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ORIGINAL ARTICLE

Location-based clinical and angiographic profile of brain arteriovenous malformations – a single-center observational study

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Abstract

Background The location of brain arteriovenous malformations (bAVM) is one of the most relevant prognostic factors included in surgical, endovascular and radiosurgical scores. However, their characteristics according to location are seldom described. The goal of this study was to describe the clinical and angiographic characteristics of bAVM classified according to their location.

Methods This retrospective observational study included patients diagnosed with bAVM and attending a national referral hospital during the period 2010–2020. Data regarding clinical and angiographic variables were extracted, including characteristics on nidus, arterial afferents, venous drainage and associated aneurysms. BAVM were classified in 8 groups according to their location: frontal, temporal, parieto-occipital, periventricular, deep, cerebellar, brainstem and mixed. Data distribution for each group was determined and between-group differences were assessed.

Results A total of 269 bAVM (in 258 patients) were included. The most frequent location was parieto-occipital; and the least frequent, brainstem. Statistically significant differences were observed between groups for most studied variables, including: clinical presentation, functional status at admission; nidus size and density, classification according to the Spetzler-Martin, Buffalo and modified Pollock-Flickinger scales; number, diameter, origin and type of afferents; number, diameter, type and direction of venous drainage, retrograde venous flow; and presence and size of flow-related aneurysms.

Conclusion The clinical and angiographic differences observed between brain AVM groups allow the formulation of profiles according to their location.

Keywords Intracranial arteriovenous malformations · Intracranial aneurysm · Intracranial hemorrhages · Cerebral angiography · Observational study

Abbreviations

bAVM	Brain arteriovenous malformation
AA	Associated aneurysm
PAR	Pittsburg AVM Radiosurgery score
ECA	External carotid artery
IQR	Interquartile range
mRS	Modified Rankin scale
SD	Standard deviation
SSS	Superior sagittal sinus
CS	Cavernous sinus
TS/SG	Transverse/sigmoid sinus
SS	Straight sinus

Introduction

Brain arteriovenous malformation (bAVM) is a rare neurovascular pathology, with annual incidence estimated to range between 0.69 and 1.32 per 100000 [21]. However, it is regarded as the main cause of hemorrhagic stroke in young adults [33]. This entity is defined by arteriovenous shunts with an intermediating zone of abnormal vascular tissue known as nidus [12]. The heterogeneity in clinical and angiographic characteristics and the diversity of therapeutic modalities still cause controversies regarding their management [5]. One of the most relevant prognostic factors for the management of this pathology is location, which is one of the variables most frequently included in surgical [9],

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endovascular and radiosurgical [32] classification schemes. Nevertheless, clinical and angiographic differences according to location are rarely described. Besides, studies on bAVM in the Latin population are scarce, with few data available for decision making regarding their management. The objective of this study was to describe the clinical and angiographic characteristics of bAVM according to location in a national Peruvian referral hospital.

Methods and materials

Study design and population

This was a retrospective descriptive observational study which included patients with diagnosis of bAVM who attended to Hospital Nacional Daniel Alcides Carrión (Callao, Peru) during the period from January 2010 to December 2020. Eligibility criteria were: 1) catheter angiography-confirmed diagnosis of bAVM, and 2) availability of clinical and imagenological records for retrospective review. Patients were included regardless of age and sex. Included cases were grouped in 8 classes according to bAVM location [14]: frontal, temporal, parieto-occipital, periventricular, deep, cerebellar, brainstem and mixed.

Data extraction

Data was extracted independently by two authors (JBF and JAM) and posteriorly merged into a database. Clinical (clinical variables) and imagenological (angiographic variables) records were checked. Clinical variables included: age, sex, clinical presentation and functional status (according to the modified Rankin scale-mRS [35]) at admission. Angiographic variables included features of nidus, feeders and draining veins such as location, volume, compactness [7], number, diameter and origin/end. Data on the characteristics of associated intracranial aneurysms (AA) were also extracted, including type [6], location, shape and size. Given the descriptive nature of this study, no outcome variables were assessed.

Statistical analysis

Data on categorical variables were summarized in frequency tables. Data on continuous variables were summarized with central-tendency measures according to their categorical distribution. Stratification according to bAVM location [14] was performed. Statistical analyses for between-group differences were performed with the epiDisplay package for R-software v4.2.1 [25].

Ethical considerations

In accordance with the requirements of the Helsinki Declaration [36], the study protocol was approved by the institutional review board. Given the observational and retrospective study design, the need for informed consent was waived. Data was anonymized by the use of clinical record numbers as identifiers. A unique database was elaborated, to which only the authors had access.

Results

Study population

During the study period, a total of 308 patients registered with diagnosis of bAVM had available clinical records. Among those patients, a total of 258 (with 269 bAVM) had imagenological archive available for revision and were included in the study. Most of the continuous variables assessed did not show normal distribution, which was anticipated given that variables such as age, nidus size, number of feeders and draining veins, are expected to be skewed to lower values within their ranges in a population of bAVM patients. The median age was 28 years, with 39 (15.1%) pediatric patients (< 18 years old), 132 (51.2%) males, 174 (67.4%) with favorable functional status at admission, and 10 (3.9%) bearing multiple bAVM (9 patients with 2 nidi, 1 patient with 3 nidi). The most frequent location was parieto-occipital (26.0%); and the least frequent, brainstem (1.5%). The most frequent subtypes for each location group were lateral frontal (10.8%), sylvian temporal (4.1%), lateral parieto-occipital (11.2%), basal ganglial (deep) (5.2%), callosal periventricular (2.6%), vermian cerebellar (4.1%), posterior mesencephalic (brainstem) (1.5%) and frontoparietal (mixed) (3.3%) (Fig. 1). Detailed data regarding proportions of location subtypes is provided in the Supplementary information (Online Resource 1).

Clinical characteristics

The clinical characteristics of bAVM according to location are detailed in Table 1. The main clinical presentation was bleeding (63.9%), with 158 (58.7%) ruptured nidi and 14 (5.2%) ruptured AA. Presentation with seizures without history of bleeding occurred in 54 (20.1%) cases. Other clinical manifestations related to the bAVM such as vascular steal, cranial nerve neuralgia and non-communicating hydrocephalus occurred in 11 (4.1%) cases. The diagnosis was incidental in 32 (11.9%) cases. Periventricular and cerebellar

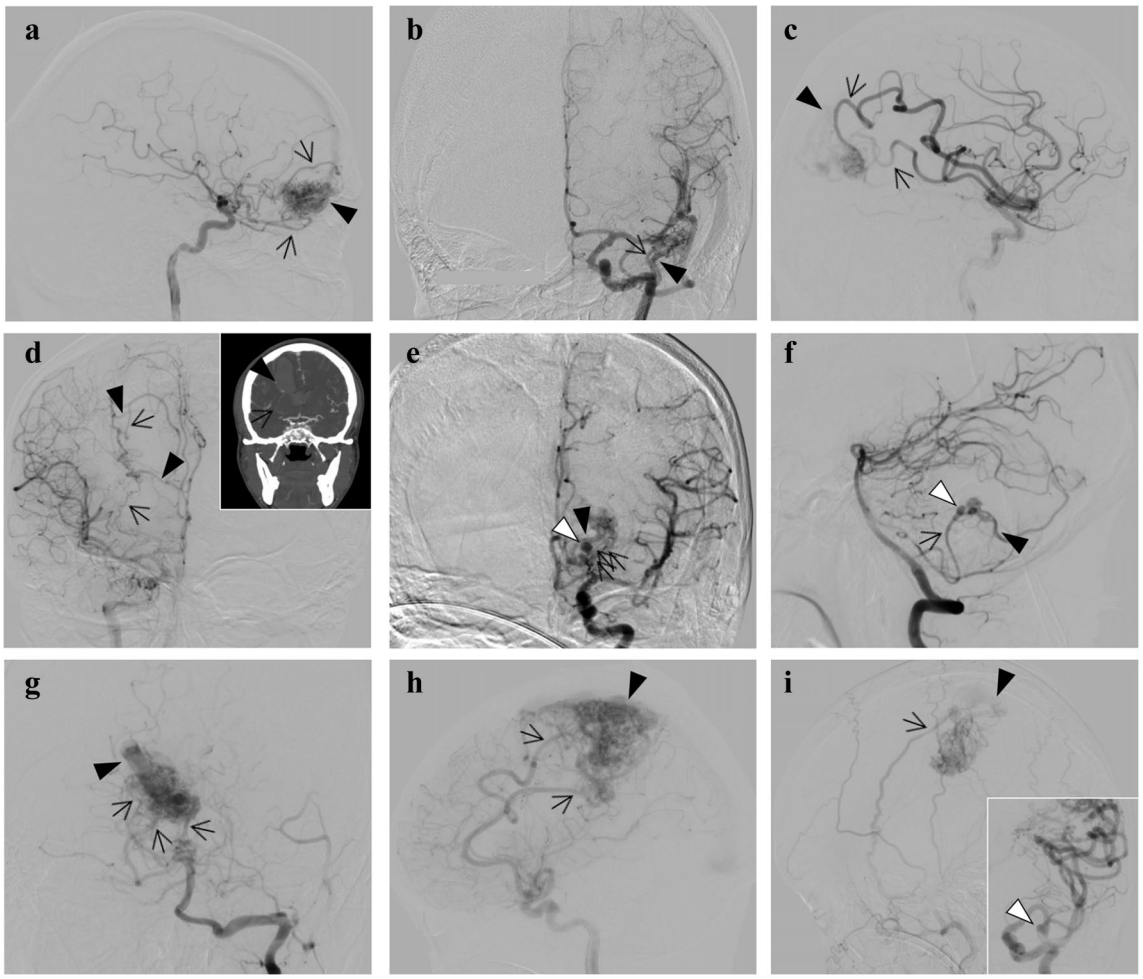

Fig. 1 Most frequent locations of brain arteriovenous malformations (bAVM). **A** Frontal bAVM, lateral subtype. **B** Temporal bAVM, sylvian subtype. **C** Parieto-occipital bAVM, lateral subtype. **D** Periventricular bAVM, callosal subtype, despite the small nidus size, is associated with an intracerebral hematoma of considerable volume (inserted image). **E** Deep bAVM, basal ganglia subtype, with associated distal flow-related aneurysm. **F** Cerebellar bAVM, vermian subtype, with associated distal flow-related aneurysm. **G** Brainstem bAVM, posterior mesencephalic subtype, with prominent draining vein. **H** Mixed bAVM, frontoparietal location, with feeder from external carotid artery **I** and proximal flow-related aneurysm at middle cerebral artery bifurcation (inserted image). The component parts of bAVM are pointed by the same symbols: feeder (→), draining vein (►) and associated aneurysm (Δ)

locations almost exclusively presented with bleeding, mostly originated from bAVM nidi.

Angiographic characteristics

The median maximum diameter and volume were 28.5 mm and 4.9 mL, respectively. Eloquent location was observed in 144 (53.5%) cases. Nidi were described as compact in 123 (45.7%) cases. Most bAVM were low-grade (Spetzler-Martin [29] I and II) (48.7%). Among intermediate-grade bAVM (Spetzler-Martin III), most showed low to intermediate scores in the supplemented classification (≤6) [15]. Most bAVM had also a favorable class according to the Buffalo [4] score (75.2%) and a median score of 1.4 in the modified Pittsburg AVM Radiosurgery (PAR) score [23]. Temporal location showed the most favorable profile for the Spetzler-Martin and Buffalo classifications (Table 2). Other favorable locations were cerebellar and parieto-occipital. Periventricular location showed the most favorable profile for the modified PAR score.

The median number of feeders was 3, with a mean diameter of 1.3 ± 0.5 mm. The origin of feeders from anterior and posterior circulation was according to the bAVM location. Feeders from external carotid artery (ECA) were observed in 7.4% of bAVM, mainly corresponding to mixed location (Table 3). Terminal, perforating, choroidal and *en passage* feeders were observed in 79.3%, 24.8%, 12.2% and 31.9% of bAVM, with perforating and choroidal feeders being the most frequent type in deep and periventricular locations, respectively.

Table 1 Clinical characteristics of study population

Characteristic	Frontal ($n=66$)	Temporal ($n=30$)	Parieto-occipital ($n=70$)	Peri-ventricular ($n=18$)	Deep ($n=35$)	Cerebellar ($n=32$)	Brainstem ($n=4$)	Mixed ($n=14$)	Total ($n=269$)	*p*-value
Age (y), median (IQR)	28.5 (19–43.8)	32 (24–35)	27.5 (20–44.5)	25 (21.5–37)	23 (19.5–31.5)	32 (20.8–46)	24 (18–37.2)	31.5 (23.8–36)	28 (20–41)	0.665[a]
Males, *n* (%)	39 (59.1)	12 (40)	37 (52.9)	9 (50)	18 (51.4)	15 (46.9)	0 (0)	8 (57.1)	138 (51.3)	0.344[b]
Clinical presentation, *n* (%)										< 0.001[c]
Bleeding from nidus	31 (47)	17 (56.7)	37 (52.9)	17 (94.4)	23 (65.7)	27 (84.4)	2 (50)	4 (28.6)	158 (58.7)	
Bleeding from AA	2 (3)	3 (10)	2 (2.9)	0 (0)	1 (2.9)	4 (12.5)	0 (0)	2 (14.3)	14 (5.2)	
Seizure	25 (37.9)	7 (23.3)	16 (22.9)	1 (5.6)	1 (2.9)	0 (0)	0 (0)	4 (28.6)	54 (20.1)	
Other	2 (3)	0 (0)	4 (5.7)	0 (0)	1 (2.9)	1 (3.1)	2 (50)	1 (7.1)	11 (4.1)	
Incidental	6 (9.1)	3 (10)	11 (15.7)	0 (0)	9 (25.7)	0 (0)	0 (0)	3 (21.4)	32 (11.9)	
Multiple bAVM, *n* (%)	6 (9.1)	0 (0)	6 (8.6)	2 (11.1)	6 (17.1)	1 (3.1)	0 (0)	0 (0)	21 (7.8)	0.236[c]
Favorable mRS at admission, *n* (%)	48 (72.7)	20 (66.7)	56 (80)	10 (55.6)	15 (42.9)	20 (62.5)	1 (25)	10 (71.4)	180 (66.9)	0.005[b]

IQR Interquartile range; *AA* Associated aneurysm; *mRS* Modified Rankin scale, favorable corresponds to 0–2 score

[a]Kruskal-Wallis' test

[b]χ^2 test

[c]Fisher's exact test

The median number and average diameter of draining veins were 1 and 2.9 mm, respectively. The higher number and larger average draining veins diameters were observed in mixed and brainstem locations, respectively (Table 4). The highest proportion of retrograde venous flow was observed also for these locations. The venous drainage type (superficial, deep and mixed) was according to the bAVM location. Locations with the highest proportion of drainage to superior sagittal, cavernous, transverse & sigmoid and straight sinuses were mixed, temporal, temporal and periventricular/brainstem, respectively.

A total of 206 intracranial aneurysms were observed in 111 bAVM. Mixed location showed the highest mean number of AA per bAVM (21/7); and temporal location, the lowest mean number (14/12). Unrelated AA (type I), flow-related AA (type II) and intranidal AA (type III) were observed in 22 (19.8%), 70 (63.1%) and 40 (36%) cases among bAVM with AA (Table 5). Most flow-related AA had saccular shape, present in 69/70 (98.6%) of bAVM with flow-related AA. The median size of both flow-related and intranidal AA was 4 mm. Proximal (type IIa) and distal (type IIb) flow-related AA were observed in 35 (50%) and 50 (71.4%) cases of bAVM with type II AA. Mixed location showed the highest proportion and size of proximal flow-related AA.

Discussion

The results of this study show that most variables assessed display statistically significant differences according to bAVM location, which allowed the formulation of profiles. Although detailed angiographic descriptions for every location are scarce in the literature, several similarities and differences from other series can be featured.

Superficial supratentorial locations

Most of the observed differences in clinical features according to location are similar to those reported in the literature. Frontal bAVM presented most frequently with seizures. This clinical presentation has been observed more frequently in cortical locations, mainly frontal and temporal [3], predominance of frontal location expectable given the involvement of the primary motor cortex. Temporal bAVM showed the highest proportion of low-risk cases according to the Spetzler-Martin and Buffalo classification schemes. This predominance of low-risk lesions has been reported previously [8]. Besides, our series showed that temporal bAVM were most frequently of lateral subtype, with small nidi and feeders mainly from anterior circulation (middle cerebral artery) and low Spetzler-Martin grade, similarly to other reported series [8]. Parieto-occipital bAVM showed

Table 2 Angiographic characteristics of nidus and bAVM classification schemes

Characteristic	Frontal ($n=66$)	Temporal ($n=30$)	Parieto-occipital ($n=70$)	Peri-ventricular ($n=18$)	Deep ($n=35$)	Cerebellar ($n=32$)	Brainstem ($n=4$)	Mixed ($n=14$)	Total ($n=269$)	p-value
Maximum diameter (mm), median (IQR)	36.8 (21.5–49.6)	24 (16.9–33)	27.6 (20–42.2)	17.6 (17–29.9)	25.9 (16–35.5)	24.2 (14.6–42.3)	32.5 (24.7–40.3)	58.1 (51–65.7)	28.5 (18.4–42.9)	<0.001[a]
Volume (mL), median (IQR)	12.5 (2.5–34.9)	3 (0.8–11.7)	6.5 (1.6–20.3)	1.8 (1–3.5)	4 (0.7–8.7)	2.3 (0.6–15.5)	10.6 (6.5–21.6)	39.4 (25.3–94.8)	4.9 (1.4–21.2)	<0.001[a]
Eloquent location, *n* (%)	33 (50)	14 (46.7)	32 (45.7)	11 (61.1)	25 (71.4)	14 (43.8)	4 (100)	11 (78.6)	144 (53.5)	0.027[b]
Nidus compactness, *n* (%)										0.033[c]
Diffuse	19 (28.8)	11 (36.7)	22 (31.4)	8 (44.4)	15 (42.9)	7 (21.9)	1 (25)	5 (35.7)	88 (32.7)	
Intermediate	19 (28.8)	3 (10)	7 (10)	4 (22.2)	7 (20)	10 (31.2)	2 (50)	6 (42.9)	58 (21.6)	
Compact	28 (42.4)	16 (53.3)	41 (58.6)	6 (33.3)	13 (37.1)	15 (46.9)	1 (25)	3 (21.4)	123 (45.7)	
Spetzler-Martin scale, *n* (%)										<0.001[c]
I-II	35 (53)	20 (66.7)	40 (57.1)	5 (27.8)	9 (25.7)	20 (62.5)	0 (0)	2 (14.3)	131 (48.7)	
III	19 (28.8)	8 (26.7)	23 (32.9)	10 (55.6)	19 (54.3)	10 (31.2)	2 (50)	4 (28.6)	95 (35.3)	
Suppl. ≤ 6	12 (63.2)	8 (100)	16 (69.6)	10 (100)	14 (73.7)	6 (60)	1 (50)	1 (25)	68 (71.6)	0.031[c]
Suppl. > 6	7 (36.8)	0 (0)	7 (30.4)	0 (0)	5 (26.3)	4 (40)	1 (50)	3 (75)	27 (28.4)	
IV-V	12 (18.2)	2 (6.7)	7 (10)	3 (16.7)	7 (20)	2 (6.2)	2 (50)	8 (57.1)	43 (16)	
Buffalo score, *n* (%)										<0.001[c]
1–3	48 (72.7)	28 (93.3)	61 (87.1)	10 (55.6)	21 (60)	27 (84.4)	1 (25)	6 (42.9)	202 (75.1)	
4–5	18 (27.3)	2 (6.7)	9 (12.9)	8 (44.4)	14 (40)	5 (15.6)	3 (75)	8 (57.1)	67 (24.9)	
PAR score, median (IQR)	2 (0.8–4.2)	1.2 (0.8–1.7)	1.4 (0.8–2.7)	1.1 (0.7–1.4)	1.4 (1–2)	1.2 (0.7–2.2)	2.1 (1.8–3.2)	4.6 (3.2–10.5)	1.4 (0.8–2.9)	<0.001[a]

IQR Interquartile range; *Suppl*. Supplemented Spetzler-Martin scale (Lawton-Young); *PAR* Pittsburgh AVM score (modified Pollock-Flickinger scale)

[a]Kruskal-Wallis' test

[b]χ^2 test

[c]Fisher's exact test

Table 3 Angiographic characteristics of feeders

Characteristic	Frontal ($n=66$)	Temporal ($n=30$)	Parieto-occipital ($n=70$)	Peri-ventricular ($n=18$)	Deep ($n=35$)	Cerebellar ($n=32$)	Brainstem ($n=4$)	Mixed ($n=14$)	Total ($n=269$)	*p*-value
Number, median (IQR)	3 (2–5)	2 (2–3)	3 (2–5)	2.5 (1.2–3.8)	3 (1–5)	2 (1–4)	4.5 (2.8–6.2)	7 (4.2–11.2)	3 (2–5)	<0.001[a]
Average diameter (mm), mean ± SD	1.4 ± 0.5	1.4 ± 0.5	1.4 ± 0.5	1 ± 0.4	1 ± 0.4	1.2 ± 0.4	1.3 ± 0.5	1.7 ± 0.5	1.3 ± 0.5	<0.001[b]
Circulation of origin, *n* (%)										
Anterior	66 (100)	26 (86.7)	54 (77.1)	17 (94.4)	29 (82.9)	1 (3.1)	0 (0)	14 (100)	207 (77)	<0.001[c]
Posterior	2 (3)	11 (36.7)	43 (61.4)	7 (38.9)	15 (42.9)	32 (100)	4 (100)	7 (50)	121 (45)	<0.001[d]
ECA	4 (6.1)	2 (6.7)	8 (11.4)	0 (0)	0 (0)	1 (3.1)	0 (0)	5 (35.7)	20 (7.4)	0.011[c]
Type, *n* (%)										
Terminal	61 (92.4)	27 (90)	66 (94.3)	8 (44.4)	4 (11.4)	32 (100)	2 (50)	13 (92.9)	213 (79.2)	<0.001[c]
Perforating	14 (21.2)	2 (6.7)	2 (2.9)	7 (38.9)	30 (85.7)	3 (9.4)	2 (50)	7 (50)	67 (24.9)	<0.001[c]
Choroidal	2 (3)	5 (16.7)	1 (1.4)	11 (61.1)	11 (31.4)	0 (0)	2 (50)	1 (7.1)	33 (12.3)	<0.001[c]
En passage	20 (30.3)	14 (46.7)	25 (35.7)	1 (5.6)	8 (22.9)	8 (25)	2 (50)	7 (50)	85 (31.6)	0.049[d]

IQR Interquartile range; *SD* Standard deviation; *ECA* External carotid artery

[a]Kruskal-Wallis' test

[b]F-test

[c]Fisher's exact test

[d]χ^2 test

the highest proportions of favorable functional status at admission and compact nidus. No previous reports about these features have been found. Furthermore, parietal and occipital locations are rarely reported jointly. Most reports focus on the occipital region, presumably due to the risk for the visual pathway. For the subgroup of occipital bAVM, differing characteristics from our parieto-occipital group have been reported, including larger size, more frequent eloquent location and deep venous drainage, and higher proportion of high Spetzler-Martin grade [37].

Deep supratentorial locations

Periventricular bAVM most frequently presented with bleeding from ruptured nidus, despite having the smallest size and narrowest feeders, mostly of choroidal type, with venous drainage least frequently showing retrograde flow, and absent proximal flow-related AA. Ruptured presentation is more frequently reported for deep and infratentorial locations [13], similar to what was observed in this study, with the highest proportions for periventricular, cerebellar and deep locations. Although there are reports of periventricular bAVM of intermediate size (> 2 cm) and more frequent temporal horn location [18], it is likely that this series involved cases of deep bAVM with ventricular extension. More recent series [20] show smaller sizes (< 2 cm), but more frequent location in III ventricle, with higher frequency of feeders from posterior circulation and superficial venous drainage, compared to our series. Deep bAVM showed the narrowest feeders, mostly of perforating type, with the smallest proximal flow-related AA. Previous reports [24] found predominance of the insular subtype, while in our series, thalamic subtype was predominant. Differences regarding nidus compactness were also observed, with compact type much less frequent in our series. Similarities between these series include smaller size, higher eloquent location and venous drainage predominately deep. No previous descriptions of flow-related AA for periventricular and deep locations have been found.

Infratentorial locations

Cerebellar bAVM showed the highest proportion of presentation with bleeding, as well as the narrowest draining veins. Regarding the flow-related AA, cerebellar bAVM showed the highest proportion of the distal type, but absence of the proximal type. The high frequency of ruptured presentation and AA has been previously reported for posterior fossa bAVM [17], which are mainly of cerebellar location. However, our series showed lower frequency of eloquent location, lower proportion of compact nidi and higher proportion of superficial venous drainage compared to other cerebellar bAVM series [26]. The proportion of eloquent region involvement was variable in the literature, with some series [19, 34] reporting values closer to that observed in our series. No previous descriptions on angiographic features of draining veins were found for cerebellar bAVM. Brainstem bAVM mostly presented with unfavorable functional status, with the highest proportion of high-risk cases according to the Buffalo classification scheme. This group showed a relatively high number of feeders, with the highest proportion of *en passage* type, the widest draining veins, and absence of proximal flow-related AA. Presentation mostly with unfavorable status has been reported in other series [10], but classifications other than Spetzler-Martin have not been used. Brainstem bAVM were more frequently located in the mesencephalon, generally presented with bleeding, had small nidi and venous drainage predominately deep [16], characteristics that have also been observed in our series. All brainstem bAVM in our series were located in the mesencephalon, and showed higher number of feeders with intermediate nidus size, similar to other published series [2], but also a higher proportion of diffuse/mixed nidi and superficial venous drainage, which differs from surgical series [10], but is similar to series with multi-modality management [1]. Notably, no proximal flow-related AA were observed for any infratentorial bAVM in our series. Previous descriptions on types of AA for this region were not found.

Mixed locations

Mixed bAVM showed the highest proportion of presentation with ruptured AA and the lowest for ruptured nidus, the largest size and the lowest proportion of compact nidi. The highest proportions of high-risk cases according to the Spetzler-Martin and modified PAR classification schemes were observed. Mixed locations showed also the highest number of feeders and draining veins, with the largest diameters of feeders, the highest proportion of feeders from ECA and *en passage* type, the highest proportion of draining veins with retrograde flow and the highest number and largest size of proximal flow-related AA. The group of mixed bAVM, which corresponds to those involving more than 1 region from Lawton's classification [14], constitutes a heterogeneous group that, in our series, was conformed mainly by rolandic and temporo-occipital bAVM. Angiographic descriptions for these subtypes are scarce, with similarities regarding size for rolandic bAVM [22] and the proportions of diffuse nidi and deep venous drainage for occipito-temporal bAVM [11]. The relatively low proportion of ruptured presentation for bAVM in these locations is another feature that has also been observed in previous studies [11, 22]. Another remarkable feature of mixed bAVM in our series was the higher proportion of feeders from ECA, compared to other locations. A previous study [30], with a similar proportion of feeders from ECA, observed that this feature is

Table 4 Angiographic characteristics of draining veins

Characteristic	Frontal ($n=66$)	Temporal ($n=30$)	Parieto-occipital ($n=70$)	Peri-ventricular ($n=18$)	Deep ($n=35$)	Cerebellar ($n=32$)	Brainstem ($n=4$)	Mixed ($n=14$)	Total ($n=269$)	*p*-value
Number, median (IQR)	1 (1–2)	1 (1–2)	1,5 (1–2)	1 (1–1)	1 (1–1.5)	1 (1–2)	1.5 (1–2)	2.5 (1.2–3)	1 (1–2)	0.007[a]
Average diameter (mm), median (IQR)	3.5 (2.2–5.3)	2.9 (2.1–4.1)	3 (1.9–4.1)	2.3 (1.6–2.8)	2.3 (1.6–3.5)	2.2 (1.5–2.9)	6.2 (4.7–7.3)	3.7 (2.9–5.6)	2.9 (2–4.1)	<0.001[a]
Retrograde flow, *n* (%)	26 (39.4)	9 (30)	15 (21.4)	3 (16.7)	10 (28.6)	11 (34.4)	2 (50)	9 (64.3)	85 (31.6)	0.037[b]
Type of venous drainage, *n* (%)										<0.001[c]
Superficial	49 (74.2)	20 (66.7)	43 (61.4)	0 (0)	7 (20)	23 (71.9)	1 (25)	9 (64.3)	152 (56.5)	
Mixed	11 (16.7)	5 (16.7)	19 (27.1)	2 (11.1)	3 (8.6)	5 (15.6)	1 (25)	4 (28.6)	50 (18.6)	
Deep	6 (9.1)	5 (16.7)	8 (11.4)	16 (88.9)	25 (71.4)	4 (12.5)	2 (50)	1 (7.1)	67 (24.9)	
Drainage end, *n* (%)										
SSS	57 (86.4)	6 (20)	49 (70)	2 (11.1)	4 (11.4)	0 (0)	2 (50)	12 (85.7)	131 (48.7)	<0.001[b]
CS	9 (13.6)	10 (33.3)	3 (4.3)	0 (0)	5 (14.3)	0 (0)	0 (0)	1 (7.1)	28 (10.4)	0.002[c]
TS/SG	3 (4.5)	18 (60)	22 (31.4)	0 (0)	4 (11.4)	19 (59.4)	0 (0)	4 (28.6)	70 (26)	<0.001[c]
SS	17 (25.8)	10 (33.3)	27 (38.6)	18 (100)	28 (80)	21 (65.6)	3 (75)	5 (35.7)	130 (48.3)	<0.001[b]

IQR Interquartile range; *SSS* Superior sagittal sinus; *CS* Cavernous sinus; *TS/SG* Transverse/sigmoid sinus; *SS* Straight sinus

[a]Kruskal-Wallis' test

[b]χ^2 test

[c]Fisher's exact test

Table 5 Angiographic characteristics of associated aneurysms

Characteristic	Frontal ($n=30$)	Temporal ($n=12$)	Parieto-occipital ($n=30$)	Peri-ventricular ($n=5$)	Deep ($n=12$)	Cerebellar ($n=15$)	Brainstem ($n=0$)	Mixed ($n=7$)	Total ($n=111$)	*p*-value
Number of aneurysms	57	14	57	10	22	25	0	21	206	
Type I, *n* (%)	5 (16.7)	4 (33.3)	5 (16.7)	1 (20)	1 (8.3)	2 (13.3)	-	4 (57.1)	22 (19.8)	0.185[a]
Type II, *n* (%)	18 (60)	6 (50)	18 (60)	2 (40)	9 (75)	11 (73.3)	-	6 (85.7)	70 (63.1)	0.568[a]
Size (mm), median (IQR)	3.6 (2.9–4.5)	5.2 (2.7–6.4)	3.9 (2.7–4.6)	3.1 (3–3.2)	3.8 (3.7–6.3)	4.5 (3.9–5.1)	-	6.5 (4.4–7.9)	4 (3–5)	0.141[b]
Saccular	18 (100)	6 (100)	17 (94.4)	2 (100)	9 (100)	11 (100)	-	6 (100)	69 (98.6)	1.000[a]
Non-saccular	2 (11.1)	1 (16.7)	6 (33.3)	0 (0)	0 (0)	1 (9.1)	-	0 (0)	10 (14.3)	0.297[a]
Type IIa, *n* (%)	10 (55.6)	2 (33.3)	12 (66.7)	0 (0)	6 (66.7)	0 (0)	-	5 (83.3)	35 (50)	<0.001[a]
Size (mm), median (IQR)	3.1 (2.6–3.3)	4.3 (3.3–5.4)	3.9 (3.4–4.9)	NA	3.1 (2.5–6.1)	NA	-	7.2 (6.5–8.3)	3.7 (2.6–5.7)	0.014[b]
Saccular	10 (100)	2 (100)	12 (100)	NA	6 (100)	NA	-	5 (100)	35 (100)	0.058[c]
Non-saccular	0 (0)	0 (0)	1 (8.3)	NA	0 (0)	NA	-	0 (0)	1 (2.9)	1.000[a]
Type IIb, *n* (%)	12 (66.7)	4 (66.7)	11 (61.1)	2 (100)	7 (77.8)	11 (100)	-	3 (50)	50 (71.4)	0.172[a]
Size (mm), median (IQR)	4.2 (3.1–4.8)	5.2 (3.5–6.7)	3.3 (2.3–4.5)	3.1 (3–3.2)	4,9 (3.9–5.5)	4.5 (3.9–5.1)	-	6 (4.7–6.2)	4.1 (3.3–5.3)	0.203[b]
Saccular	11 (91.7)	3 (75)	8 (72.7)	2 (100)	7 (100)	10 (90.9)	-	3 (100)	44 (88)	0.636[a]
Non-saccular	2 (16.7)	1 (25)	6 (54.5)	0 (0)	0 (0)	1 (9.1)	-	0 (0)	10 (20)	0.089[a]
Type III, *n* (%)	14 (46.7)	3 (25)	9 (30)	3 (60)	4 (33.3)	4 (26.7)	-	3 (42.9)	40 (36)	0.623[a]
Size (mm), median (IQR)	4.6 (3.5–7.8)	2.9 (2.7–3.7)	4.7 (3.3–7.4)	4.1 (4–6.4)	3 (2.4–4)	3.2 (2.6–5.1)	-	4.8 (4.3–5.8)	4 (3.1–6.8)	0.458[b]

IQR Interquartile range

n (%): refers to the number of bAVM with the corresponding type of aneurysm

[a]Fisher's exact test

[b]Kruskal-Wallis' test

[c]χ^2 test

associated with larger nidus size and eloquent location, a profile that fits with that observed in mixed bAVM in our series. Of note, despite their rare description as a group, this location showed remarkable characteristics that warrant further study.

Limitations

Some characteristics of our population limit the generalizability of our results. First, pediatric patients are under-represented, given that national referrals of these cases are usually derived to centers specialized in the pediatric population. Second, brainstem bAVM cases were scarce, likely due to the lack of angiographic studies in the setting of poor prognosis associated with ruptured presentation. Therefore, our results could not be accurate for these subgroups of patients.

Implications for practice and research

Although no definitive guidelines have been established for the management of bAVM, treatment decisions are usually based on ruptured status, the risks of treatment complications estimated by several scores, and the expected benefits of treatment [31]. Besides the procedural technical implications of lesion location, it has also found to be relevant for outcome prediction [27, 28]. The differing location-based profiles observed in this study imply that treatment decisions should also take them into consideration, both for management algorithms and cost-effectiveness analyses. It is arguable that general tools could display differing performances if stratified by location, such as bleeding risk scores and predictive classification schemes. Of note, mixed locations displayed particular features not accounted for by the sum of their components. Therefore, further research is needed regarding differences in performance of scores according to location, as well as further study on subgroups such as brainstem bAVM and pediatric patients, which were underrepresented in our population, and mixed location, which outstands as a special subgroup.

Conclusion

The clinical and angiographic heterogeneity of bAVM warrants their grading or classification in order to allow the design of tailored treatment strategies. Our results evidence that the classification according to location is justified, given the existence of differences in several features, which allows the establishment of clinical and angiographic profiles according to location. The formulation of diagnostic and therapeutic management strategies according to bAVM location should ease the standardization of management and optimization of resources use.

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Data availability Data from the present study can be made available upon reasonable request.

Code availability Not applicable.

Declarations

Ethical approval Approval was obtained from the ethics committee of National University of San Marcos. The procedures used in this study adhere to the tenets of the Declaration of Helsinki.

Informed consent The need for informed consent was waived by the ethical committee as this was a retrospective study.

Consent for publication All authors consent to the publication of this work.

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