical, Codman & Shurtleff, Inc., Concentric Medical, ev3/Covidien Vascular Therapies, GuidePoint Global Consulting, Lazarus Effect, MicroVention, Penumbra, Inc., Stryker Neurovascular and Pulsar Vascular; belongs to the speakers' bureaus of Codman & Shurtleff, Inc. and Genentech; serves on National Steering Committees for the following company-sponsored trials: 3D Separator (Penumbra, Inc.), FRED (Microvention), and SWIFT PRIME (Covidien); serves on advisory boards for Codman & Shurtleff and Covidien Neurovascular; and has received honoraria from Abbott Vascular and Codman & Shurtleff, Inc. for training other neurointerventionists in carotid stenting and for training physicians in endovascular stenting for aneurysms. Dr. Siddiqui receives no consulting salary arrangements. All consulting is per project and/or per hour. Dr. Snyder serves as a consultant to, a member of the speakers' bureau, and has received honoraria from Toshiba. He serves as a member of the speakers' bureau for and has received honoraria from ev3/Covidien and The Stroke Group.

REFERENCES

1. Feliciano CE, de Leon-Berra R, Hernandez-Gaitan MS, Rodriguez-Mercado R. A proposal for a new arteriovenous malformation grading scale for neuroendovascular procedures and literature review. P R Health Sci J 2010;29:117-20.
2. Hamilton MG, Spetzler RF. The prospective application of a grading system for arteriovenous malformations. Neurosurgery 1994;34:2-7.
3. Hartmann A, Pile-Spellman J, Stapf C, Sciacca RR, Faulstich A, Mohr JP, *et al*. Risk of endovascular treatment of brain arteriovenous malformations. Stroke 2002;33:1816-20.
4. Haw CS, terBrugge K, Willinsky R, Tomlinson G. Complications of embolization of arteriovenous malformations of the brain. J Neurosurg 2006;104:226-32.
5. Kim LJ, Albuquerque FC, Spetzler RF, McDougall CG. Postembolization neurological deficits in cerebral arteriovenous malformations: Stratification by arteriovenous malformation grade. Neurosurgery 2006;59:53-9.
6. Ledezma CJ, Hoh BL, Carter BS, Pryor JC, Putman CM, Ogilvy CS. Complications of cerebral arteriovenous malformation embolization: Multivariate analysis of predictive factors. Neurosurgery 2006;58:602-11.
7. Pollock BE, Flickinger JC. Modification of the radiosurgery-based arteriovenous malformation grading system. Neurosurgery 2008;63:239-43.
8. Pollock BE, Flickinger JC. A proposed radiosurgery-based grading system for arteriovenous malformations. J Neurosurg 2002;96:79-85.
9. Spetzler RF, Martin NA. A proposed grading system for arteriovenous malformations. J Neurosurg 1986;65:476-83.
10. Strozyk D, Nogueira RG, Lavine SD. Endovascular treatment of intracranial arteriovenous malformation. Neurosurg Clin N Am 2009;20:399-418.
11. Tawk RG, Tummala RP, Memon MZ, Siddiqui AH, Hopkins LN, Levy EI. Utility of pharmacologic provocative neurological testing before embolization of occipital lobe arteriovenous malformations. World Neurosurg 2011;76:276-81.
12. van Beijnum J, van der Worp HB, Buis DR, Al-Shahi Salman R, Kappelle LJ, Rinkel GJ, *et al*. Treatment of brain arteriovenous malformations: A systematic review and meta-analysis. JAMA 2011;306:2011-9.
13. Yuki I, Kim RH, Duckwiler G, Jahan R, Tateshima S, Gonzalez N, *et al*. Treatment of brain arteriovenous malformations with high-flow arteriovenous fistulas: Risk and complications associated with endovascular embolization in multimodality treatment. Clinical article. J Neurosurg 2010;113:715-22.