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Review Article

Cerebral arteriovenous malformations classification systems in comparison with Spetzler-Martin: A comparative review

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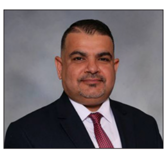

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ABSTRACT

Background: Arteriovenous malformations (AVMs) are complex vascular anomalies requiring classification systems to guide treatment and predict outcomes. This review evaluates multiple AVM classification systems, including the widely used Spetzler-Martin Grading System (SMGS), emphasizing their importance in neurosurgery for improving clinical decision-making and communication.

Methods: We conducted a literature search using Google Scholar, PubMed, and Scopus to gather information on AVM classification systems. Our inclusion criteria involved articles that referenced a well-established classification system with at least two components. Radiological, surgical, and clinical outcomes systematically categorized nine distinct AVM grading systems. The review focuses on comparing the advantages and limitations of different AVM classification systems to the SMGS.

Results: A review of 33 articles highlights the evolution of AVM classification systems, with the SMGS as a foundation for surgical outcomes. Systems such as the Pollock-Flickinger and Pittsburgh AVM scale improve radiosurgery predictions, while Lawton-Young adds factors for surgical precision. Specialized scores refine grading for specific cases, and simplified systems like Spetzler-Ponce enhance usability in unique contexts.

Conclusion: AVM classification systems, including Spetzler-Martin, Pollock-Flickinger, and Lawton-Young, provide critical insights into treatment and prognosis. While Spetzler-Martin effectively predicts surgical outcomes, systems like Lawton-Young enhance accuracy by incorporating additional factors but may face challenges in clinical application due to complexity. Continued refinement and validation are essential to improve predictive accuracy, optimize patient care, and connect research with clinical practice.

Keywords: Arteriovenous malformations, Brain, Cerebral angiography, Classification, Grading system, Outcome prediction, Pollock-Flickinger, Radiosurgery, Scoring, Spetzler-martin grading

INTRODUCTION

Arteriovenous malformations (AVMs) are complex vascular lesions that can occur in the brain or spinal cord, and their treatment requires a multidisciplinary approach involving neurosurgeons, interventional radiologists, and radiation oncologists.[25] Classification systems guide treatment decisions and optimize clinical outcomes by risk stratification based on factors such as size, location, venous drainage, eloquence of brain region, and associated features such as aneurysms.[3] Standardized classification systems facilitate data collection, comparison, and analysis across different studies and institutions.[30]

Classification systems play a critical role in medicine by providing a standardized framework for organizing and classifying medical information. According to the International Classification of Diseases, a widely used classification system in healthcare, classification systems are used to facilitate communication, enable comparisons of health data across different regions and countries, and aid in clinical decision-making.[13] The use of classification systems has become increasingly important with the rise of electronic health records, which rely on structured data to support clinical workflows and data analysis. As a result, classification systems are an essential tool for healthcare professionals in providing high-quality care and improving patient outcomes.[2]

In neurosurgery, classification systems prove important in facilitating communication among healthcare professionals and providing a framework for treatment planning. The most commonly used classification systems in neurosurgery include the Glasgow coma scale for assessing the severity of traumatic brain injury, the Spetzler-Martin Grading System (SMGS) for cerebral AVMs, and the Hunt and Hess grading system for subarachnoid hemorrhage. Previous literature identified a total of 77 different classification systems used in neurosurgery.[12,31] Most of those systems focus on specific disease entities such as gliomas, meningiomas, and pituitary tumors. It is noteworthy that the abundance of classification systems highlights the inherent complexity and variability of neurosurgical disorders, underlining the importance of continual refinement and validation to enhance patient care and clinical outcomes.

Location, venous drainage, eloquence of brain region, and associated features such as aneurysms[34] are key parameters in many AVM classification systems. Standardized classification systems facilitate data collection, comparison, and analysis across different studies and institutions.[29]

Developed in 1986, the SMGS is the most widely used classification system for AVMs and is based on the size, location, and eloquence of the lesion.[22] Other classification systems have been developed to refine the SMGS, such as the Lawton-young grading system (LYGS) and the supplementary grading system.[1] Comparing AVM classification systems allows for standardization, treatment selection, prognostic assessment, and research collaboration. We aim to evaluate the effectiveness of different available AVM classification systems, determining their advantages and limitations and comparing them to the most prominent SMGS.[11]

MATERIAL AND METHODS

Literature search

A systemic review of the literature was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). PubMed, Scopus and Web of Science were searched from database inception up to the 12th of August 2023, using targeted keywords and phrases, including "intracranial vascular malformations" and "intracranial AVMs classification," to identify relevant articles. Studies thereafter were exported to Endnote, and duplicates were removed.

Study selection

Pre-specified inclusion and exclusion criteria were set. Studies were included if they: (1) written in English and (2) articles that discussed established AVM classification systems with two or more components – articles that provided a comprehensive description of the classification systems, their components, and their application in clinical practice and articles that compared different AVM classification systems, highlighting their advantages and limitations. Our exclusion criteria included articles that focused solely on case reports or descriptions of individual AVM cases without discussing classification systems and articles that lacked substantial information on AVM classification systems or their comparison. Titles and abstracts were independently screened by two reviewers (M.A. and A.M.), with full texts of potentially relevant studies assessed against the inclusion criteria. Discrepancies were resolved through discussion with a third reviewer (S.H.). Only studies meeting all predefined criteria were included in the final analysis. Full-text articles were then retrieved for the selected abstracts and further assessed for eligibility by two more reviewers with single blinding. Articles that met the inclusion criteria were included in the final review.

Data extraction

Data extraction involved categorizing and summarizing different AVM classification systems discussed in the selected articles. The key components of each classification system, their strengths, limitations, and their application in clinical practice were systematically analyzed and compared. We emphasized understanding how each classification system contributed to treatment decisions, prognosis prediction, and patient outcomes and how it eventually compares to the standardized SMGS.

RESULTS

The classification and grading of brain AVMs have undergone significant evolution, aiming to enhance predictive accuracy. This evolution has given rise to various systems, each presenting distinct strengths and limitations. After filtering data from our initial search yielding 2185 articles, we chose 33 articles according to the PRISMA flowchart demonstrated in Figure 1. The various classification systems for AVMs can be grouped based on their primary focus into the following: surgical, radiological, and clinical.

Surgical classification systems encompass a range of tools designed to assess the complexity and surgical risk of AVMs. These include the Lawton-Young scale, Nisson score, AVM-related intracerebral hemorrhage (AVICH) scale, VALE score, Spetzler-Ponce scale, Spetzler-Martin classification, radiosurgery-based AVM score (RBAS), Pittsburgh AVM scale, Virginia AVM scale, Buffalo score, and R2eD AVM score. Each system evaluates different aspects of the AVM, such as size, location, and the eloquence of the lesion, helping to predict surgical outcomes and guide treatment decisions.

On the radiological side, classification systems like the Pollock-Flickinger AVM scale, Hemorrhage–Nidus diffuseness–Venous drainage–Lesion-to-Eloquence distance (HDVL) score, and the Spetzler-Martin classification assess the size, location, and drainage patterns of the AVM through advanced imaging techniques such as computed tomography (CT) and magnetic resonance imaging (MRI), helping clinicians determine the best approach for intervention.

Clinical classification systems such as the Spetzler-Martin classification, Lawton-Young scale, Nisson score, and AVICH scale all integrate clinical parameters such as patient age, neurological status, and bleeding history to predict outcomes and refine treatment strategies.

As demonstrated by Figure 2, some systems blend multiple approaches. For example, the RBAS, Pittsburgh AVM scale, Virginia AVM scale, Buffalo score, and R2eD AVM score combine radiological and surgical factors to offer a

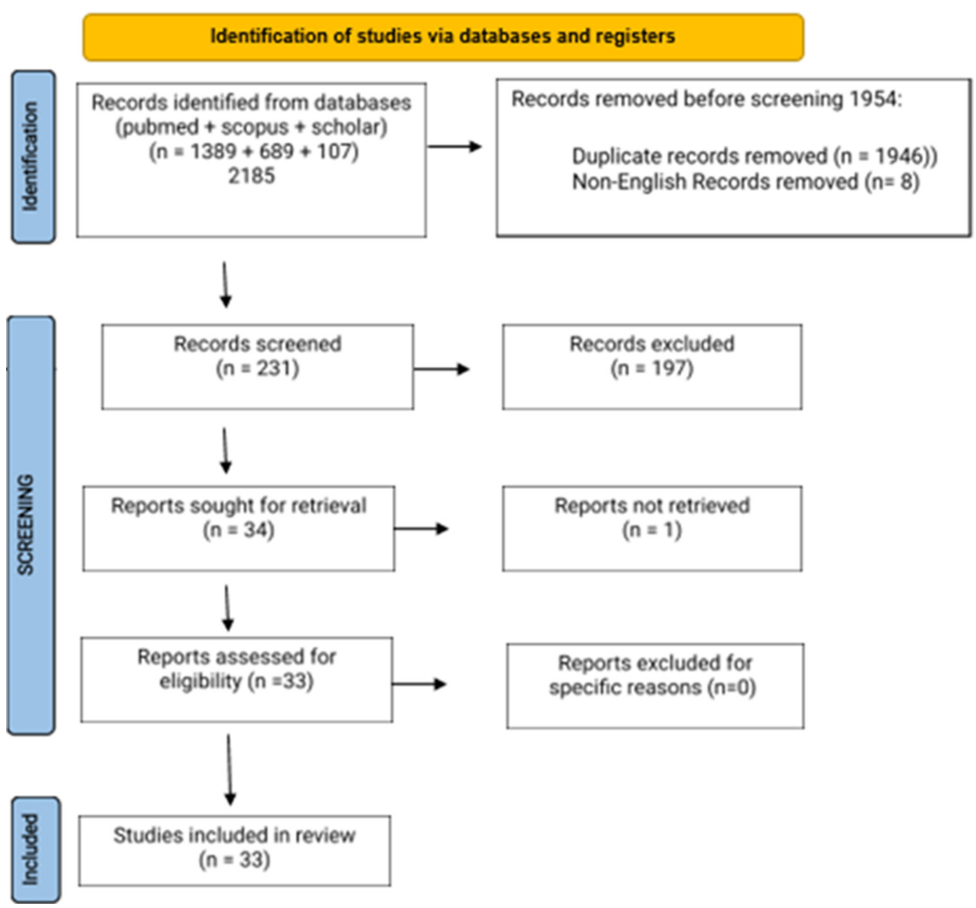

Figure 1: Preferred Reporting Items for Systematic Reviews and Meta-Analyses flowchart demonstrating database search and extraction steps.

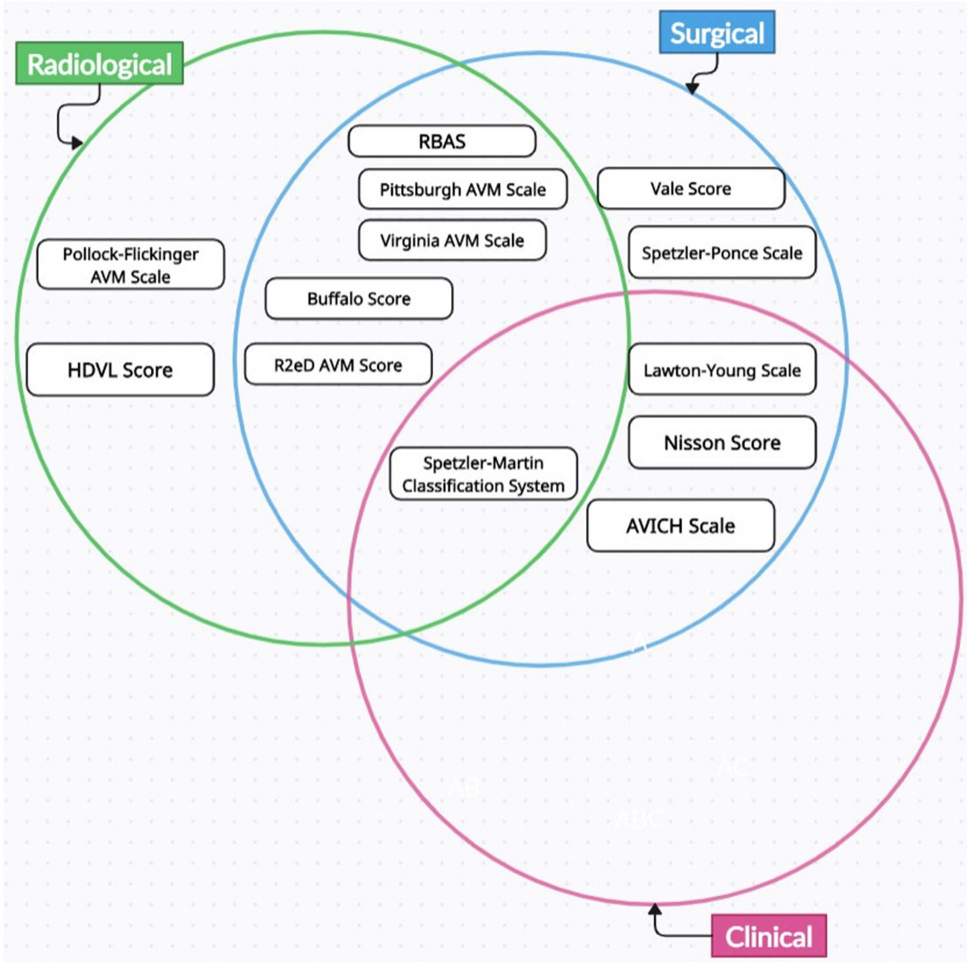

Figure 2: The Venn diagram illustrates the classification systems for arteriovenous malformations (AVMs) according to their primary focus. Radiological classification systems include the Pollock-Flickinger arteriovenous malformation (AVM) score and the Hemorrhage–Nidus Diffuseness–Venous Drainage–Lesion-to-Eloquence Distance (HDVL) score. Systems combining radiological and surgical classifications include the Radiosurgery-Based arteriovenous malformation (AVM) score (RBAS), Pittsburgh arteriovenous malformation (AVM) scale, Virginia arteriovenous malformation (AVM) scale, Buffalo score, and R2eD arteriovenous malformation (AVM) score. The Spetzler-Martin classification integrates radiological, surgical, and clinical elements. Systems combining surgical and clinical classifications include the Lawton-Young scale, Nisson score, and Arteriovenous Malformation–Related Intracerebral Hemorrhage (AVICH) scale. Finally, the Vale score and the Spetzler-Ponce scale represent purely surgical classification systems.

comprehensive risk assessment. Meanwhile, the Spetzler-Martin classification goes even further by integrating radiological, surgical, and clinical elements for a well-rounded evaluation. The Lawton-Young scale, Nisson score, and AVICH scale also cover both surgical and clinical classifications to facilitate decision-making for the neurosurgeon.

Several AVM classification systems are tailored for specific anatomical locations or clinical scenarios. For instance, the Spetzler-Ponce scale is specified for supratentorial AVMs, while the Nisson score focuses on infratentorial AVMs, particularly cerebellar AVMs, addressing a limitation of the widely used Spetzler-Martin system in this region.

Certain systems are designed for specific clinical presentations. For unruptured AVMs, the Nisson score, R2eD AVM score, Spetzler-Ponce, and Vale score are applicable, while the AVICH system is specialized for ruptured AVMs. The Pittsburgh AVM scale can be used at the first presentation of AVMs, as its factors are unrelated to specific treatment protocols. Similarly, the Vale score is another versatile system suitable for early evaluation and decision-making. Conversely, the Lawton-Young scale is a dynamic system that adapts to different treatment modalities, making it particularly useful for personalized patient management.

In terms of simplicity, systems such as the Virginia, Buffalo, and R2eD AVM scores are straightforward and easy to apply, while more complex systems such as Lawton-Young, AVICH, and Pollock-Flickinger require additional parameters and are less user-friendly. Moreover, some scales, such as

Table 1: Comparison of all AVM classification systems according to year of development, factors of grading, and comparison with the Spetzler-Martin Grading System.

AVM Grading System	Factors	Features	Aim/Purpose/ Features	Application
Spetzler-Martin[7]	1. Nidus size 2. Eloquence of adjacent brain areas. 3. Pattern of venous drainage[7]	5-tier system[10] Grades: I, II, III, IV and V[7]	Risk of operation for cerebral AVM[10]	Easily calculated Widely applied
Lawton-Young (Supplementary SM) [21]	1. Age. 2. History of haemorrhage 3. Nidus type. 4. AVM size 5. Existence of deep vein drainage. 6. Eloquence of location[22]	SM+age, prior Hemorrhage, and nidus type[22]	Improved predictive accuracy[22]	Dynamic (modified by treatment modalities)[22]
NIisson score[22]	1. Patient age. 2. Deep venous drainage. 3. Presence of brainstem component.	Has deep venous drainage with SM but focuses more on the clinical factors	Unruptured Infra-tentorial	Cerebellar AVM accuracy has room for enhancement
AVICH[24]	1. AVM Size. 2. Eloquence of adjacent brain areas. 3. Deep venous drainage. 4. Patient age. 5. Presence of diffuse nidus. 6. Glasgow Coma Scale score. 7. Intracerebral hemorrhage volume. 8. Intraventricular hemorrhage	ICH score+modified SM	Limitation of ICH score in AVM-related ICH	Non-traumatic ICH Ruptured bAVM: outcome prediction
Pittsburgh (Radiosurgery)[25]	1. Patient age. 2. AVM volume. 3. AVM location	Initially had 5 factors Location: (deep/others)	Prediction of outcomes of radiosurgery	Pediatrics, Deep AVM, AVM treated with linear accelerator-based radiosurgery
RBAS (Radiosurgery)[26]	1. AVM volume. 2. Patient age. 3. AVM location.	Use patient age unlike Hemorrhage in Virginia and eloquence rather than depth as in Pittsburgh	Inaccuracy of SM in Radiosurgery Cases	Radiosurgical cases
Virginia (Radiosurgery)[27]	1. AVM volume. 2. Eloquent AVM location. 3. History of hemorrhage.	SM but the history of Hemorrhage instead of a venous drainage pattern	Context of Gamma Knife Procedures	Simpler and more practical than SM
Buffalo Score[28]	Number of arterial pedicles Arterial pedicle diameter Anatomical (functional) location of AVM	Accounts for anatomical and functional AVM features making endovascular embolization more difficult.	Estimate risk of endovascular AVM embolization To predict complications and guide endovascular treatment	Assist neuro interventionists in risk estimation
R2eD AVM Score[29]	Race Exclusive deep location AVM size Venous drainage Monoarterial feeding	Based on a study of 789 AVM patients from 1990 to 2017. Total score ranges from 0 to 6 points.	Risk stratification for hemorrhage in patients with brain AVMs and guide therapeutic decisions	Bedside application for unruptured AVMs

(Contd...)

Table 1: *(Continued).*

AVM Grading System	Factors	Features	Aim/Purpose/ Features	Application
Pollock-Flickiniger[30]	1. AVM volume. 2. AVM Location. 3. Patient age.	SM+age and prior Hemorrhage	Better predictive results in radiosurgery	Adoption and validation are not widespread
HDVL[31]	1. Presence of hemorrhage. 2. Nidus diffuseness. 3. Deep venous drainage. 4. Lesion-to-eloquence distance.	Similar to supplementary SM but without the age and AVM size variable and with more focus on eloquence	Lesion-to-eloquence distance increases the predictive accuracy	Need further external validation (both supra and infra tentorial bAVMs)
Spetzler-Ponce (Modified SM) [32]	1. Nidus size 2. Eloquence of adjacent brain areas. 3. Pattern of venous drainage[32]	SM but simpler (3-tier system) A: I, II B: III C: IV, V[32]	Clearer Framework for surgical decision making Enhanced statistical power for comparative analysis[33]	Better clinical utility unruptured supratentorial AVM[33]
Vale Score[34]	Ventricular system involvement Venous aneurysm Deep location Exclusively deep drainage	Total score ranges from 4 to 5 points, categorized into low, moderate, and high-risk groups	Discerning rupture risk in patients with AVMs	Identify low-risk AVMs, aid in decision-making for early intervention
AVM Grading System	**Limitations**	**Remarks**	**Year**	
Spetzler-Martin[7]	Variability between grading systems Heterogeneity of Grade III solely based on Radiological markers[19]	Needs CT or MRI with Angiography [11]	1986	
Lawton-Young (Supplementary SM) [21]	Inter-observer variability Complex[23]	Nidus type: (enraptured/ diffuse) Age: (<20/20-40/>40)[22]	2010	
NIisson score[22]	Doesn't focus on angioarchitectural features. Used for cerebellum solely	preoperative neurological status and emergency surgery component show more significance in predicting outcomes	2019	
AVICH[24]	Very complex	Initially had a higher area under the curve for the ICH score	2016	
Pittsburgh (Radiosurgery)[25]	Doesn't consider venous drainage eloquence or nidus type	Factors not related to any treatment protocol. Can be used at 1st presentation	2011	
RBAS (Radiosurgery)[26]	Cortical eloquent areas unlike deep eloquent area are less prone to injury in radiosurgery but has the same score	The majority of radiosurgery cases volume<3cm unlike resection cases in SM	2013	
Virginia (Radiosurgery)[27]	Variables limited to Radiosurgical cases	Provide eloquence of location rather than deep or others as in Pittsburgh	2013	

(Contd...)

Table 1: *(Continued).*

AVM Grading System	Limitations	Remarks	Year
Buffalo Score[28]	no prospective assessment to date and no evident correlation with complete endovascular obliteration	Simple, easily reproduced, and clinically valuable	2015
R2eD AVM Score[29]	Simple bedside tool for therapeutic decision-making and counseling in unruptured AVM cases.	Simple validated prediction tool	2019
Pollock-Flickiniger[30]	Complex Need further studies to assess the efficacy	Direct comparison between anticipated radiological and expected surgical outcomes	2002
HDVL[31]	Could have diminished predictive value without fMRI and DTI evaluation	potential to influence clinical decisions when SM and HDVL grades diverge	2018
Spetzler-Ponce (Modified SM) [32]	Doesn't consider clinical factors (age and Hemorrhage)[33]	Equivalent predictive accuracy for surgical outcomes compared to a 5-tier system[33]	2011
Vale Score[34]	Developed and validated in a predominantly Chinese population. Hemorrhage-free survival probability may be overestimated. Only includes 4 variables from imaging data.	Dependable and practical tool contributes to a reduction in unnecessary procedures, aids informed decisions	2023

VM: Arteriovenous malformation; SM: Spetzler-Martin; ICH: Intracerebral hemorrhage; bAVM: Brain Arteriovenous Malformation; DTI: Diffusion tensor imaging; HDVL: Hemorrhage–Nidus diffuseness–Venous drainage–Lesion-to-Eloquence distance.

Table 2: Criteria used in Spetzler-Martin AVM classification system.

Nidus size (angiography)	Eloquent areas	The pattern of venous drainage
Small: < 3 cm	No: 0	Superficial drainage only: 0
Medium: 3 – 6 cm	Yes*: 1	Deep drainage**: 1
Large: > 6 cm		

*Sensorimotor, speech or visual cortex; thalamus/hypothalamus; internal capsule; brainstem; deep cerebellar nuclei; cerebellar peduncles.
**Internal cerebral vein, basal vein of Rosenthal, or precentral cerebellar vein. Cerebellar hemispheric veins

Pollock-Flickinger, Hemorrhage–Nidus diffuseness–Venous drainage–Lesion-to-Eloquence distance (HDVL), and Vale score, need further studies for external validation and efficacy assessment. Table 1 summarizes a comparison of all AVM classification systems according to year of development, factors of grading, and comparison with the SMGS.

DISCUSSION

In this extensive review of the literature on cerebral AVMs, the author reviews various schemes of AVM classification. Realizing the diversity in the classification criteria depending on the purpose, parameters, and clinical importance, the study reviews the literature to offer a systematic review of nine different AVM classification systems. These systems are categorized into clinical outcome, radiosurgical, radiological, and surgical groups, as illustrated in Figure 2. The Spetzler-Martin Classification System (SMCS) is one of the most popular five-level systems and is highlighted, especially for its use in predicting the risk of AVM surgeries through the size, location, and venous drainage of the nidus. The discussion continues to other important systems; however, the categorization is not strict, as some systems may cross over into more than one category, but this provides a general idea of the primary focus of each grading system. The clinical outcome category includes the Lawton-Young (Supplementary SM) system, the Nishimoto score, and the AVICH. The radiosurgical category includes the Pittsburgh system, RBAS, and the Virginia system. The Pollock-Flickinger system and HDVL are part of the radiological category. Finally, the surgical system is the Spetzler-Ponce (Modified SM) system.

The SMCS

The SMGS is a commonly used 5-tier classification for characterizing cerebral AVMs.[15] Its first introduction was in 1986 in the USA.[31] The score is calculated by correlating the site and size of the nidus with the venous drainage pattern, using either CT or MRI with cerebral angiography, respectively.[14] The score aims to assess the risk of operation in terms of mortality and morbidity [1] as well as the frequency of hemorrhage.[24]

Grading criteria

The grade is made in Roman numbers from 3 categories (size, eloquence, and venous drainage), where Grade I is the lowest and Grade V is the highest.[31] Criteria are demonstrated in Table 2.

Prognostic implications

In Grade I-III AVMs, radiosurgery has similar outcomes to surgery aside from timing of obliteration, while in Grade IV, the staged-dose radiosurgery resulted in obliteration only in 50% of cases.[18]

1. Grade I and II: Surgery is safe in terms of immediate decompression, faster recovery, and shorter hospital stay.
2. Grade III: Pose difficulty in deciding the appropriate approach, where some might use surgery as the treatment of choice,[19] others might opt for radiosurgery or other multimodality regimens.[16]
    a. Type 1 = S1E1V1
    b. Type 2 = S2E1V0
    c. Type 3 = S2E0V1
    d. Type 4 = S3E0V0 (rare).
3. Grade IV and V: Considered by most in-operable. And other conservative measures are taken to reduce re-bleeding and morbidity.

Limitations

Inter-observer variability

Differences in subspecialties can affect the reporting of results, which may lead to the upgrading or undergrading of AVM scores.[23]

Variability of morbidity between grading components

Most of the morbidity in surgical management was associated with eloquence rather than deep venous drainage. In one series, they found that the risk was 0.6% in non-eloquent areas compared to 9.5% in eloquent areas. On the other hand, none of the patients with deep venous drainage had any adverse outcomes.[28] Indicating that eloquence is more important than drainage and should not have the same score.

Heterogenousity of grade III S-M

Grade III can present in variable forms of AVM with different appropriate management. For instance, S2E1V0 would lead to high surgical risk and be managed conservatively, like high Grades IV and V, while S2E0V1 would pose immediate risk and sometimes might be managed surgically.[21] It is evident that the size of the nidus was the only component that correlated with the development of new neurological deficits, suggesting the need to sub-classify Grade III according to their size (<3 and ≥3 cm) to account for treatment risk.[10]

Usage in cerebellar AVM

The SMGS was mainly designed for cerebral AVMs; its eloquence and venous drainage components might be insufficient to accurately grade cerebellar AVMs due to its distinct anatomy, thereby affecting surgical risk assessment. The supplementary system might have the upper hand.[17]

Surgical-Clinical outcome classification systems

The LYGS

In 2010, Lawton *et al*. proposed a new grading scale to enhance the preoperative risk prediction for brain AVMs (bAVMs) to improve patient selection and to predict surgical risk more accurately.[17] LYGS, also known as the Supplemented Spetzler-Martin grade (Supp-SM), adds patient age, history of hemorrhage, and nidus type in addition to the classical SMGS factors. Age has 3 groups: <20 achieved 1 point, between 20 and 40 achieved 2 points, and over 40 years achieved 3 points. There is 1 point for enraptured presentation and 1 point for diffuseness of the nidus. The Supp-SM grading system has nine different grades.[2-10] In this system, grade 6 is considered the cutoff point for acceptable surgical risk. The new system is a better predictor of neurologic outcomes after AVM surgery. Age and bleeding status are changeable factors. Furthermore, nidus shape and AVM size could be changed by radiotherapy and embolization. For that reason, Supp-SM proved to be a dynamic scale system and may be modified by other treatment modalities, particularly endovascular treatment.[1]

The LYGS boasts several strengths when compared with the original 5-tier SMGS. Notably, it integrates a broader set of factors, such as brain eloquence, deep perforator supply, and venous drainage pattern. This provides a more comprehensive assessment of AVM complexity and potential surgical risks. This expanded scope acknowledges the pivotal role of functional brain regions in surgical planning, potentially leading to more tailored treatment strategies. Subsequent studies have demonstrated that LYGS exhibits improved predictive accuracy compared to SMGS when determining the surgical outcomes of brain AVMs. The Supp-SM stratifies surgical risk more equitably and has great predictive accuracy on its own. In addition, the Supp-SM is simple to use at the operating table, where it is meant to enhance preoperative risk prediction and surgical patient selection.

Nonetheless, LYGS encounters challenges, including its inherent subjectivity that could introduce interobserver variability in grading. Moreover, the system's increased complexity might hinder ease of use in clinical practice, demanding careful assessment and interpretation. While the SMGS may be straightforward, it might not possess the intricate predictive capabilities exhibited by the LYGS. Nevertheless, the simplicity of the Spetzler-Martin approach could enhance its ease of use and reproducibility. In essence, the Lawton-Young system's integration of eloquence and angioarchitectural complexity renders it a beneficial alternative to the Spetzler-Martin system.[26]

The Nisson score

This score introduces a specialized grading system tailored for unruptured infratentorial AVMs, uniquely addressing lesions of the posterior fossa. Developed in collaboration with Spetzler and Lawton, this system incorporates three variables: patient age, deep venous drainage, and the presence of a brainstem component. The Nisson score aims to prognosticate morbidity and mortality risks linked to microsurgical resection of infratentorial AVMs. In comparison to the widely used Spetzler-Martin (SM) grading system, the Nisson score underscores several strengths and weaknesses. Notably, it surpasses the SM system in accuracy, aligning it with, or even outperforming, the SM and Lowton-Yount grading systems for brain AVMs. While the SM system emphasizes angioarchitectural characteristics, the Nisson score exhibits reduced relevance in this regard, with deep venous drainage being the sole shared feature between the two. The Nisson system attributes more weight to clinical factors such as patient age, preoperative neurological status, and emergency surgery, indicative of their significance in predicting outcomes. This emphasis on clinical elements addresses a critique leveled at the SM grading system and is particularly relevant for cerebellar AVMs, where lesion characteristics exhibit intricate interplay with patient-related variables. Although the Nisson system offers a refined prognostic tool for cerebellar AVMs, its predictive accuracy, while acceptable by conventional standards, does entail room for enhancement.[10]

The AVICH system

The AVICH grading system, an innovative approach to assess ruptured bAVMs, emerged in 2016 in response to the limitations of the original ICH grading system and its applicability to bAVM-related intracranial hemorrhage (ICH). Originally designed for non-traumatic ICH risk assessment, the ICH grading system faced challenges in reflecting the distinct pathophysiology of bAVM-related ICH. In response, Neidert *et al*. fused the ICH score with the augmented SMGS to formulate the AVICH grading system. This new approach was validated through a single-center cohort study followed by an international multicenter validation study comprising a total of 325 patients from eleven centers.[20] Despite the initial publication indicating a higher area under the curve for the ICH score, the external validation showcased the AVICH score's superiority in outcome prediction for bAVM-related ICH. While the AVICH system offers enhanced precision compared to the original ICH score, it carries a greater complexity, incorporating eight scoring factors (including emphasized considerations of size and age) within an extended range of 11. This improved accuracy must be balanced against the system's intricacy and potential challenges in practical implementation. In comparison to the original SMGS, the AVICH grading system presents a more nuanced approach that combines the ICH score and Spetzler-Martin system, offering potential benefits in outcome prediction for ruptured bAVMs.[33]

Radio surgical outcome classification systems

The Pittsburgh radiosurgery-based AVM grading scale

Despite the SMGS being a tool to predict outcomes following AVM surgeries. The SMGS does not accurately predict the outcomes after radiosurgery. Therefore, the new grading scale for prediction of outcomes of radiosurgery was the Pittsburgh radiosurgery-based AVM grading scale, which was improved later by accounting for location as a two-tiered variable (deep vs. other). The Pittsburgh scale was initially based on five variables, which resulted in its initial complexity and lack of practicality, which was simplified afterward into three factors (patient age, AVM volume, and AVM location). Another advantage of the Pittsburgh scale was that no factors used in the radiosurgery-based AVM grading scale were in any way related to a treatment protocol, which made the system usable at the time of the first patient encounter to formulate the management plan. In addition, this scale was proven to successfully predict the outcomes in pediatric AVM patients, patients with deep AVMs, and patients whose AVMs were treated using linear accelerator-based radiosurgery.[7]

The RBAS

Another grading system designed to predict patient outcomes after Gamma Knife surgery for AVMs was the RBAS. In contrast, the SMGS is based on AVM size, location, and pattern of venous drainage, which the majority of neurosurgeons had prospectively validated to predict patient outcomes after AVM resection. The problem is that the indicators for successful surgical removal of brain AVMs are not perfectly similar to the factors that can predict the success rate of radiosurgery. For example, the Spetzler-Martin grading scale gives a different score to different AVM sizes, with <3 Cm being 1 point, 3–6 cm being 2 points and larger than 6 cm being 3 points, all measured in their greatest linear dimension. In comparison, a high percentage of AVMs having single-session radiosurgery are, in fact, <3 Cm in greatest dimension with the standard treatment volumes having a range of 1–14 cm^3.[3] This proves that the SMGS is considered inaccurate to AVM volume, given its role as a crucial factor when determining a successful AVM radiosurgery. In addition, multiple cortical placements that are said to be "eloquent" in the SMGS are less prone to injury from radiosurgery treatment than the surgical counterpart, so the risk of these areas should not be counted as an equal risk of radiosurgery for AVMs in the basal ganglia, thalamus, or brainstem.[8]

The Virginia radiosurgery AVM scale

The Virginia Radiosurgery AVM scale was later developed in which patients were given a score of 1 point for having each of the following:

1. An AVM volume of 2–4 cm (2 points for having an AVM volume >4 cm.)
2. Eloquent AVM location
3. A history of hemorrhage.

The predictive nature of the Virginia Radiosurgery AVM Scale was quite accurate in the context of Gamma Knife treatment procedures. One difference between the SMGS and the Virginia Radiosurgery AVM scale is that the latter provided the best assessment. More so, the Virginia Radiosurgery scale was simpler and much more practical to use. However, radiosurgery-specific variables limited the scale predictive values due to the nature of the parameters used in scaling in cases of patients undergoing stereotactic radiosurgery.[27]

The Buffalo score

The Buffalo score is a newly proposed grading system that accounts for the anatomical and functional AVM features that have been observed to make endovascular embolization procedures difficult and liable to complications. These parameters include the number of arterial pedicles, their diameter, and the anatomical (functional) location of the AVM. While the SMGS accounts for the features of venous drainage (V), size (S), and eloquence (E).

The proposed grading system relies on the observed risk alongside the endovascular treatment of AVMs. Basically, smaller vessels are injured more easily with catheterization; a larger number of arterial pedicles produce more potential risk with each embolization, and an eloquent location increases the risk of developing a neurological deficit. The size of the AVM nidus and the venous drainage pattern of the AVM have less importance during endovascular embolization procedures but are of much more significance during surgical procedures. Therefore, the proposed grading scheme gives a simple confluence of these concepts that helps neurointerventionists estimate the risk of endovascular AVM embolization.[9]

The R2eD AVM score

The R2eD AVM is a scoring system for hemorrhage risk stratification in patients with brain AVMs that was developed in 2019. The system aims to guide therapeutic decisions and improve the management of unruptured AVMs. The study used a large cohort of 789 AVM patients presenting between 1990 and 2017. The scoring system was developed by identifying risk factors predictive of hemorrhagic presentation in this cohort. The factors used in the grading system include race (non-white vs. white), exclusive deep location, AVM size (small vs. large), venous drainage (exclusive deep vs. other), and monoarterial feeding (1 vs. >1 feeding artery). Every risk factor was worth 1 point except race, which was worth 2 points, with a total score varying from 0 to 6 points. The development of this new grading system provides a simple validated prediction tool that can be applied at the bedside to help guide therapeutic decisions and aid counseling in patients with unruptured AVMs.[5]

Pure radiological outcome classification systems

The Pollock-Flickinger AVM grading system

This radiosurgery-based classification emerged in 2002 from a multivariate analysis of AVM patients treated with stereotactic radiosurgery. This system incorporates five key components: AVM size, location, deep venous drainage, patient age, and prior hemorrhage. The Pollock-Flickinger system boasts several strengths in comparison to the SMGS. It accounts for critical factors such as deep venous drainage, patient age, and prior hemorrhage that significantly influence AVM radiosurgery outcomes. By doing so, it presents a more accurate means of predicting radiosurgery results compared to SMGS. Moreover, the Pollock-Flickinger system facilitates a direct comparison between anticipated radiosurgery outcomes and expected surgical resection outcomes predicted by SMGS for individual patients. However, certain weaknesses are inherent in the Pollock-Flickinger system. Its adoption and validation within the neurosurgical community have not been widespread, necessitating further studies to corroborate its efficacy. In addition, the system's increased complexity compared to the SMGS might pose challenges in its practical application in clinical settings.[32]

The HDVL score

The HDVL grading system emerges as a valuable supplementary scale aimed at enhancing surgical outcomes for patients with bAVMs. It achieves that by considering lesion-to-eloquence distance. This system holds distinct advantages over the Spetzler-Martin grading approach. Primarily, it boasts superior predictive accuracy compared to the Spetzler-Martin grade. This accuracy is further elevated by incorporating information about eloquent fiber tracts and quantifying the relationship between the nidus and eloquent cortex and fiber tracts. Moreover, the HDVL grading system introduces the potential to influence clinical decisions when Spetzler-Martin and HDVL grades diverge. However, this innovative approach is not devoid of limitations. The lack of external validation raises questions, necessitating further validation through prospective studies encompassing a larger patient cohort, both supra- and infratentorial bAVMs. It is important to acknowledge that the HDVL grading system might not extend to other brain lesions and could see diminished predictive accuracy without the aid of fMRI or DTI evaluation.[4]

Pure surgical outcome classification systems

The Spetzler-Ponce scale

In 2011, Spetzler and Ponce introduced a streamlined three-tier classification system for cerebral AVMs, building on the foundation of the original five-tier SMGS. This novel classification takes into account AVM size, the eloquence of the surrounding brain tissue, and the presence of deep venous drainage, which were central to the Spetzler-Martin approach. The three-tier system simplifies the classification process while still offering a valuable treatment guide and predictive capacity for surgical outcomes. The categorization involves combining Grades I and II AVMs into Class A, Grade III AVMs into Class B, and Grades IV and V AVMs into Class C. This approach is rooted in the understanding that the differences in surgical outcomes between these respective pairs are relatively small. By reducing the number of categories, the revised system not only simplifies treatment recommendations but also enhances statistical power for comparative series analyses.[32] Furthermore, the Spetzler-Ponce Classification system provides a clearer framework for surgical decision-making. Lower-grade AVMs (Grade I and II) are generally more amenable to surgical resection, while higher-grade AVMs (Grade III) may necessitate alternative treatment strategies due to their increased complexity. The Spetzler-Ponce score is easy to memorize and quick to calculate, adding to its clinical utility. In addition, it is important to note that the Spetzler-Ponce score is a grading system specifically designed for supratentorial unruptured brain AVMs. Although there is a reduction in granularity, the three-tier classification remains predictive of surgical outcomes and effectively captures the prevailing treatment landscape for AVMs. Notably, when pooled data were examined, both the five-tier and three-tier systems exhibited equivalent predictive accuracies for surgical outcomes, demonstrating the practical viability of the more streamlined classification scheme.[13]

VALE score

The balance between the inherent risk of natural rupture and the potential adverse outcomes associated with intervention poses a significant dilemma for individuals with unruptured AVMs. To address this challenge, the VALE scoring system was developed with the aim of discerning rupture risk in patients with AVMs. Stratifying unruptured AVMs using this system can assist in identifying those with a low risk of rupture, thereby helping patients and physicians make informed decisions. The term "VALE" is derived from the four key risk factors considered in the system, which are ventricular system involvement, venous aneurysm, deep location, and exclusively deep drainage. A score of one point is allocated to AVMs with a deep location, while those with ventricular system involvement and exclusively deep drainage receive two points each. Venous aneurysm, on the other hand, is deemed a protective factor against AVM rupture, and therefore, a deduction of four points is made if a venous aneurysm is present. The total VALE score can range from −4 to 5 points, with the predicted probability of rupture increasing as the VALE score rises. For practical clinical use, the VALE score is further categorized into three groups based on hemorrhagic risk: low risk (score <-2), moderate risk (score ranging from −2 to 1), and high risk (score exceeding 1) that provide estimated hemorrhage-free probability for future years. The VALE scoring system is a dependable and practical tool that can assist in identifying individuals who might benefit from early intervention. Its use can contribute to a reduction in unnecessary procedures and unexpected AVM ruptures, aid both clinicians and patients in making well-informed decisions, and guide future clinical research toward more personalized and tailored approaches.[13]

Challenges and limitations of existing systems

First, the assessment of nidus diffuseness remains a subjective endeavor despite efforts to enhance objectivity through advanced radiological technologies. Second, the predictive scope of these systems may be constrained by their inability to fully account for additional influential factors, such as the presence of associated aneurysms, the timing of surgery post-rupture, and the involvement of perforators. Moreover, the inclusion of cases with prior treatment modalities for originally unruptured AVMs, which are subsequently classified as ruptured, could introduce complexities in comparing grading systems. Finally, the complexity of multimodal treatment approaches in contemporary clinical practice poses challenges, potentially affecting the generalizability of findings.

The applicability of surgical grading systems should be seen as a foundational step in evaluating operability, considering diverse factors such as natural history, patient comorbidities, treatment modalities, and individual expectations. The ARUBA study underscored the challenge of balancing natural history and treatment risks, highlighting the need for nuanced risk evaluation.[18] In light of these limitations, ongoing refinement and validation of AVM grading systems are imperative to enhance their predictive accuracy and optimize their clinical utility.

Impact of novel AVM classification systems

The SMGS remains the most widely used classification system for AVMs due to its simplicity and high inter-observer reliability. However, newer grading systems, such as the HDVL score and the Nisson AVM grading system, provide additional anatomical details that may improve treatment planning. The HDVL score offers a comprehensive approach to risk stratification, particularly for AVMs located near eloquent areas. This innovative system holds the promise of enhanced predictive accuracy compared to existing grading methods and could potentially influence clinical decision-making.[13] This presents a forward-looking avenue for improved AVM classification and treatment strategies. Ultimately, the Nisson AVM grading system introduces a tailored approach for cerebellar AVMs, rectifying the limitations of traditional grading systems in this unique context. By focusing on specific characteristics relevant to infratentorial lesions, this system demonstrates its potential in predicting patient outcomes and aiding vascular neurosurgeons in making informed clinical decisions. We summarize the year of development, factors of scoring, and points of comparison of all the aforementioned systems with the SMGS in Table 1.

CONCLUSION

Classifying AVMs is essential for optimizing treatment and improving outcomes, with systems such as the Spetzler-Martin, Pollock-Flickinger, and Lawton-Young offering varying strengths and limitations. The Spetzler-Martin system is widely used for surgical outcomes but falls short in predicting radiosurgery results, whereas the Lawton-Young system improves surgical predictions by adding factors such as brain eloquence and venous drainage but is more complex and subjective. The Pollock-Flickinger system focuses on radiosurgery outcomes but requires further validation. Refining these systems through future research is critical to enhancing their predictive accuracy and clinical utility, ultimately improving patient care.

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