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Original Article

Management of Brain Stem Cavernomas in Setting of Multiple Intracranial Cavernomas: A Retrospective Analysis of Single Institutional Experience

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BACKGROUND: Cavernomas in the brain stem are associated with higher hemorrhagic rates. Several studies discussed the surgical techniques, safety and outcome results of brainstem cavernomas. In this study, we tried to find the effect of multiple cerebral cavernomas on management of brainstem cavernomas.

OBJECTIVE: Review and assess our institutional experience in managing brain stem cavernomas in the setting of multiple cerebral cavernomas through a retrospective comparative study.

PATIENTS AND METHODS: Using retrospective analysis for the patients who have brain stem cavernomas , older than 18 years old and at least 2 years follow up, we divided them into two groups: The (Non-concomitant) group (Brain stem cavernomas only) and the (concomitant) group (Brainstem and non-brain stem cavernomas). We conducted a comparative study using the demographic criteria, clinical and radiological data, management strategy and cavernoma bleeding difference rates between two groups and its effect on outcome.

RESULTS: Patients were divided into two groups: concomitant group (N= 21) (48.8%)) and non-concomitant group (N= 22) (51.2%)). Radiological types according to modified Zabramski classification showed that the hemorrhagic types are IA, IB, II which accounts for 6 (27.3%) in non-concomitant group, and 15 (71.4%) in concomitant group. ($\chi 2$= 8.384, p value 0.004). Outcome using modified Rankin scale (mRs) showed no difference between two group's outcome neither on presentation nor after a minimum of 2 years (u=199.500, p= 0.397) and (u=180.500, p=0.145), respectively.

CONCLUSION: We concluded that the Multiplicity of Cerebral Cavernomas carries a statistically significant risk for hemorrhagic presentation in brain stem Cavernomas.

KEYWORDS: Brain stem, Concomitant cavernomas, Non-concomitant cavernoma.

INTRODUCTION

The prevalence of cerebral cavernous malformations (CCMs) ranges between 0.4% and 0.9 percent in multiple studies.[1-4] They represent approximately 5% to 10% of all cerebral vascular malformations with 20% located in the brain-stem.[5-7] Managing brain stem cavernomas presents a neurosurgical challenge that must balance the risk of cavernoma bleeding with the high functionality of brain stem regions. Cavernomas in the brain- stem are associated with higher hemorrhagic rates.[8] Several studies have been conducted to explore the different treatment modalities for brain stem cavernomas, but most have taken a holistic approach. They have focused on surgical techniques, safety and outcome results without specifically comparing internal subpopulation to study the effect of multiple cavernomas on the treatment of brain stem cavernomas.[8] Our study examines the effect of multiple CCMs on brain stem cavernoma bleeding and management outcomes.

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PATIENTS AND METHODS

After obtaining approval from various ethical committees (King Fahad medical city, Suez Canal University, and Tanta University) and reviewing the electronic records from 2007 to 2023, patients with brain stem cavernoma, who were over 18 years old and had at least 2 years of follow-up were selected for the study. Patients were consented for both data publication and surgical treatment. The study population was divided into two groups: The (Non-concomitant) group (Brain stem cavernomas only) and the (Concomitant) group (Brainstem and non-brain stem cavernomas). Bleeding was defined as the development of new acute or subacute symptoms or worsening of previous symptoms attributed to the brainstem cavernoma associated along

with evidence of hemorrhage on magnetic resonance imaging (MRI) imaging using modified Zabramski classification.8,11,12 According to our protocol, high risk patients for hemorrhage (younger age, female sex, lesion larger than 1 cm, and history of previous hemorrhage),[13] were screened by magnetic resonance imaging (MRI) yearly, while others underwent MRI if they developed new symptoms. Surgical indications included more than two episodes of hemorrhage, progressive neurological decline, lesion size larger than 2 cm, exophytic lesion, and lesions that were abutting the pial surface which can be accessed via a safe entry zone. Cavernoma bleeding which resolved spontaneously or was small in size and was considered non-surgical.[8]

A retrospective comparative study was conducted using demographic criteria, clinical and radiological data, management strategies, difference in cavernoma bleeding rates between the two groups and its effect on outcomes.

Data were input into the computer and analyzed using IBM statistical package for the social sciences (SPSS) software package version 20.0. (Armonk, NY: IBM Corp). Categorical data were presented as numbers and percentages. The Chi-square test was used to compare between the two groups. Alternatively, the Fisher Exact and Monte Carlo correction test were applied when more than 20% of the cells had an expected count of less than 5. For continuous data, normality was tested using the Shapiro-Wilk test. Quantitative data were expressed as range (minimum and maximum), mean, standard deviation and median. The Student t-test was used to compare two groups for normally distributed quantitative variables, while, the Mann Whitney test was used for not normally distributed quantitative variables. Significance of the results was determined at the 5% level.

RESULTS

After revising the records, it was found that 43 out of 180 patients met the inclusion criteria. These patients were divided into two groups: the concomitant group which included patients with both brain stem cavernoma and extra brain stem cavernoma (N=21, 48.8%) and the non-concomitant group which consisted of patients with brain stem cavernoma only (N=21, 51.2%) **(Fig. 1).**

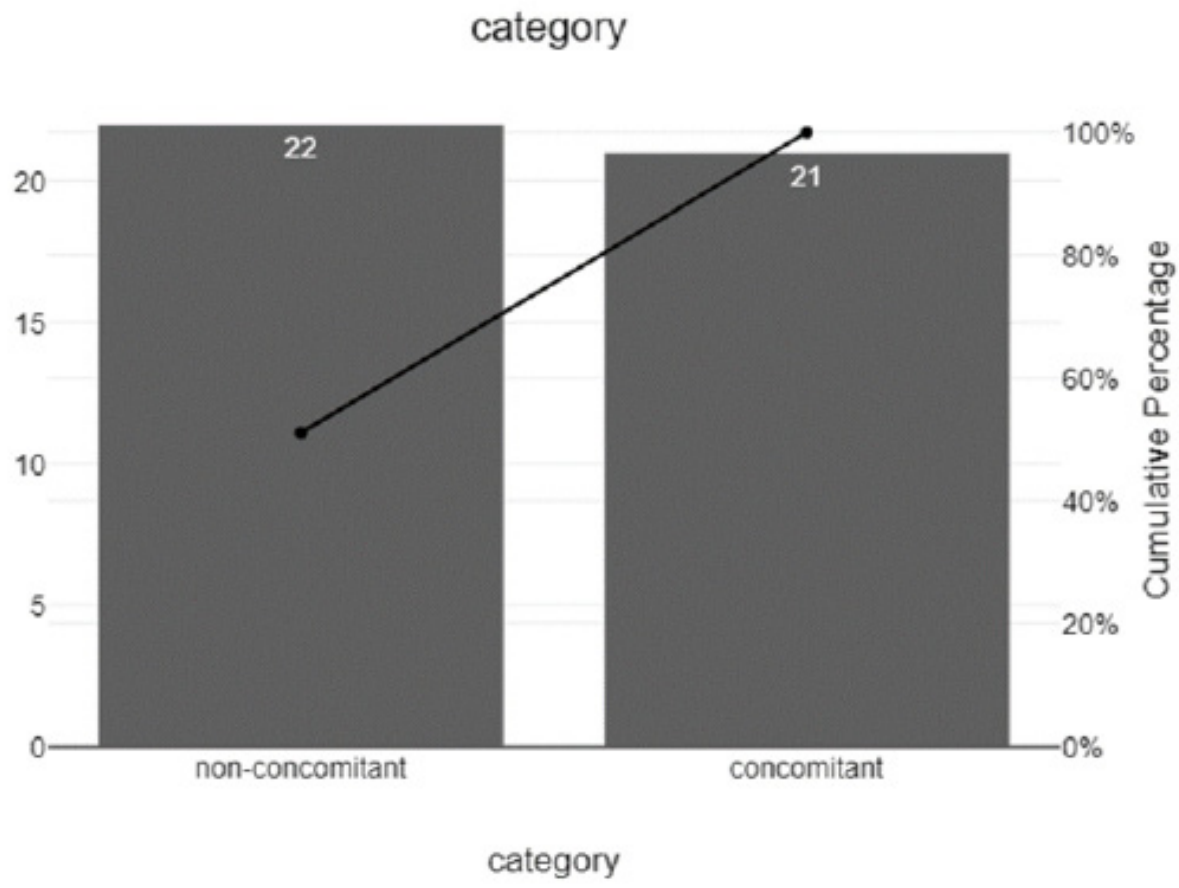

Fig 1: Distribution of patients into 2 groups, concomitant and non-concomitant.

Clinical and demographic criteria

The concomitant group consisted of 8 males (38.1%) and 13 females (61.9%) with a mean age of 38.3 ± 10.4 years. The other non-concomitant group consisted of 9 males (40.9%) and 13 females (59.1%) with a mean age of 44.4 ± 13.2years. The clinical presentations are summarized in Table 1. Seizures were the most common presenting symptom in the concomitant group (11 patients, 52.3%), while focal neurological deficits were the main presentation in the non- concomitant group (13 patients, 59.1%). Additionally, 3 patients from the concomitant group were from the same family.

Radiological results

The site and size of cavernomas in both groups are presented in **(Table 2).** The Pons was the most common location of cavernoma in both groups with 10 (45.5%) in the non- concomitant and 12 (54.5%) concomitant group .The difference in cavernoma size between the two groups was statistically insignificant (U= 195.000 , p value = 0.375). Radiological types according to the modified Zabramski classification are shown in Table 2. The hemorrhagic types IA, IB and II accounted for 6 (27.3%) in the non-concomitant group, and 15 (71.4%) in the concomitant group. Bleeding in cavernomas was statistically significant in the concomitant group compared to the non-concomitant group ($\chi 2$= 8.384, p=0.004) **(Fig. 2).**

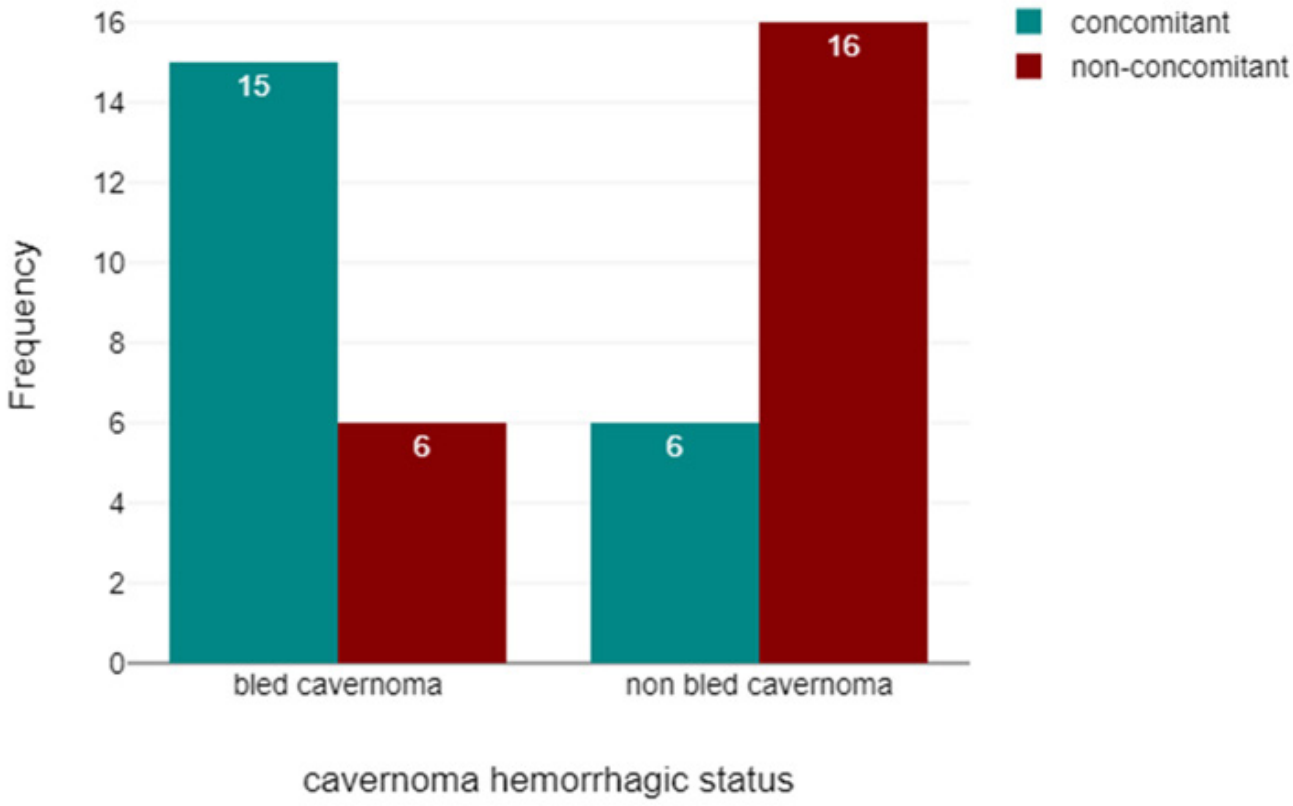

Fig 2: Hemorrhagic status difference between two groups.

Management and outcome

Surgical excision was performed in 5 cases (22.7%) in the non-concomitant group and in 4 cases (19%) in the concomitant group. The various surgical approaches are detailed in **Table 3**. The Outcome as measured by the mRs showed no difference between the two group either upon presentation or after a minimum of 2 years (u=199.500, p= 0.397) and (u=180.500, p=0.145), respectively as shown in **(Table 4).**

Table 1: Demographic and clinical data of both groups

	Non-concomitant (n = 22)	Concomitant (n = 21)	Test of Sig.	p
Sex				
Male	9 (40.9%)	8 (38.1%)	χ^2= 0.036	0.850
Female	13 (59.1%)	13 (61.9%)		
Age (years)				
Mean ± SD.	44.4 ± 13.2	38.3 ± 10.4	t= 1.674	0.102
Median (Min. – Max.)	45 (24 – 67)	41 (15 – 55)		
Presentation				
Asymptomatic	-	1 (4.8%)		
Incidental discovery	2 (9.1%)	-		
Hydrocephalus	-	1 (4.8%)		
Focal neurological deficits	13 (59.1%)	8 (38%)	χ^2=20.777*	^{MC}p <0.001*
Seizures	1 (4.5%)	11 (52.3%)		
Headache	6 (27.3%)	-		
Intraventricular hemorrhage	-	2 (9.5%)		

SD: Standard deviation, t: Student t-test X^2: Chi square test, MC: Monte Carlo.

P: p value for comparing between the two studied groups, *: Statistically significant at $p \leq 0.05$.

Table 2: Radiological appearance and hemorrhagic rate difference between the studied groups

Variable	Non-concomitant (n = 22)	Concomitant (n = 21)	Test of Sig	P
Site in brain stem				
Mid brain	3 (13.6%)	3 (14.3%)		
Ponto-mesencephalic	2(9.1%)	3(14.3%)		
Medullary	5 (22.7%)	1 (4.8%)	χ^2= 6.607	^{MC}p= 0.057
Ponto-medullary	2 (9.1%)	2 (9.5%)		
Pontine	10 (45.5%)	12 (54.5%)		
Maximal diameter (mm)				
Mean ± SD.	8.1 ± 6.5	7.52 ± 6.80	U= 195.000	0.375
Median (min. – max.)	5.0 (2.0 – 27.0)	5.0 (2.0 – 25.0)		
Type of brain stem cavernoma in MRI (modified zabramiski classification)				
IA	1 (4.5%)	4 (19%)		
IB	3 (13.6%)	2 (9.5%)		
II	2 (9.1%)	9 (42.9%)		
III	10 (45.5%)	4 (19%)		
IV	6 (27.3%)	2 (9.5%)		
Bleeding in brain stem				
Non bled cavernoma	16 (72.7%)	6 (28.6%)	χ^2= 8.384*	0.004*
Bled cavernoma	6 (27.3%)	15 (71.4%)		

SD: Standard deviation, U: Mann Whitney Test, X^2: Chi square test, MC: Monte Carlo.

P: p value for comparing between the two studied groups.

*: Statistically significant at $p \leq 0.05$.

Table 3: Management of brainstem cavernomas in both groups

Variable	Non-concomitant	Concomitant	Test of Sig.	p
Treatment for brain stem Cavernoma				
Surgical	5 (22.7%)	4 (19%)	χ^2= 0.088	^{FE}p= 1.000
Conservative	17 (77.3%)	17 (81%)		
Surgical approach	**(n = 5)**	**(n = 4)**		
Left retrosigmoid approach	1 (20%)	1 (25%)		
Occipital transtentorial	0 (0%)	1 (25%)		
Orbitozygomatic craniotomy	1 (20%)	0 (0%)		
Subtemporal	0 (0%)	1 (25%)		
Right far lateral approach	1 (20%)	0 (0%)		
Suboccipital and telovelar approach	2 (40%)	1 (25%)		

X^2: Chi square test, FE: Fisher Exact, P: p value for comparing between the two studied groups, *: Statistically significant at $p \leq 0.05$.

Table 4: Comparison between the two studied groups according to mRs

mRs	Non-concomitant (n = 22)	Concomitant (n = 21)	U	p
Presentation				
Mean ± SD.	1.2 ± 1.2	1.5 ± 1.2	199.500	0.397
Median (min. – max.)	1 (0 – 4)	1 (0 – 5)		
After minimum 2 years				
Mean ± SD.	0.9 ± 1	1 ± 0.6	180.500	0.145
Median (min. – max.)	1 (0 – 4)	1 (0 – 3)		

SD: Standard deviation, U: Mann Whitney test, p: p value for comparing between the two studied groups.

DISCUSSION

Brain stem cavernoma has been extensively studied in the literature through retrospective and prospective studies.[14-17] However, there are specific knowledge gaps regarding the management of brain stem cavernoma that need to be addressed. One of these questions is the bleeding risk and subsequent management of brain stem cavernoma in the setting of multiple intracranial cavernomas.[8] In this study, 43 patients were divided into two groups: Concomitant and non-concomitant group. The mean age group was in the 4th and 5th decades in the concomitant and non-concomitant group respectively.

Clinical presentation was divided largely into seizures in the concomitant group (47.6%) and focal neurological deficits in the non-concomitant groups (59.1%). A cross sectional study from Morocco, an Arabic country, presenting their 20 years of experience of managing intracranial Cavernomas found that it was more common in the age group 20-40 years (58%, n=26) with seizures being the most prevalent symptoms (47%; n=21) and focal neurological deficit coming in second (27%; n=12).[18] These findings were consistent with Kivelev, et al, who reported 33 patients with concomitant brain stem cavernoma, showing similarities in age group predominance and seizures as the main clinical presentation.[12] Santos, et al reported a total of 238 patients with multiple cerebral Cavernomas. The concomitant brain stem cavernomas were reported in 39 patients (16.4%). The main presentation of the whole study group was intracerebral hemorrhage (130 patients, 55.3%) and Cavernoma related epilepsy was found in 60 patients (26.1%). However, no specific analysis of the concomitant brain stem group was done.[19] Mespreuve et al, reviewed familial forms of cavernomas and found that the most common presentation was seizures followed by focal neurological deficits (38%– 55%) and (35%–50%) respectively.[20] In cases of the non-concomitant cavernomas in the brain stem, an analysis of 104 patients carried out by Garcia et al. showed a mean age of 42.1 years with 99% presenting with hemorrhages which could be explained by the fact that all patients studied underwent surgery from the start.[10] Kupersmith et al. studied the natural history of brain stem cavernous malformations using the Rankin grade for presentation assessment and found that most patients exhibited minimal clinical dysfunction. Patients were classified as of Rankin Grade 0, and Rankin Grade 1 in 46% and 23% respectively.[21] Our findings using the same scoring system showed a mean grade of 1 in both groups. Fritschi et al. also reported similar observations with 43% of normal and 23% experiencing mild dysfunction.[22]

Brain stem cavernomas are most commonly found in the pons as seen in our study and several others. Kupersmith et al. reported a pontine cavernoma rate of 48.6%; however this study did not indicate whether there were patients with multiple cavernomas or not.[21] Many surgical trials included patients who were candidates for surgical resection of brain stem Cavernomas without

clearly defining which were concomitant and which were non-concomitant.[10,21, 23-25] The sizes of Cavernomas in our study ranged between 3mm and 2.5 cm with a mean of (8.1 ± 6.5) and (7.52 ± 6.80) for both the non-concomitant and concomitant groups respectively.

Kupersmith et al found during their follow up of the natural history of brain stem Cavernomas (Only three patients had concomitant type), that the mean largest diameter was 13.9 mm (SD, ± 7.4 mm; range, 2–30 mm).[21] Surgical indication for brain stem cavernoma in relation to size was more than or equal to 2 cm in multiple surgical series. However, those studies did not include the non-surgical candidates.[10,13,24] To the best of our knowledge, there have been no studies analyzing the size differences of cavernomas between patients with concomitant and non-concomitant brainstem cavernomas. The definition of a hemorrhagic Cavernomas is based on both clinical symptoms and radiological evidence. Utilizing a modified Zabramski classification, we determined the hemorrhagic type based on its appearance in MRI scans, and clinical presentation of the patients. Hemorrhagic cavernoma were present in 27.3% of the non-concomitant group, and 15 (71.4%) in the concomitant group. The risk factors for bleeding in brain stem cavernomas have been extensively studied , but the risk factor for multiplicity has not been clearly included for comparison. Natural history studies of brain stem cavernoma have identified the hemorrhagic presentation to be around 73%.[13,26] LI Da, et al. conducted a prospective analysis of 708 cases of brain stem cavernoma. They found that 192 (27.1%) were classified as Zabramski I and 330 (46.6%) as Zabramski II without multiplicity subdivision. Multiple CCMs accounted for 92 out of the 708 patients (13.0%). Among these, 63 patients had no ictus, 18 patients had one ictus and 11 had more than one ictus of bleeding. This is contradictory to our findings which showed that bleeding is statistically significant in the concomitant group.[26] This may be due to the assessment of hemorrhagic risk on a per-lesion basis. A higher rate of hemorrhage per patient is attributed to its cumulative effects.[23,27-29] The consensus recommendations based on a systematic literature review by the Angioma Alliance Scientific Advisory Board Clinical Experts Panel stated that multiplicity is a risk factor for an increased hemorrhagic presentation in patients with multiple cavernoma as a whole.[8] The mean modified Rankin scale (mRs) on presentation was (1.2 ± 1.2) and (1.5 ± 1.2) in the non-concomitant and concomitant group respectively. After a minimum 2 years follow up the MRS was (0.9 ± 1) and (1 ± 0.6) in non-concomitant and concomitant patients respectively. The outcome difference between both groups in our study was statistically insignificant based on multiplicity as a risk factor. To our knowledge, the management methods of brain stem cavernous malformation do not clearly identify whether the multiplicity of cavernomas affects the outcome or not. The surgical series selected patients who are candidates for surgery based on different indications and the natural history studies were also based on surgical series as well[13] using different methods to assess the outcome.[9,13,23]

CONCLUSION

This study aimed to study the relationship between the presence of multiple Cavernomas and the hemorrhagic presentation of brain stem Cavernomas . The study concluded that the Multiplicity of Cavernomas is a statistically significant risk factor for hemorrhagic presentation in brain stem Cavernomas. Information should be considered when counseling patients with multiple supratentorial and infratentorial cavernomas to determine the most appropriate treatment. However it is important to note that the study was limited by its retrospective nature and relatively small sample size, therefore a large prospective trial to further investigate this specific risk factor is recommended.

List of Abbreviations

CCM: Cerebral cavernous malformations.
MRI: Magnetic resonance imaging.
SD: Standard deviation.
MC: Monte Carlo.
MRS: Modified Rankin Scale.

Disclosure

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

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REFERENCES

1. Al-Holou WN, O'Lynnger TM, Pandey AS, et al. Natural history and imaging prevalence of cavernous malformations in children and young adults. *J Neurosurg Pediatr.* 2012;9(2):198-205.

2. Del Curling O Jr, Kelly DL Jr, Elster AD, Craven TE. An analysis of the natural history of cavernous angiomas. *J Neurosurg.* 1991;75(5):702-8.

3. Kim DS, Park YG, Choi JU, Chung SS, Lee KC. An analysis of the natural history of cavernous malformations. *Surg Neurol.* 1997;48(1):9-17; discussion 17-8.

4. Pandey P, Westbroek EM, Gooderham PA, Steinberg GK. Cavernous malformation of brainstem, thalamus, and basal ganglia: a series of 176 patients. *Neurosurgery*. 2013;72(4):573-89; discussion 588-9.

5. Abla AA, Lekovic GP, Turner JD, de Oliveira JG, Porter R, Spetzler RF. Advances in the treatment and outcome of brainstem cavernous malformation surgery: a single-center case series of 300 surgically treated patients. *Neurosurgery.* 2011;68(2):403-14; discussion 414-5.

6. De Aguiar PH, Zicarelli CA, Isolan G, et al. Brainstem cavernomas: A surgical challenge. *Einstein (Sao Paulo).* 2012;10(1):67-73.

7. Ohue S, Fukushima T, Friedman AH, Kumon Y, Ohnishi T. Retrosigmoid supraflocculer transhorizontal fissure approach for resection of brainstem cavernous malformation. *Neurosurgery.* 2010;66(6 Suppl Operative):306-12; discussion 312-3.

8. Akers A, Al-Shahi Salman R, Awad AI, et al. Synopsis of Guidelines for the Clinical Management of Cerebral Cavernous Malformations: Consensus Recommendations Based on Systematic Literature Review by the Angioma Alliance Scientific Advisory Board Clinical Experts Panel. *Neurosurgery.* 2017;80(5):665-680.

9. Yuen J, Whitfield PC. Brainstem cavernous malformations - no longer a forbidden territory? A systemic review of recent literature. *Neurochirurgie.* 2020;66(2):116-126.

10. Garcia RM, Ivan ME, Lawton MT. Brainstem cavernous malformations: Surgical results in 104 patients and a proposed grading system to predict neurological outcomes. *Neurosurgery.* 2015;76(3):265-77; discussion 277-8.

11. Zabramski JM, Wascher TM, Spetzler RF, et al. The natural history of familial cavernous malformations: results of an ongoing study. *J Neurosurg.* 1994;80(3):422-32.

12. Kivelev J, Niemelä M. Natural History of Cavernous Malformations. *Basic Science to Clinical Practice.* 2020;69-91.

13. Li D, Yang Y, Hao SY et, al. Hemorrhage risk, surgical management, and functional outcome of brainstem cavernous malformations. *J Neurosurg.* 2013;119(4):996-1008.

14. Aiba T, Tanaka R, Koike T, Kameyama S, Takeda N, Komata T. Natural history of intracranial cavernous malformations. *J Neurosurg.* 1995;83(1):56-9.

15. Al-Shahi Salman R, Hall JM, Horne MA, et al. Scottish Audit of Intracranial Vascular Malformations (SAIVMs) collaborators. Untreated clinical course of cerebral cavernous malformations: a prospective, population-based cohort study. *Lancet Neurol.* 2012;11(3):217-224.

16. Mai JC, Ramanathan D, Kim LJ, Sekhar LN. Surgical resection of cavernous malformations of the brainstem: evolution of a minimally invasive technique. *World Neurosurg.* 2013;79(5-6):691-703.

17. Porter PJ, Willinsky RA, Harper W, Wallace MC. Cerebral cavernous malformations: Natural history and prognosis after clinical deterioration with or without hemorrhage. *J Neurosurg.* 1997;87(2):190-7.

18. Boutarbouch M, Bankole NDA, Arkha Y, Melhaoui A, El Ouahabi A, El Khamlichi A. Intracranial cavernomas management and outcomes: Cross-sectional study from 20 years of experience at Speciality Hospital, Rabat, Morocco. *PAMJ Clin Med.* 2022;9:10.

19. Santos AN, Rauschenbach L, Saban D, et al. Multiple cerebral cavernous malformations: Clinical course of confirmed, assumed and non-familial disease. *Eur J Neurol.* 2022;29(5):1427-1434.

20. Mespreuve M, Vanhoenacker F, Lemmerling M. Familial Multiple Cavernous Malformation Syndrome: MR Features in This Uncommon but Silent Threat. *J Belg Soc Radiol.* 2016;100(1):51.

21. Kupersmith MJ, Kalish H, Epstein F, et al. Natural history of brainstem cavernous malformations. *Neurosurgery.* 2001;48(1):47-53; discussion 53-4.

22. Fritschi JA, Reulen HJ, Spetzler RF, Zabramski JM. Cavernous malformations of the brain stem. A review of 139 cases. *Acta Neurochir (Wien).* 1994;130(1-4):35-46.

23. Xie MG, Li D, Guo FZ, et al. Brainstem Cavernous Malformations: Surgical Indications Based on Natural History and Surgical Outcomes. *World Neurosurg.* 2018;110:55-63.

24. Santos AN, Rauschenbach L, Darkwah Oppong M, et al. Assessment and validation of proposed classification tools for brainstem cavernous malformations. *J Neurosurg.* 2020;135(2):410-416.

25. Mathiesen T, Edner G, Kihlström L. Deep and brainstem cavernomas: a consecutive 8-year series. *J Neurosurg.* 2003;99(1):31-7.

26. Li D, Wu ZY, Liu PP, et al. Natural history of brainstem cavernous malformations: Prospective hemorrhage rate and adverse factors in a consecutive prospective cohort. *J Neurosurg.* 2020;134(3):917-928.

27. Li D, Hao SY, Jia GJ, Wu Z, Zhang LW, Zhang JT. Hemorrhage risks and functional outcomes of untreated brainstem cavernous malformations. *J Neurosurg.* 2014;121(1):32-41.

28. Barker FG 2nd, Amin-Hanjani S, Butler WE, et al. Temporal clustering of hemorrhages from untreated cavernous malformations of the central nervous system. *Neurosurgery.* 2001;49(1):15-24; discussion 24-5.

29. Hauck EF, Barnett SL, White JA, Samson D. Symptomatic brainstem cavernomas. *Neurosurgery.* 2009;64(1):61-70; discussion 70-1.