REVIEW ARTICLE

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Management and Surgical Outcomes of Brain Stem Cavernomas: A Nine-Year Retrospective Analysis of 20 Cases

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Abstract

Background: Brain stem cavernomas (BSCs) are rare vascular malformations, accounting for 8-22% of intracranial cavernoma lesions. These lesions can cause severe neurological deficits and life-threatening hemorrhages, making their management challenging.

Aimes: This study retrospectively evaluates the clinical presentation, surgical management, and outcomes of patients with BSCs to improve clinical strategies and patient care.

Methods: This retrospective study analyzed 20 patients with BSCs treated at Loghman Hakim Hospital, Tehran, Iran, from 2014 to 2023. Clinical data were collected from medical records, including demographic information, clinical presentations, imaging findings, and surgical intervention details. Lesion characteristics were documented and classified. Surgical approaches were based on lesion location and proximity to critical structures. Outcomes were assessed using the Modified Rankin Scale (MRS), resolution of cranial nerve (CN) palsies, incidence of rebleeding, and postoperative complications. Descriptive statistics was used to summarize patient characteristics and outcomes.

Results: The study included 20 patients (mean age 34.25 years; 55% male) with a mean follow-up of 37.1 months. The most common presentation was headache (30%), followed by hemiparesis (15%) and cerebellar symptoms (70%). Prior hemorrhage occurred in 75% of cases. Lesions were predominantly deep-seated (60%) and averaged 30 mm in diameter. Postoperative outcomes showed improvement in MRS scores in 75% of cases, with CN palsies resolving in 20%. Rebleeding occurred in 20% of patients, and other complications included ataxia and gait disturbances. Surgical management, primarily through suboccipital telovelar and retrosigmoid approaches, significantly improved neurological function and quality of life.

Conclusion: Surgical intervention for symptomatic BSCs, particularly through suboccipital telovelar and retrosigmoid approaches, leads to favorable clinical outcomes. Accurate patient selection, preoperative planning, and meticulous microsurgical techniques are crucial for optimizing results. Future research should focus on refining surgical approaches and exploring genetic and molecular aspects of BSCs to enhance management strategies and patient outcomes.

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Introduction

Brain stem cavernomas (BSCs) are rare vascular malformations with a prevalence of 0.3% to 0.7% in the general population (1). The prevalence has increased with the advent of advanced imaging techniques such as MRI, which can detect these malformations more effectively. They account for approximately 8– 22% of all intracranial cavernoma lesions (2). Due to their autosomal dominant inheritance, familial forms represent about 10% of cavernomas, often resulting in multiple lesions (3).

BSCs are clinically significant due to their potential to cause severe neurological deficits and life-threatening hemorrhages. The annual hemorrhage risk is estimated to be between 0.5% to 3%, with a higher risk in individuals with a history of previous hemorrhages. 4 Given the brain stem's critical role in controlling vital functions such as breathing, heart rate, and motor coordination, even small lesions can have significant clinical consequences. Symptoms may include focal neurological deficits, seizures, headaches, and hemorrhagic events (5).

The decision between surgical and conservative management of BSCs is challenging. Surgical intervention can lead to significant temporary or permanent neurological deficits due to the dense concentration of critical neurological pathways in the brain stem. Therefore, conservative management is often considered for asymptomatic or minimally symptomatic patients to avoid surgical risks.

However, this approach necessitates careful monitoring (6, 7).

This study aims to retrospectively evaluate the clinical presentation, surgical management, and outcomes of patients with BSCs. The goal is to provide insights into the effectiveness of different management approaches, improve clinical management strategies, and enhance patient care and outcomes for individuals with BSCs.

Methods

We retrospectively analyzed patients with BSCs treated at Loghman Hakim Hospital in Tehran, Iran, from 2014 to 2023. This study included 20 patients diagnosed with BSCs who underwent conservative management or surgical intervention during this period.

Clinical data were collected retrospectively from patient medical records. The data included demographic information, clinical presentations, imaging findings (Figure 1A), and details of surgical interventions. Lesion characteristics, such as size and location, were also documented. Lesions were classified as deep or superficial. The Zabramski classification was used to categorize the cavernomas based on their MRI characteristics. (Figure 1B).

The surgical approach was chosen based on the proximity of BSCs to pial or ependymal surfaces and critical structures such as cranial nerves. For lesions in the posterior fossa, the Suboccipital Telovelar approach was used in 45% of cases. This approach provides a wide surgical corridor to deep-seated brain stem lesions while minimizing damage to cerebellar tissue.

For lesions near the cerebellopontine angle (CPA), the Retrosigmoid Approach was utilized in 25% of cases. This technique involves a craniotomy behind the sigmoid sinus, allowing direct access to the lateral aspect of the brainstem and the cerebellopontine cistern. Other approaches included C1 laminectomy, transcerebellar, and subtemporal, chosen by an experienced neurosurgeon based on the lesion's location and proximity to critical structures (Figure 2).

Clinical outcomes were evaluated using the Modified Rankin Scale (MRS) to assess postoperative neurological function. Additional outcomes included the resolution of cranial nerve (CN) palsies, the incidence of rebleeding, and other postoperative complications.

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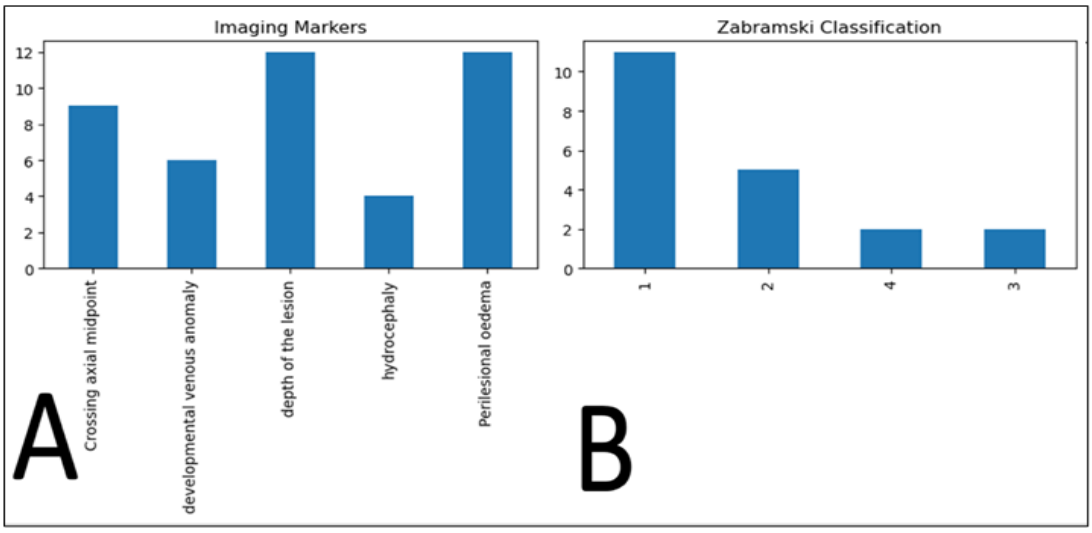

Figure 1. Imaging markers and Zabramski classification**,** bar graphs presenting the distribution of imaging markers (A) and Zabramski classification (B) of brain stem cavernomas. Zabramski's classification highlights the prevalence of different lesion types.

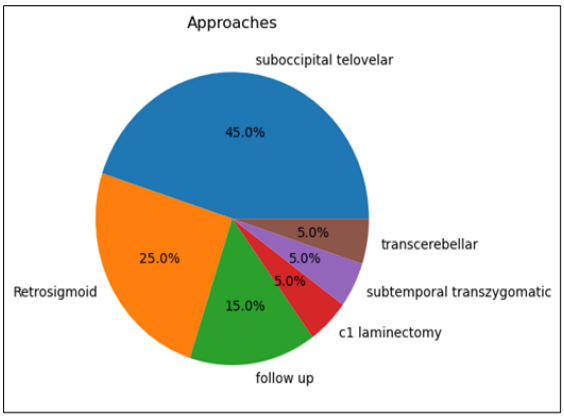

Figure 2. Surgical Approaches, pie chart depicting the distribution of surgical approaches used in the study. The suboccipital telovelar approach was the most common (45%), followed by the retrosigmoid approach (25%), C1 laminectomy, transcerebellar, and subtemporal transzygomatic approaches (each 5%). Additionally, 15% of cases were managed with follow-up alone.

Statistical Analysis

Descriptive statistics were used to summarize the demographic and clinical characteristics of the patients. Outcomes were analyzed to determine the effectiveness of the surgical interventions and the incidence of complications. Key metrics included improving clinical outcomes as measured by the Modified Rankin Scale and the resolution rates of cranial nerve palsies. The frequency of rebleeding was also statistically analyzed to understand the risk profile of the surgical interventions.

Results

This study included 20 patients with BSCs, with a mean age of 34.25 years (range 16-58 years), 55% of whom were male. The mean follow-up period was 37.1 months. The most common clinical presentation was headache, occurring in 30% of patients, while hemiparesis was observed in 15% of cases. Cerebellar symptoms were significant, with 70% of patients exhibiting an unsteady gait and 55% presenting with hypotonia. Additional symptoms included nystagmus, paresthesia, ataxia, and vertigo. Prior hemorrhage was documented in 75% of cases. The average maximum diameter of the cavernomas was 30 mm. (Figure 3) Lesions were classified based on location, with 12 (60%) deep-seated and 8 (40%) superficial. Concurrent venous anomalies were present in 6 cases (30%), adding complexity to the surgical approach. Postoperative clinical outcomes were assessed using the Modified Rankin Scale (MRS). Improvement in MRS scores was observed in 75% of cases, indicating favorable neurological recovery. Cranial nerve (CN) palsies were present in 75% of patients before surgery, with the trochlear nerve being the most

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commonly affected (40%). Postoperatively, CN palsies resolved in 20% of these cases. Rebleeding occurred in 20% of patients. Other postoperative complications included deafness, ataxia, gait disturbance, pseudobulbar syndrome, vertigo, and sensory or motor deficits. Patients were monitored for clinical and radiological outcomes during the follow-up period. The resolution of symptoms and the decline in rebleeding rates underscored the effectiveness of the surgical interventions. Despite the inherent risks, surgical management substantially improved patient quality of life and neurological function. Descriptive statistics were used to summarize the demographic and clinical characteristics of the patients. The effectiveness of surgical interventions was evaluated by comparing preoperative and postoperative MRS scores, showing significant improvement in most cases (Figure 4).

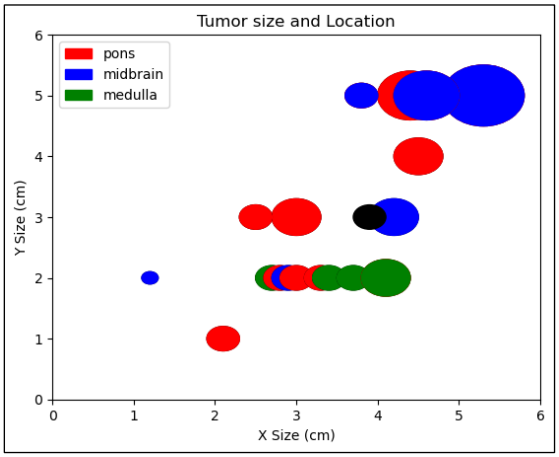

Figure 3. Tumor Size and Location, scatter plot showing the distribution of brain stem cavernomas based on their size and location in the pons (red), midbrain (blue), and medulla (green). Bubble size corresponds to tumor size, indicating the relative dimensions of each lesion.

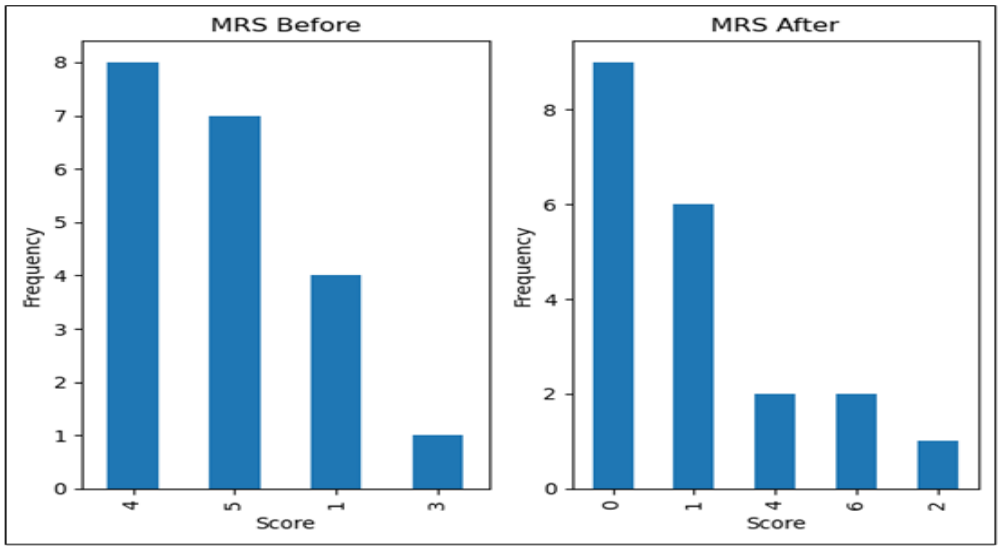

Figure 4. Modified Rankin Scale (MRS) Scores Before and After Surgery, bar graphs illustrate the distribution of the Modified Rankin Scale (MRS) scores before and after surgical intervention. The left graph depicts preoperative MRS scores, while the right graph shows postoperative scores, demonstrating significant improvement in patient outcomes following surgery.

Discussion

BSCs, also known as brainstem cavernous malformations, are vascular abnormalities that often present with a range of neurological symptoms due to their critical location in the brainstem, which controls essential functions such as motor coordination, sensory pathways, and autonomic functions. Clinical manifestations typically include focal neurological deficits like cranial nerve palsies, hemiparesis, and ataxia. Patients may also experience seizures, headaches, and sensory disturbances. Symptomatic lesions often have a high event rate, with recurrent neurological deficits frequently observed, especially following initial hemorrhagic events.

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Hemorrhagic events are common and can lead to sudden neurological deterioration, often presenting as acute onset of severe symptoms such as dizziness, double vision, difficulty swallowing, and respiratory issues. Some cases remain asymptomatic until a significant hemorrhagic event occurs (5, 8–10). Our study provides significant insights into the management and outcomes of BSCs over nine years. Most patients presented with headache, hemiparesis, and cerebellar signs.

BSCs can be sporadic or familial genetic conditions. Familial BSCs follow an autosomal dominant inheritance pattern and are associated with mutations in three main genes: CCM1 (KRIT1), CCM2, and CCM3 (11). These mutations lead to the formation of multiple cavernomas and a higher frequency of symptomatic presentations, such as hemorrhages and neurological deficits, often at a younger age (3). Familial cases also exhibit a dynamic nature, with lesions growing, hemorrhaging, and sometimes developing "de novo" over time. This genetic predisposition can significantly impact the management and prognosis of BSCs, necessitating a comprehensive approach, including genetic counseling and potentially future gene therapies (12).

Both conservative and surgical treatments have roles in managing BSCs. A meta-analysis comparing conservative and surgical treatments for BSCs found that surgery significantly reduces the risk of re-hemorrhage and can improve neurological outcomes in appropriately selected patients (13). While surgical intervention carries significant risks, including new neurological deficits due to the location of lesions, conservative management is suitable for asymptomatic or minimally symptomatic cases. In contrast, surgical intervention is necessary for symptomatic patients with recurrent hemorrhages or significant neurological deficits. The treatment choice should be individualized based on patient-specific factors such as age, overall health, neurological function, and lesion characteristics, including location, size, depth, accessibility, and their relationship with surrounding neural structures to optimize outcomes.

Surgical Treatment

Surgical intervention is considered for symptomatic patients, particularly for those with recurrent hemorrhages or significant neurological impairments. Various surgical approaches adjust for the lesion's location to minimize damage to critical brainstem structures (14).

Intraoperative neurophysiological monitoring and neuronavigation are crucial to reduce surgical risks and improve outcomes. Common approaches include the medial suboccipital, lateral suboccipital, subtemporal, transcerebellar, and C1 laminectomy approaches.

Suboccipital Telovelar Approach:

The suboccipital telovelar approach is frequently used to access BSCs located in the fourth ventricle or the dorsal aspect of the brainstem. This approach involves a midline suboccipital craniotomy, allowing direct access to the fourth ventricle by splitting the cerebellomedullary fissure without requiring cerebellar retraction. It provides excellent exposure to the floor of the fourth ventricle, making it particularly suitable for lesions in the dorsal pons and the upper medulla. The primary advantage of this approach is its minimal invasiveness and reduced risk of cerebellar damage, resulting in fewer postoperative complications and quicker recovery (14, 15).

Retrosigmoid Approach

The retrosigmoid (or lateral suboccipital) approach is another commonly used method for surgically removing BSCs, particularly those located in the lateral aspects of the brainstem. This approach involves a craniotomy behind the ear, providing access to the cerebellopontine angle. It is favored for its versatility in reaching the lateral and anterolateral regions of the pons and medulla, and it allows for removing lesions

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that are close to the cranial nerves and the brainstem surface. The retrosigmoid approach is advantageous for its broad exposure and the ability to preserve hearing in some cases. However, it often requires more extensive cerebellar retraction, which can increase the risk of cerebellar injury and postoperative complications (16, 17).

Subtemporal Approach

The subtemporal approach involves a temporal craniotomy to access the lateral and anterolateral surfaces of the midbrain and upper pons. Enhanced exposure can be achieved by combining this with a zygomatic osteotomy and petrous apex drilling. This approach provides direct visualization of the lesion area, making it ideal for anteriorly located mid to lower pontine and upper medullary cavernomas, allowing safe entry without damaging vital structures. However, it carries the risk of temporal lobe damage, swelling, and potential postoperative cranial nerve deficits such as oculomotor nerve palsy (18, 19).

Transcerebellar Approach

The transcerebellar approach involves a posterior fossa craniotomy to access the cerebellum and brainstem, providing access to lesions located in the dorsal and lateral aspects of the brainstem. This approach offers a good angle for accessing deep-seated lesions, particularly in the dorsal regions, and minimizes cerebellar retraction. However, it offers limited exposure to the ventral brainstem regions and carries the risk of cerebellar injury and postoperative complications such as cerebellar swelling (20).

C1 Laminectomy Approach

The C1 laminectomy approach involves removing the posterior arch of the first cervical vertebra (C1) to access the ventral brainstem and upper cervical spinal cord. This approach provides direct access to the ventral brainstem and cervicomedullary junction, making it useful for decompressing the brainstem in Chiari malformations and ventral brainstem compression cases. However, it carries the risk of spinal instability, often requiring fusion, and offers limited exposure to the upper brainstem regions. Potential complications include postoperative instability and the need for spinal fusion (21).

Conservative Treatment

Conservative management is often chosen for asymptomatic or minimally symptomatic patients with BSCs due to the high risks associated with surgical intervention. This approach involves regular monitoring to detect any changes in the lesion or new symptoms through imaging studies, such as MRI (6). Symptomatic treatments may include medications for pain management and anti-seizure drugs (22). Patient education about the symptoms of hemorrhage and neurological deterioration, (23) and lifestyle modifications, such as engaging in safe physical activities that do not increase intracranial pressure (6). Studies have shown that conservative management can be appropriate, particularly in cases where the lesion has not caused significant neurological deficits or multiple hemorrhages. Conservative treatment aims to avoid the potential morbidity associated with brainstem surgery, such as new neurological deficits.

Our results demonstrated that surgical intervention, mainly through suboccipital telovelar and retrosigmoid approaches, led to favorable clinical outcomes, significantly improving Modified Rankin Scale (MRS) scores in 75% of cases. The findings of this study underscore the importance of meticulous surgical planning and technique in managing BSCs. Given the high incidence of preoperative cranial nerve palsies and their partial resolution postoperatively, our study highlights the potential for substantial neurological recovery through appropriate surgical intervention. Resolving symptoms such as unsteady gait and hypotonia further emphasizes the benefits of surgical treatment. However, the occurrence of postoperative complications such as rebleeding and ataxia underscores the need for careful

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patient monitoring and follow-up. These results call for a balanced approach that considers both the potential benefits and risks associated with the surgical management of BSCs.

One of the strengths of our study is the comprehensive follow-up period, averaging on 37.1 months, which allowed for an in-depth assessment of long-term outcomes and complications. Additionally, consistent surgical techniques by a single experienced neurosurgeon contributed to the reliability of our findings. However, the study has several limitations. The retrospective nature of the analysis may introduce selection bias, and the relatively small sample size limits the generalizability of the results. Future research should focus on larger, multicenter studies to validate our findings and enhance the generalizability of the results. Comparative studies evaluating surgical versus conservative management of BSCs would provide valuable insights into the most effective treatment strategies. Additionally, advancements in neuroimaging and intraoperative monitoring techniques could further refine surgical approaches and reduce complication rates. Investigating the genetic and molecular underpinnings of BSCs may also offer new therapeutic targets and improve patient outcomes.

Conclusion

In conclusion, although surgical intervention for BSCs is associated with a significant risk of postoperative complications such as new-onset neurological deficits and mortality, our findings support surgery as the first therapeutic option for symptomatic BSCs. The study demonstrates that surgical removal, mainly through suboccipital telovelar and retrosigmoid approaches, leads to favorable clinical outcomes, including improved Modified Rankin Scale scores, resolution of cranial nerve palsies, and reduced rebleeding rates. These results underscore the importance of accurate patient selection, preoperative planning, and meticulous microsurgical techniques to achieve optimal outcomes with minimal complications. Continuous neuroimaging, surgical approaches, and genetic research advancements will refine BSC management, ultimately enhancing patient care and outcomes.

Acknowledgments

Not declared.

Conflicts of Interest

The authors declare no conflicts of interest.

Ethics

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References

1. Brunon J, Nuti C. [Natural history of cavernomas of the central nervous system]. Neurochirurgie. 2007;53(2-3 Pt 2):122-130. doi:10.1016/j.neuchi.2007.02.006

2. Houtteville JP. Brain cavernoma: a dynamic lesion. Surg Neurol. 1997;48(6):610-614. doi:10.1016/s0090-3019(96)00551-4

3. Labauge P. [Familial forms of central nervous system cavernomas: from recognition to gene therapy]. Neurochirurgie. 2007;53(2-3 Pt 2):152-155. doi:10.1016/j.neuchi.2007.02.007

4. Dorsch NWC, McMahon JHA. Intracranial cavernous malformations - natural history and management. Crit Rev Neurosurg. 1998;8(3):154-168. doi:10.1007/s003290050073

5. Janićijević A, Repac N, Nikolić I, et al. The Clinical Features and Surgical Approaches for BSCs. J Neurol

Journal of Otorhinolaryngology and Facial Plastic Surgery 2023;9(1):1-8.
https://doi.org/10.22037/orlfps.v9i1.47016

Surg A Cent Eur Neurosurg. 2015;76(S 02):s-0035-1566376. doi:10.1055/s-0035-1566376

6. Tarnaris A, Fernandes RP, Kitchen ND. Does conservative management for BSCs have better long-term outcome? Br J Neurosurg. 2008;22(6):748-757. doi:10.1080/02688690802354210

7. Bertalanffy H, Benes L, Miyazawa T, Alberti O, Siegel AM, Sure U. Cerebral cavernomas in the adult. Review of the literature and analysis of 72 surgically treated patients. Neurosurg Rev. 2002;25(1-2):1-53; discussion 54-55. doi:10.1007/s101430100179

8. Requena I, Arias M, López-Ibor L, et al. Cavernomas of the central nervous system: clinical and neuroimaging manifestations in 47 patients. J Neurol Neurosurg Psychiatry. 1991;54(7):590-594. doi:10.1136/jnnp.54.7.590

9. Hauck EF, Barnett SL, White JA, Samson D. Symptomatic BSCs. Neurosurgery. 2009;64(1):61-70; discussion 70-71. doi:10.1227/01.NEU.0000335158.11692.53

10. Dumas G, Schmerber S. [Cavernous haemangiomas: hearing and vestibular inaugural symptoms]. Ann Otolaryngol Chir Cervicofac. 2004;121(5):272-281. doi:10.1016/s0003-438x(04)95520-x

11. Sahoo T, Johnson EW, Thomas JW, et al. Mutations in the gene encoding KRIT1, a Krev-1/rap1a binding protein, cause cerebral cavernous malformations (CCM1). Hum Mol Genet. 1999;8(12):2325-2333. doi:10.1093/hmg/8.12.2325

12. Bravi L, Malinverno M, Pisati F, et al. Endothelial Cells Lining Sporadic Cerebral Cavernous Malformation Cavernomas Undergo Endothelial-to-Mesenchymal Transition. Stroke. 2016;47(3):886-890. doi:10.1161/STROKEAHA.115.011867

13. Fotakopoulos G, Kivelev J, Andrade-Barazarte H, Tjahjadi M, Goehre F, Hernesniemi J. Outcome in Patients with Spinal Cavernomas Presenting with Symptoms Due to Mass Effect and/or Hemorrhage: Conservative versus Surgical Management: Meta-analysis of Direct Comparison of Approach-Related Complications. World Neurosurg. 2021;152:6-18. doi:10.1016/j.wneu.2021.05.094

14. Pechstein U, Zentner J, Van Roost D, Schramm J. Surgical management of brain-stem cavernomas. Neurosurg Rev. 1997;20(2):87-93. doi:10.1007/BF01138189

15. Hong I, Kim KH, Oh HJ, et al. The surgical outcomes and nuances of the telovelar approach for pontine and medullary cavernous malformations: A multi-institutional case series. Journal of Korean Skull Base Society. 2023;18(2):75-84.

16. Abla AA, Turner JD, Mitha AP, Lekovic G, Spetzler RF. Surgical approaches to brainstem cavernous malformations. Neurosurg Focus. 2010;29(3):E8. doi:10.3171/2010.6.FOCUS10128

17. Wang Z, Qian C, Shi L, Wang L, Zhang J, Wang Y. Surgery Approaches to Brainstem Cavernous Malformations. J Craniofac Surg. 2015;26(7):e577-580. doi:10.1097/SCS.0000000000002128

18. Sarma S, Sekhar LN. BSCs excised by subtemporal-infratemporal approach. Br J Neurosurg. 2002;16(2):172-177. doi:10.1080/02688690220131831

19. Salunke P, Sahoo S, Futane S. Successful excision of a pontomesencephalic cavernoma through anterior subtemporal route without mapping: Anatomical landmarks as a road map. Surg Neurol Int. 2014;5:15. doi:10.4103/2152-7806.126044

20. Ziyal IM, Sekhar LN, Salas E. Subtonsillar-transcerebellomedullary approach to lesions involving the fourth ventricle, the cerebellomedullary fissure and the lateral brainstem. Br J Neurosurg. 1999;13(3):276-284. doi:10.1080/02688699943682

21. Hwang SW, Heilman CB, Riesenburger RI, Kryzanski J. C1-C2 arthrodesis after transoral odontoidectomy and suboccipital craniectomy for ventral brain stem compression in Chiari I patients. Eur Spine J. 2008;17(9):1211-1217. doi:10.1007/s00586-008-0706-x

22. Kivelev J, Niemelä M, Hernesniemi J. Treatment strategies in cavernomas of the brain and spine. J Clin Neurosci. 2012;19(4):491-497. doi:10.1016/j.jocn.2011.08.015

23. Rodríguez R, Molet J, de Teresa S, et al. [Intraoperative neurophysiological monitoring of brain stem in a case of cavernoma in the pons]. Neurocirugia (Astur). 2005;16(2):117-123.