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Review Article

Cerebral arteriovenous malformation calcifications: A systematic review, case series, and a proposed classification system

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ABSTRACT

Background: Brain arteriovenous malformations (AVMs) are intracranial vascular lesions characterized by a nidus of vessels fed by an artery and drained by a vein, lacking intervening capillaries. Angiography remains the gold standard for a definitive diagnosis. There is a paucity in the literature regarding clinical presentation and management of patients with calcified cerebral AVM (cCAVM). This study aims to highlight the clinical presentation and management of patients with cCAVM and also to propose a classification of calcification patterns in cCAVMs based on brain computed tomography (CT) findings.

Methods: A systematic review using PubMed, Scopus, and Web of Science was done according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines to identify cases that illustrate cCAVM. A case series was also presented to supplement the current literature.

Results: Twenty patients with cCAVM were included, with the male gender representing more than 50% of the patient population. Their age ranged from 11 to 69 years, with seizures being the most common presenting symptom. The frontal lobe was the most common location of AVMs, followed by the parietal lobe. Most (80%) of the calcifications were nidal, with the remaining being extranidal (20%).

Conclusion: The CT scans of patients displayed significant variability due to the unique characteristics of each cCAVM. To address this diversity, a novel classification system was developed to provide a comprehensive framework for understanding cCAVMs based on their location, size, and extent.

Keywords: Arteriovenous malformation, Brain, Calcification, Cerebral, Computed tomography

INTRODUCTION

Brain arteriovenous malformations (AVMs) are defined as intracranial vascular lesions composed of a nidus of vessels fed by an artery and drained by a vein with no intervening

capillaries, resulting in shunting of blood from the arterial to the venous system.[17,20] The estimated incidence of cCAVMs is about 1.3/10,000 person-year.[17] Of unruptured cCAVMs, focal or generalized seizure and headache are the common presenting symptoms of these patients, followed by focal neurological deficits or being asymptomatic.[16,17] Although AVMs can manifest at any age, the peak incidence is usually in young adults between 20 and 40 years old.[16,17] AVM diagnosis is generally made by obtaining initial computed tomography (CT) or magnetic resonance imaging (MRI) in the emergency setting for patients presenting with seizure or electively in patients with indolent symptoms such as headache.[13] Brain AVM diagnosis is based on the presence of a nidus and venous drainage with better visualization on dynamic studies.[10] Digital subtraction angiography is still considered the gold standard for diagnosing brain AVM, providing the best evaluation of shunting.[13]

Despite the aforementioned information regarding the radiological diagnosis, other radiological feature deviants can be encountered. However, multiple intracranial calcifications or large solitary ones, referred to as cerebral calculi or brain stones, are less commonly encountered.[11] When diagnosing a brain stone or cerebral calculus, it is important to consider the possibility of a calcified AVM. Despite this, there is scarce data and uncertainty regarding calcified AVMs and their treatment options. From that perspective, this study proposes a classification of calcified cCAVMs on CT scans. To the best of our knowledge, this study is the first of its kind to compile and present information on different patterns of calcification related to AVMs.

METHODS

Literature search

A systemic review of the literature was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses. PubMed, Scopus and Web of Science were searched from database inception to June 27, 2023, using the search query: ([Cerebral] OR [Intracranial] OR [Brain] AND [Calcified] AND [Arteriovenous malformation] OR [AVM] AND [Computed tomography] to review the data about calcified cCAVMs). 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: were (1) written in English and (2) involved at least one patient with cCAVM on brain CT scans. Studies were excluded if they: (1) were reviews, letters, editorials, or conference abstracts and (2) cCAVMs identified on brain images other than CT scans.

Titles and abstracts were independently screened by two reviewers (K.A. and U.A.), 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.

Data extraction

Two independent reviewers (K.A and U.A) extracted data from included articles, which were confirmed by a third reviewer (S.H). Extracted data involved: author and publication year, number of patients in each study, patients' age, comorbid conditions or chronic health problems, presenting symptoms, rupture of AVM, period from having the symptoms until established AVM diagnosis, AVM calcification characteristics on brain CT scans, location of AVM, size of AVM lesion in cm, venous drainage, Spetzler-Martin grading, management of AVM, AVM modified Rankin score (mRS), and follow-up.

Data synthesis and quality assessment

The primary outcome of interest was to evaluate the different characteristics of cCAVMs on brain CT to provide a proposed classification obtained from these different brain CTs. The risk of bias was assessed using the Joanna Briggs Institute checklist, and it showed an overall low risk of bias based on the inclusion of well-documented case studies and rigorous methodology.[19]

Statistical analysis

Univariate analysis for the qualitative variables by frequency and for the quantitative variables by measures of central tendency was done using the Statistical Package for the Social Sciences.

RESULTS

Electronic search yield

An initial electronic search of PubMed, Scopus, and Web of Science yielded 4444 studies [Figure 1]; however, we ended up having 10 case reports with a total of 10 patients and complemented them with a series of 10 of our patients.

Patient population

Twenty patients were identified with calcified cCAVM [8-16,20], including the case presented in this study, with one patient having two CAVMs: 55% were male, and the population age ranged from 11 to 69 years, with an average of 32.9 years. Six of the 20 patients had comorbid conditions [Table 1].

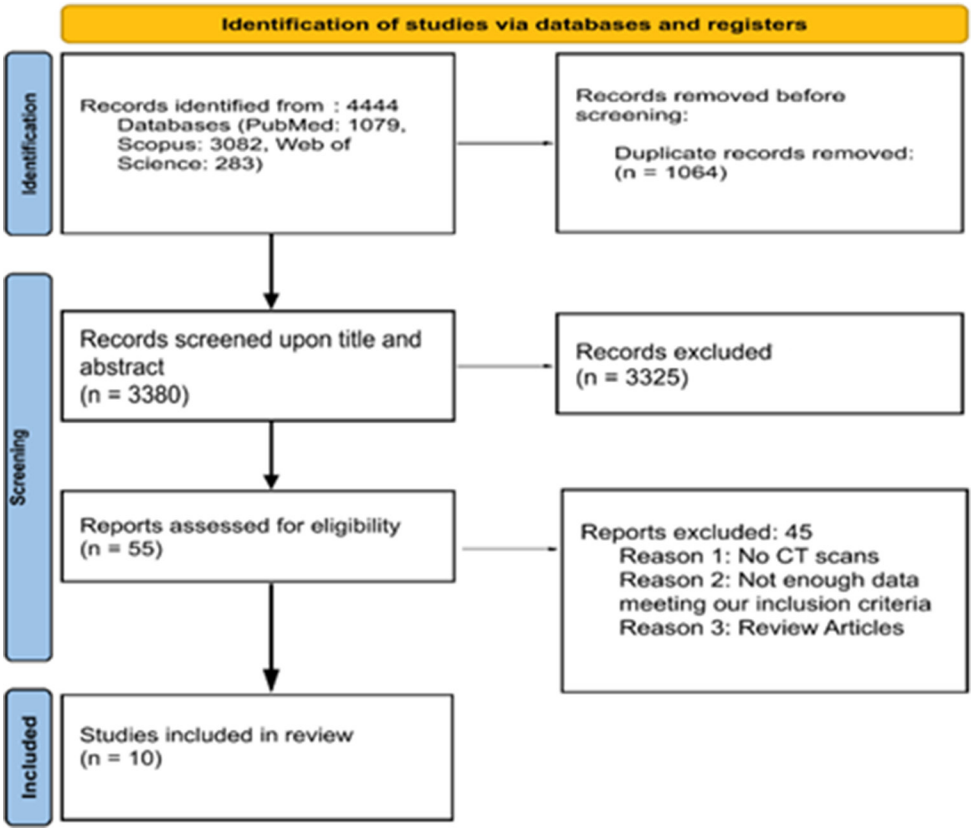

Figure 1: Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram.

Presenting symptoms

The time from symptom to diagnosis ranged from 2 h to 23 years, with an average of 8 years. The most common symptom at presentation was seizures (70%) followed by headaches (65%) [Table 1]. About 45% of the patients had headaches accompanying seizures.

AVM characteristics

The most frequently involved location of the AVM is in the frontal lobe (35%), followed by the parietal lobe (15%). The size of the AVM ranged from 2 cm to 7.5 cm, with an average size of 3.6 cm. About 65% of the cCAVM were draining into the superficial superior sagittal sinus, 15% drained into the deep galenic system, and 5% of cCAVM had a mixed drainage system. About 45% of the cCAVM were found in eloquent locations [Table 1]. The defined eloquent locations were the sensorimotor area, language-related cortical regions, visual cortex, thalamus, hypothalamus, internal capsule, brain stem, cerebellar peduncles, and deep cerebellar nuclei. There were an equal number of cCAVM with a Spetzler-Martin grading of 2 and 3 (25%) and an equal number of grading of 1 and 4 (15%). Most patients (80%) had a nidal calcification [Table 2 and Figures 2 and 3], while the remaining cases had an extra-nidal pattern of calcification (20%).

Treatment and patient outcomes

Surgical resection alone was used in 70% of the cases, while 20% opted for endovascular embolization. The average follow-up period was 16.7 months, ranging from 0.5 to 36 months. All patients had improved after being treated. Improvement was described using the mRS. Of the patients managed by surgery, 13 (65%) had an mRS score of 1, and 1 (5%) had an mRS score of 2. All patients treated by endovascular embolization had an mRS score of 1, except for one death outcome [Table 3].

DISCUSSION

This study contributes to the limited literature on cCAVMs by not only highlighting their features but also proposing a classification system based on their characteristics observed on CT scans.

Pathophysiology of calcification in AVMs

AVMs are the second most common type of vascular malformation in the brain and the second most common type of brain lesion to calcify.[11] The exact pathophysiology of calcification in AVMs is not yet fully understood. Some possible causes of calcification in AVMs include chronic venous ischemia, vasculitis, repeated hemorrhage,

Table 1: Demographics, Presenting Symptoms, & Arteriovenous malformation characteristics

Demographics, Presenting Symptoms, & AVM characteristics	
	Patients, n (%)
Number of patients	**20 (100)**
Age (years), average (range)	32.9 (11 – 69)
Gender	
Male	11 (55)
Female	9 (45)
Co-morbidities	
Asthma	1 (5)
Mental Retardation	2 (10)
Chronic Obstructive Pulmonary Disease	1 (5)
Hypertension	1 (5)
Temporal Lobe Epilepsy	1 (5)
Location	
Frontal	7 (35)
Parietal	3 (15)
Occipital	2 (10)
Temporal	1 (5)
Frontoparietal	2 (10)
Parietooccipital	2 (10)
Frontoparietotemporal	1 (5)
Basal Ganglia	1 (5)
NA	1 (5)
Presenting Symptoms	
Seizures	14 (70)
Headache	13 (65)
Hemiparesis	4 (20)
Altered Mental Status	3 (15)
Visual Deficit	3 (15)
Nuchal Rigidity	2 (10)
Photophobia	1 (5)
Nausea & Vomiting	1 (5)
Presence of AVM Rupture	
Yes	3 (15)
No	17 (85)
Presence of AVM In Eloquent Areas/Regions	
Yes	9 (45)
No	7 (35)
NA	4 (20)
Venous Drainage	
Superficial Superior Sagittal Sinus	13 (65)
Deep Galenic System	3 (15)
Superficial Superior Sagittal Sinus + Deep Galenic System	1 (5)

(Contd...)

Table 1: *(Continues).*

Demographics, Presenting Symptoms, & AVM characteristics	
	Patients, n (%)
Number of patients	**20 (100)**
NA	3 (15)
Spetzler-Martin AVM Grading	
Grade 1	3 (15)
Grade 2	5 (25)
Grade 3	5 (25)
Grade 4	3 (15)
NA	4 (20)

Abbreviations: AVM; Arteriovenous malformation, NA; Not Available.

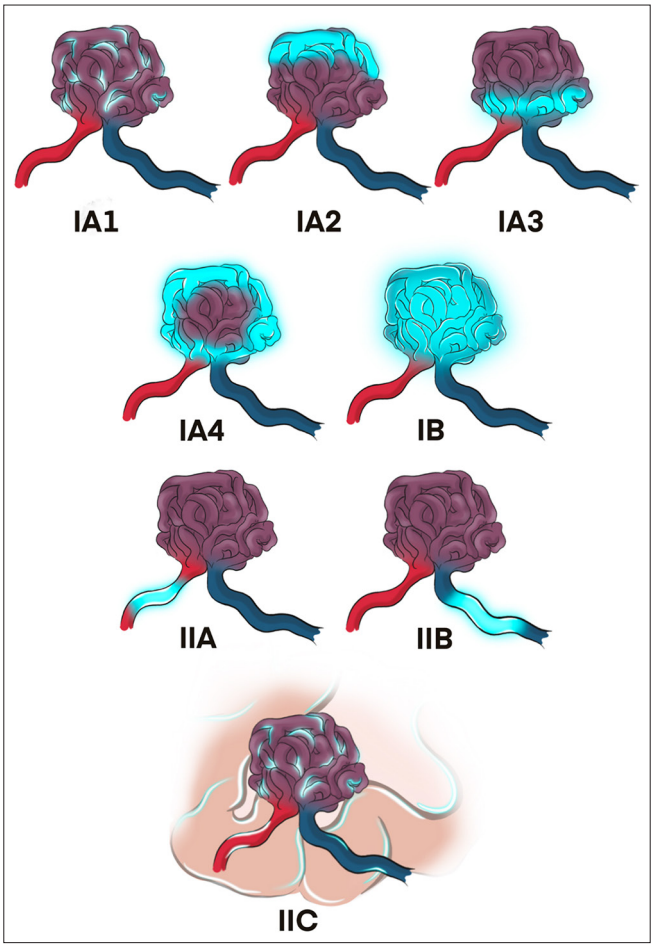

Figure 2: Proposed classification and patterns of arteriovenous malformation AVM: Arteriovenous malformations. This figure categorizes AVM calcifications into Type I (Nidal Calcification) and Type II (Extra-Nidal Calcification). Type I includes partial (IA1–IA4) and total (IB) calcifications of the nidus. Type II involves extra-nidal calcifications, affecting the feeding artery (IIA), draining vein (IIB), or presenting as generalized cerebral calcifications (IIC).

Table 2: Characteristics of Arteriovenous Malformation Calcifications.

Characteristics of Arteriovenous Malformation Calcifications Calcifications			Patients (n) (%)
Type I: Nidal calcification	Type IA: Partial	IA1: Punctate	4 (20)
		IA2: Superficial part	7 (35)
		IA3: Deep part	2 (10)
		IA4: Circumferential	3 (15)
	Type IB: Total		1 (5)
Type II: Extra-Nidal calcification	IIA: Feeding artery		1 (5)
	IIB: Draining vein		2 (10)
	IIC: Generalized cerebral calcifications		1 (5)

Table 3: Outcomes Based on Treatment Method for All Lesion Locations.

Treatment Type	Number of Patients (n)	Outcome (mRS scoring)	Patients (n) (%)
Surgery	14	1	13 (65)
		2	1 (5)
Endovascular Embolization	4	1	3 (15)
		6	1 (5)
Surgery+Endovascular Embolization	1	1	1 (5)
Stereotactic Radiosurgery	1	2	1 (5)

Table 4: Proposed Classification and Patterns of Calcified AVM.

TYPE I: Nidal calcification:
- TYPE IA: Partial calcification of Nidus (IA1: Punctate; IA2: Superficial part of nidus; IA3: Deep part of nidus; IA4: Circumferential).
- TYPE IB: Total calcification of Nidus

TYPE II: Extra-Nidal calcification:
- TYPE IIA: calcification of feeding artery.
- TYPE IIB: calcification of draining vein.
- TYPE IIC: Generalized cerebral calcifications.

intraluminal thrombosis, chronic inflammation, and vascular steal, which shunts more blood toward the AVM, causing calcium deposition on ischemic and dystrophic parenchyma, or damaged tissue.[3,4,11,28] Another postulated theory behind calcification is that AVMs spontaneously involute and regress, causing the lesion to become sclerotic and filled with calculi, which causes the AMV to shrink and become calcified.[15]

Classification and patterns of calcified AVM

The calcification was found to be located within or outside the nidus. This is consistent with the findings of Florian *et al.* and Sayani *et al.*, who reported that calcification in AVMs is predominantly within the nidus, in the vessels, or possibly extended to the cerebral tissue.[8,22] Based on the data extracted,[5,7-9,20-23,25,26] we propose a new classification system for calcified AVMs according to the underlying pathophysiology of calcified AVM patterns [Table 4]. Type I nidal AVM calcification entails calcification that could be type IA partial (IA1, IA2, IA3, and IA4) or type IB total (IB). The partial calcification has several patterns, including punctate (IA1), superficial part (IA2), deep part (IA3), or circumferential (IA4) [Figure 2]. Type II extra-nidal calcification can be found in the feeding artery (IIA), draining vein (IIB), or cerebral parenchyma (IIC) [Figure 2]. This new classification system provides a clear and concise way to describe the location, size, and extent of calcification, which will help in diagnosing and managing calcified AVMs.

Calcified cCAVMs characteristics

The Spetzler-Martin AVM grading system is influenced by AVM size, the eloquence of the adjacent brain, and the venous drainage pattern.[24] The mean size of cCAVMs was 3.6 cm, with the largest measuring 7.5 cm. Larger AVM size correlates with higher Spetzler-Martin grading scores, which, in turn, guide diverse management approaches.[24] Notably, 45% of our cCAVM were in eloquent brain regions, and this localization's potential impact on outcomes warrants examination. However, Mascitelli *et al.*'s investigation involving 241 patients with eloquent brain AVMs found no significant association between eloquent locations and AVM outcomes.[18] In addition, most patients exhibited venous drainage into the superficial superior sagittal sinus, akin to

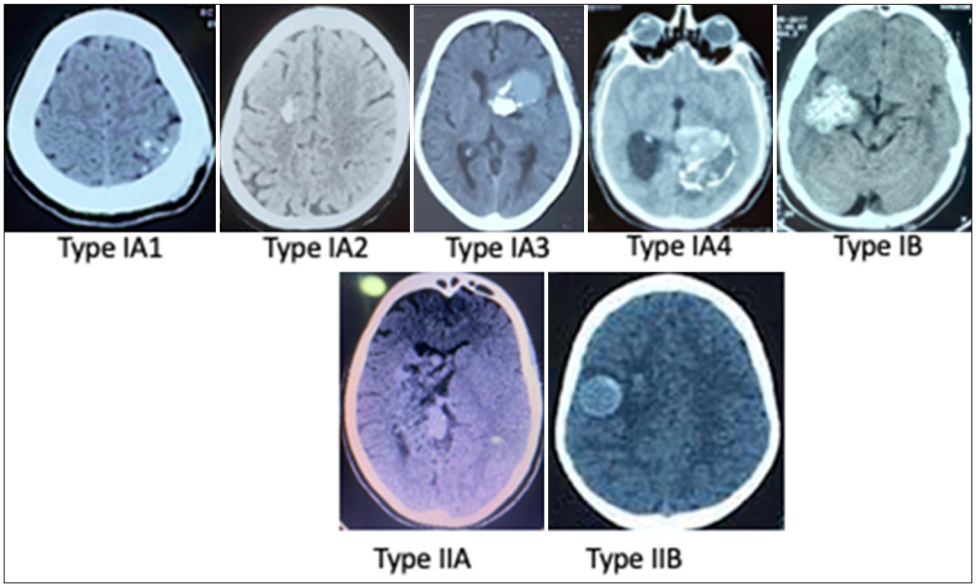

Figure 3: Patterns of calcified arteriovenous malformation on brain computed tomography scans. This figure illustrates various patterns of AVM calcifications, categorized into Type I (Nidal Calcification) and Type II (Extra-Nidal Calcification). Type I: Nidal Calcification includes IA1 (Punctate Calcification), characterized by small, focal calcifications scattered within the nidus; IA2 (Superficial Calcification of Nidus), where calcifications are limited to the outer regions of the nidus; IA3 (Deep Calcification of Nidus), involving deeper portions of the nidus; IA4 (Circumferential Calcification of Nidus), where the nidus is entirely surrounded by calcification; and IB (Total Calcification of Nidus), indicating advanced or chronic changes with complete nidus calcification. Type II: Extra-Nidal Calcification includes IIA (Calcification of Feeding Artery), where the arterial supply to the AVM shows calcification, possibly due to prolonged vascular stress; IIB (Calcification of Draining Vein), which involves the venous outflow pathway and may suggest altered hemodynamics or chronic venous hypertension; and IIC (Generalized Cerebral Calcifications), involving widespread calcifications beyond the AVM, potentially indicating extensive vascular pathology or secondary brain tissue changes.

the drainage pattern observed in Huang *et al*.'s study, where over 70% of patients had superficial drainage.[14]

Presenting symptoms

About 70% of our involved patients presented with seizures followed by headaches. About 45% of patients presented concomitantly with a history of seizures and headaches. A systematic review conducted by Abecassis *et al*. reported that intracranial hemorrhage was the most common initial presenting symptom among all nine single-center studies, followed by seizure and headache.[1] In a retrospective review study by Gorgan *et al*., more than 60% of the patients presented with ruptured AVMs, and more than 30% presented with seizures.[12] Our study aligns with the study mentioned above that seizures were the most common presenting symptom. Nonetheless, it is imperative to acknowledge that the entirety of our patient cohort exhibited calcification in the CAVM, raising inquiry regarding the potential influence of this particular pathology on the predominant manifestation of seizures as the most frequent presenting symptom, in stark contrast to the prevailing literature, wherein hemorrhage typically prevails as the primary presentation.

AVM treatment modalities

Many options have emerged regarding the treatment modalities of AVMs to balance between favorable and adverse outcomes. The three main treatment options include microsurgical resection, stereotactic radiosurgery, and endovascular embolization. A study by Wu *et al*. focused on endovascular embolization only; complete obliteration post-embolization was reported to be 58.3%.[27] Moreover, a study by Davidson and Morgan reports that 96.9% obliteration rates were achieved in surgery-only patients.[6] In addition, Al-Smadi *et al*. suggested that a multimodality treatment plan consisting of surgery and endovascular embolization offers a safe and favorable outcome; however, the findings are not statistically significant when compared to a surgical treatment alone.[2] Our study achieved a successful outcome in the therapeutic management of the patient, achieving a ≤2 mRS score using surgery, endovascular embolization,

or a combination of both. However, one patient treated by endovascular embolization experienced a death outcome, which could be attributed to the high Spetzler-Martin grade. Nevertheless, our study findings necessitate the need for more studies of cCAVMs and the relevant treatment options to achieve a positive outcome. In selecting the ideal treatment strategy, a multidisciplinary approach is required to assess the individual characteristics of each patient's AVM to achieve optimal outcomes.

Clinical implications of cCAVMs

The general understanding of the diagnostic significance of calcification visualization through CT scans in cAVMs elucidates the chronic nature of the pathological lesion. However, the correlation between the calcification type in the CT scan and the intraoperative finding or outcome is not feasible at this early phase. Substantiating this assertion necessitates the inclusion of a bigger cohort of patients with detailed imaging, and intraoperative documentation would be fruitful through future studies.

Based on our experience, type IB (total nidal calcification) and IA3 (partial nidal calcification-deep part), for example, tend to be relatively low-flow AVMs intraoperatively with considerably shorter operative time and related intraoperative complications. In contrast, type IA2 and IA4 (partial nidal calcification-superficial part and partial nidal calcification-circumferential, respectively) seem to be correlated with a straightforward initial dissection and skeletonization of the cAVM structure. Nonetheless, it is important to acknowledge that based on the currently limited sample size, such significant observations remain inconclusive in their robustness.

We believe that this study will highlight the importance of the detailed and systematic description of cAVM calcification in future studies, and that would represent the first step toward a better understanding of the potential clinical and/or surgical impact of such relatively common imaging findings.

Limitations

The existing body of literature pertaining to the comprehensive characterization of tomographic imaging attributes specific to cCAVMs remains notably limited, necessitating the incorporation of case reports within the framework of this systematic review. Although this is not the best practice from an evidence-based perspective, the intrinsic value of this review lies in its potential to represent the initial solid steps toward an improved understanding of the clinical impact of calcification patterns beyond being a mere diagnostic indicator.

Our study of calcification is based on CT scan findings, which is the preferred initial diagnostic imaging for AVM, particularly those presented with intracerebral hemorrhage. It is noteworthy, however, that a limitation emerges due to the non-uniform inclusion of CT scan data across studies, with certain investigations exclusively relying on MRI findings, which, in conjunction with angiography, serve as the preferred diagnostic tools.[13] In addition, bleeding from cAVM may obscure the full calcification pattern in select cases.[20]

CONCLUSION

cCAVMs are common but underreported lesions of the brain. The pooled cases from the literature showed that headaches and seizures were the frequent presenting symptoms. However, heterogeneity was apparent in CT heads in patients' cCAVMs. Our classification system has been proposed due to the diverse patterns that describe the location, size, and extent of the cCAVMs, which will enable comparison in future studies across different centers.

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Use of artificial intelligence (AI)-assisted technology for manuscript preparation: The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

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